Water protection in mining rehabilitation in Peru

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Preface

(Excerpts from the speech by Dr Regina Heinecke-Schmitt, Saxon State Ministry of Energy, Climate Protection, Environment and Agriculture (SMEKUL), at the final expert meeting for the project "Water protection in mining rehabilitation in Peru" on 2 September 2022 in Dresden as part of the Federal-State-Programme BLP of the German Federal Ministry of Economic Cooperation and Development (BMZ) coordinated by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

The special value of this guide lies in the fact that it incorporates the findings from many years of environmental rehabilitation at saxon reference sites. The guide provides the subnational Peruvian authorities with a tool for how [environmental] law is implemented in the context of sustainable water management at mining sites for the benefit of the people affected. At the same time, to the affected communities is offered a technical basis and a catalogue of methods [toolbox] for assessing existing and potential impacts of mining activities on the quality of water bodies. Furthermore, the results of the project can also be used by mining companies to improve in-house environmental protection [measures].

…

As part of a program item financed by the Saxony Trade & Invest Corporation [WFS], saxon experts … during the second trip to Peru [recognized] the responsible use of limited [local] water resources. In the last few weeks and months in particular, we have repeatedly found that a strained water availability has also become a reality in Saxony as an indicator of climate change.

…

As a result, I can say that the professional exchange has contributed to sustainable water management for both sides and can bring benefit also in the future. It is satisfying and an undeniable success when a project work leads to a mutual knowledge gain.

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List of Abbreviations

AHK	Außenhandelskammer / German Foreign Chamber of Commerce
AMD	Acid mine drainage
ANA	National Water Agency – Peru
BBodSchG	Bundesbodenschutzgesetz / German Federal Soil Protection Act
BBodSchV	Bundesbodenschutzverordnung / Federal Soil Protection Ordinance
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe / German Federal Institute for Geosciences and Natural Resources
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung / German Federal Ministry of Economic Cooperation and Development
BOD	Biochemical Oxygen Demand
BLP	Bund-Länder-Programm / Federal-State-Programme
COD	Chemical Oxygen Demand
DGFZ	Dresdner Grundwasserforschungszentrum e.V./ Dresden Groundwater Research Centre
DU	Detailuntersuchung / Detailed Investigation
EQS	Environmental Quality Standard
GDR	German Democratic Republic
GERESA	Regional Health Department – Peru
GIS	Geoinformation System
GIZ	Gesellschaft für Internationale Zusammenarbeit / German Agency for International Cooperation
GKZ	Geokompetenzzentrum Freiberg e.V. / Centre of Geocompetence Freiberg
GrwV	Grundwasserverordnung / German Groundwater Ordinance
HE	Historische Erkundung / Historical Investigation
INGEMMET	Geological, Mining, and Metallurgical Institute of Peru
LABO	Bund/Länder-Arbeitsgemeinschaft Bodenschutz / Federal/States Working Group on Soil Protection
LAWA	Bund/Länder-Arbeitsgemeinschaft Wasser / Federal/States Working Group on Water
LfULG	Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie / Saxon State Office for Environment, Agriculture and Geology
LTV	Landestalsperrenverwaltung Sachsen / State Dam Administration of Saxony
masl	Meters above sea level
MEL	Mining environmental liabilities
MINAM	Ministry of Environment of Peru
MINEM	Ministry of Energy and Mines of Peru
NGO	Non-Governmental Organisation
OEFA	Agency for Environmental Assessment and Enforcement of Peru
OGewV	Oberflächengewässerverordnung / German Surface Water Ordinance
OU	Orientierende Untersuchung / Oriented Investigation
PISCO	Peruvian-interpolated data of the SENAMHI's climatological and hydrological observations
RNSAB	Natural Reserve Salinas y Aguada Blanca
SAN	Sanierung / Remediation

SDG	Sustainable development goals
SEDAPAR	Drinking Water and Sewerage Service of Peru
SENAMHI	National Service of Meteorology and Hydrology of Peru
SERNANP	National Service of Natural Protected Areas by the State of Peru
SMEKUL	Sächsisches Staatsministerium für Energie, Klimaschutz, Umwelt und Landwirtschaft / Saxon State Ministry for Energy, Climate Protection, Environment and Agriculture
SU	Sanierungsuntersuchung / Remedial Investigation
TC	Technical Cooperation
UN	United Nations
WFD	Water Framework Directive of the European Union
WFS	Wirtschaftsförderung Sachsen / Saxony Trade & Invest Corporation
WHG	Wasserhaushaltsgesetz / German Water Resources Act

1. Introduction

The project "Water protection in the mining rehabilitation in Peru" is part of the German Government and Federal States Programme (German: Bund-Länder-Programm, BLP), which is coordinated by the *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) GmbH on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ). The project was financed by the BMZ and co-financed from tax funds based on the budget passed by the members of the Parliament of the Free State of Saxony.

1.1 Project objectives and the motivation of the state of Saxony

The Andean region is expecting a new raw material boom. This is due to the increasing demand for raw materials for the energy and transport transition (e.g., lithium, copper, gold, silver as well as cobalt and nickel as accompanying elements). Modern mining in the Andean countries plays an essential role for broad-based green growth and the provision of raw materials for climate-friendly technologies. However, mining also generates conflicts of use due to environmentally harmful mining methods. One of the main conflict potentials of active mining and its aftercare arises from the overuse and damage of natural water resources and the impairment of local water cycles. Without having implemented effective mechanisms for water protection, mining activities and their legacies alter water structures and introduce local pollutants. Particularly in the water-scarce regions of the Andean countries, conflicts of use of the scarce resource water arise due to multiple uses (mining, fishing, agriculture, settlements), as is the case in Peru. Peru has established a complete administrative structure for mining rehabilitation. However, the know-how of the responsible subnational regional administrations for an effective implementation of the existing laws on water protection in mining rehabilitation is still limited.

Germany can be a role model here and contribute to mutual learning with the experience it has gained. Dealing with mining waste is a special Saxon competence and at the same time also a Saxon long-term problem. In the wake of bitter experiences with mining legacies since reunification of Germany in 1990, Saxony has implemented a comprehensive set of regulations for water protection in mining rehabilitation over the past 30 years. Saxony was among the first regions within the EU to draw up its own raw materials strategy and has recently updated it. This strategy attaches particular importance to international cooperation with resource-rich countries, technology transfer from Saxony, especially to partner countries of German development cooperation, and the qualification of skilled workers. At the same time, Saxony has made nationally recognized contributions to the regulations and standards for the investigation and remediation of contaminated mining sites, in particular of waters affected by mining (surface and ground waters), which have been included, for example, in the working aids of the Federal-State Working Groups on Water (LAWA) and on Soil (LABO). Due to climate change and the ending of lignite coal mining, one of the main tasks in environmental management in Saxony will be to re-organize sustainable management of water as a resource over the next few decades. As a guideline for future water management decisions, SMEKUL has recently drawn up the “Principal Concept for Water Supply 2030”.

1.2 Project partners and organization

The project "Water protection in the mining rehabilitation in Peru" is part of the German Government and Federal States Programme (German: Bund-Länder-Programm, BLP), which is coordinated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). The BLP project was carried out in direct cooperation between the *Dresden Groundwater Research Centre* (DGFZ) and the *Geokompetenzzentrum Freiberg e.V.* (GKZ). All activities in Peru were conducted with the support of three Peruvian coordinators and advisors, which formed part of the project team of DGFZ. The complete project organization is shown in **Figure 1-1**.

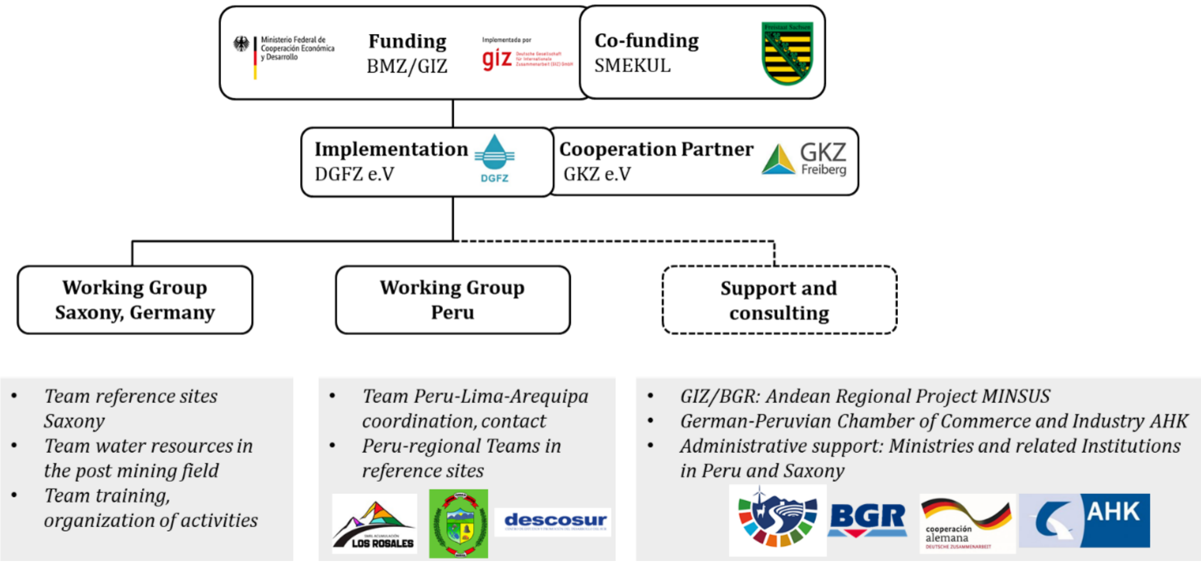


Figure 1-1. *Scheme of the organization of the BLP project*

Two reference sites from the Southern Andean Region of Peru were selected initially from various alternatives for the BLP project. Cooperation agreements were signed with the local responsible authorities and institutions. The selection was made considering access to historical information, willingness of landowners to provide access to the site and allow on-site activities, and the existence of the water-related conflicts aligned with the objective of the BLP project. At one of them, the Los Rosales site, the BLP project has been performed with the support of and collaborating with the MINSUS project (Regional Cooperation for the Sustainable Management of Mineral Resources in the Andean Region) of the German Federal Ministry of Economic Cooperation and Development (BMZ). This project has been carried out by the GIZ and the German Federal Institute for Geosciences and Natural Resources (BGR). Recognizing a demand of the Peruvian partners, it has been agreed to include additionally a third reference site during the first trip to Peru, which forms part of the National Reserve Salinas y Aguada Blanca (RNSAB). The project development in Southern Peru would not have been possible without the support by local authorities, stakeholders, and site managing entities. These are: the municipal administration of El Madrigal, the National Water Agency (ANA) offices in Arequipa and Juliaca, the National Service of National Protected Areas (SERNANP), the University of the Highlands in Puno, the mining company Acumulaciones Los Rosales S.M.R.L., and the Centre of Studies and Promotion of the Development of the South (DESCOSUR).

On the other hand, saxon reference sites were selected for the project, considering their excellence in water management for post-mining rehabilitation (i.e., mine water treatment, monitoring, covering and protection, among others). Two former mining sites were chosen from Ecological Remediation Main Projects of Saxony: the SAXONIA project in Freiberg and the Coschuetz-Gittersee project in Dresden. The access to the Gittersee site has been facilitated by the Environmental Office of the capital of Saxony. Additional information on mining site rehabilitation has been included from saxon closed mining sites of the federal mining remediation companies Wismut GmbH and LMBV mbH. The State Dam Administration of Saxony (LTV) supported the studies of enhanced water retention and storage at RNSAB sharing their competence in management of the saxon water storage dam system in the Ore Mountains region. An exchange with the Recomine alliance of mining site investigation has been coordinated with support of the Saxony Trade & Invest Corporation (WFS). The Recomine coordination is at Helmholtz Institute Freiberg for Resource Technology (HIF). The alliance has the vision of further developing regionally grown competences in the field of environmental technologies and linking them with technologies for the development of disperse raw material sources.

Due to the COVID-19 pandemic and travel restrictions worldwide, in-situ activities at the study sites were not possible at the beginning of the project in 2020. As an alternative, in August 2021 Peruvian experts of the DGFZ team visited the study sites and performed first field activities to obtain more detailed information. This was coordinated by and transmitted online to the German experts. In November 2021 field activities were conducted by the saxon specialists in Peru. The activities included water sampling and installation of monitoring shallow wells. In June/July 2022, the German specialists had a second trip to Peru to present and discuss the preliminary results of the project to interested parties, including local stakeholders of the study sites, and local authorities. In addition, various trainings were conducted with local stakeholders, concerning in-situ measurement of chemical parameters in mine water and groundwater sampling. Interviews were also conducted with stakeholders to collect experiences and perceptions on social issues related to water management. The information received during this trip was taken into account for this report.

A technical field trip to Saxony, Germany, of a delegation of Peruvian specialist took place in August/September. This field trip aimed to strengthen the capacities of both national and regional administrations in Peru to incorporate international standards and experiences of water protection in post-mining rehabilitation. This included field visits to emblematic mitigation projects in Saxony, which were presented and explained by the companies and institutions implicated in the rehabilitation. A final International Conference "Water Protection in Mine Remediation in Saxony and Peru - Results and Benefits of a Development Cooperation Project" was held, which included presentations and discussions by experts and exchange of experiences.

1.3 Structure of the Guide report

The following report is structured as a guide which includes both, the findings from the Peruvian study sites, gathered from the activities carried out during the trips to Peru, as well as the experiences of the saxon reference sites in relation to post-mining water management. Recommendations are given regarding measures that can be applied.

The guide provides in **Chapter 2** the fundamentals of water management at mining sites in Peru and Germany, as well as the threshold values for both countries. This chapter also contains the Saxon methodology for contaminated sites management and the state of the art in water treatment. The **Chapter 3** describes the Peruvian and saxon reference sites. An outlook of the site comparison concept is introduced. The **Chapter 4** provides the main part of the guide: the technical toolbox for mine water management at post-mining sites. In this toolbox, technical site investigations are first presented using the examples of the Peruvian sites (Madrigal and Los Rosales), as well as the SAXONIA project. The following subchapters deal with the remediation of mining installations and mine-affected waters by presenting the techniques involved through examples. In addition, protection or containment measures are listed. Finally, monitoring examples from the Gittersee and Königstein sites are described, as well as the proposed monitoring plan for the Peruvian site Los Rosales. **Chapter 5** examines social conflicts in post-mining sites in Peru from different perspectives. It presents a study case as well as several interviews recorded during a trip to Peru that capture local impressions. Local water management solutions are also described through an exemplary case in a National Reserve in southern Peru. Finally, **Chapter 6** summarizes the project results taking into account statements of representatives of the State of Saxony, and the Peruvian project partners.

2. Fundamentals of Water Management at Mining Sites in Peru and Germany

A general review on the fundamentals for water management is presented in this chapter. The regulatory framework in Peru and Germany is presented, including the relevant laws and threshold values for parameters of interest. In addition, the Saxon methodology for contaminated sites management is discussed. Finally, a review on the state of the art of water treatment techniques is presented as proposals.

2.1 Regulatory Framework

2.1.1 Peru

Among South American countries, Peru can be considered to have the most comprehensive legislation related to abandoned mining sites and environmental liabilities, since 1995 efforts were made for identifying environmental problems related to mining (Oblasser, 2016). International cooperation supported this achievement: The German Federal Ministry for Economic Cooperation and Development (BMZ), through the GIZ, helped the Ministry of Mining and Energy in 2008 to set the legal framework for the remediation of PAM´s (Chappuis, 2020). In 2015, the Korean International Cooperation Agency, and the Mine Reclamation Corporation (MIRECO) along with the Peruvian Ministry of Mining and Energy worked together on the bilateral project “Strengthening Management for the Remediation of Mining Environmental Liabilities in Peru” (Oblasser, 2016).

Mining operations in Peru are the responsibility of private actors. Large and medium mining are in charge of the central government, while small scale and artisanal mining are overseen by regional governments.

The State is involved in managing *mining environmental liabilities* (MEL). *Activos Mineros S.A.C*. (AMSAC), a state-owned company assumes the rehabilitation works on MEL left by the state mining activities terminated in 2006. Up to 2017, over 1000 MEL have been remediated by AMSAC, with over 64 million dollars invested **(Table 2-1).** Although several remediation projects are underway, there is little information available in the public domain about monitoring strategies (Oblasser, 2016).

The following three Peruvian laws are relevant for mine water management in post-mining:

The **General Environment Law** (*Ley General del Ambiente*, *Ley No. 28.611*) establishes the legal framework for developing environmental management programs, environmental quality standards and stipulates the maximum permissible concentrations of substances, and defines the responsibilities for environmental damages (Oblasser, 2016). Environmental quality standards are defined as the concentration levels of different substances that represent no significant harm or threat to the health of humans or the environment. These levels are defined for different water body classifications, according to the final use they have as defined by the supreme decree 004-2017-MINAM. Also included in this law are the maximum permissible limits (*Límite Máximo Permisible, LMP)*. These limits refer to discharges from anthropogenic activities and are defined for different industries and discharge types (e.g., gas, water).

Table 2-1. *Investment for Mining Environmental liabilities remediation in Peru*

Year	Invested (USD MM)
2007	1.53
2008	2.66
2009	3.23
2010	3.14
2011	3.12
2012	4.29
2013	8.39
2014	1.50
2015	5.21
2016	11.47
2017	19.65
Total	64.19

Source: Chappuis (2020)

The **Water Resources Law** (*Ley de Recursos Hídricos, Ley No. 29.338)* mandates that national water bodies must be classified according to their natural characteristics and final use. Classification of water bodies are the following:

- **Category 1 – Household and recreational:** waters that are destined for human consumption or recreational purposes.
- **Category 2 – Extraction, growth and other coastal marine and continental activities:** waters that are used for the growth of different fish and shellfish, also waters surrounding ports and other industrial activities.
- **Category 3 – Crop irrigation and cattle feed:** waters that are destined for the irrigation of different crops and for the feeding of different animals.
- **Category 4 – Aquatic environment preservation:** water bodies which are part of fragile ecosystems, protected areas with special characteristics which are meant to be preserved.

The Law for Regulation of **Mining Activity Environmental Liabilities** (*Ley que Regula los Pasivos Ambientales de la Actividad Minera, law n°28.271*) regulates the remediation of environmental liabilities in the mining industry (Chappuis, 2020). According to this law, the Ministry of Energy and Mining (*Ministerio de Energía y Minas, MINEM*) is responsible for keeping an updated database of mining environmental liabilities, as well as for identifying the responsible owners. In case no responsible or owner is found for a particular mining environmental liability, the State is the responsible party for the remediation of it.

During the 1990´s, water quality monitoring was regulated by different public agencies, depending on the sector (mining, agriculture, environmental, oil, etc.), thus creating a multiplicity of criteria on site selection, parameters, limits, and duplicity on Estate functions, which led to conflicts with different inspection authorities and unnecessary public expenditure. In 2011 the *Autoridad Nacional del Agua* (National Water Authority, ANA) published the Water Resources Quality Monitoring Protocol. This technical guide aims to unify criteria for the sampling and data acquisition across the country, in order to generate a unique data base on a national water resource data system for an integrated watershed management system (ANA, 2011).

2.1.2 European Union Directives

The European Union (EU) has created many directives related to environmental protection which are applicable to all Member States. Among these, the following are related to water protection in mining areas:

- Water Framework Directive
- Groundwater Directive
- Environmental Liability Directive

The **EU Water Framework Directive** (WFD) provides a framework for water quality management for all EU Member States. WFD was adopted in 2000. The WFD aims to protect and enhance water quality and aquatic ecosystems, while promoting sustainable water use (Ross, 2016). Among key elements included in the WFD are: river basin management based on river basin plans, a linking between emission limit values and environmental quality standards for pollution control, definition for “good water status” and the principle of full cost recovery of water (Page and Kaika, 2003).

Although establishing clear objectives, each Member State may determine how to achieve them. These objectives are (Directive 2000/60/EC, 2000):

- Good ecological and chemical status for surface waters,
- Good chemical and quantitative status for groundwater, and
- Good ecological potential of heavily modified or artificial water bodies.

EU Member States must achieve these goals by the end of the 3rd management cycle (2021-2027, see

Figure 2-1). Subsequently, a new 6-year cycle begins, and the achievement of objectives is constantly reassessed.

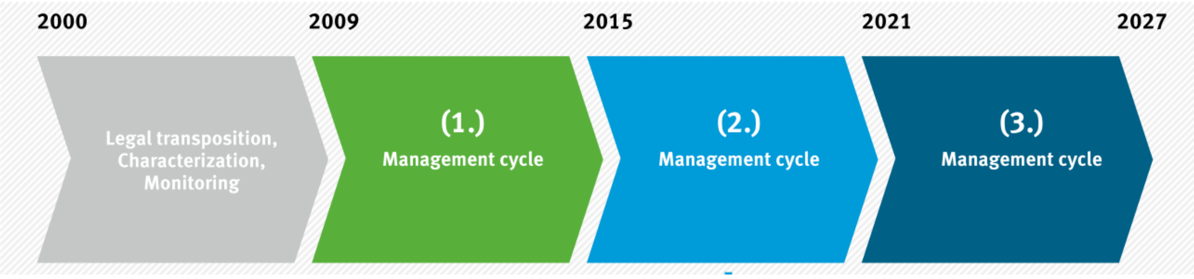


***Figure 2-1.** timeline of the EU Water Framework Directive*

Source: BMUB/UBA (2016)

The **EU Groundwater Directive** was adopted in 2006 as a daughter directive from WFD for specific purposes on groundwater status criteria. There was a need to clarify the criteria for good chemical status on groundwater bodies, as well as the identification and reversal of pollution trends. This directive requires Members to define and characterize groundwater bodies within river basin districts, identifying those at risk of not meeting WFD objectives, establish registers of protected areas, define environmental quality standards (threshold values), pollution trends and implement preventive measures or limit pollutants input into groundwater, as well as establish monitoring networks (European Commission, 2008). The EU Groundwater Directive was transposed into national law in the Groundwater Ordinance (GrwV).

2.1.3 German Regulations

In Germany, the reclamation of mining-affected areas is regulated by the **Federal Mining Act** (*Bundesberggesetz - BBerG*). Mining and water authorities must agree on water related issues that are included in the mining approval procedures.

The Federal Republic of Germany has made the protection of the natural foundations of life a state objective in its Basic Law (Article 20a). This also includes the protection of our waters. Within the framework of comprehensive environmental protection, which is to ensure the supply of the population and in particular also that of future generations, water protection is one of the top priorities. The **Water Resources Act** (*Wasserhaushaltsgesetz* - WHG), which originally dates back to 1957, forms the core of water protection law. Its purpose is to protect water bodies as a component of the natural balance, as the basis of human life, as a habitat for animals and plants, and as a usable resource through sustainable water management (section 1 WHG).

The WHG aims to create the legal conditions for the orderly management of surface and underground water in terms of quantity and quality, and to control human impacts on water bodies. The WHG stipulates that water bodies must be secured as a component of the natural balance and as a habitat for animals and plants and managed in such a way that they serve the public good and, in harmony with it, also the benefit of individuals. Avoidable impairments of their ecological functions should be avoided (precautionary principle). Overall, a high level of protection for the environment shall be ensured.

The EU legal requirements are implemented uniformly throughout Germany in the **Surface Water Ordinance** (*Oberflächengewässerverordnung – OGewV*) in order to ensure an overall similar level of protection for surface waters throughout Germany. The goal is a coherent and comprehensive implementation of all EU legal requirements for the protection of surface waters. The OGewV sets the criteria for good chemical status and good ecological status in natural surface water bodies. Type specific measurements of surface water bodies (coastal water, lakes, and rivers) are defined in the OGewV. Ecological status is based on an integrative assessment. Monitoring programs are defined by regional authorities (*Länder*) to assess ecological quality of water bodies and potential sources of pollution (German Environmental Agency, 2017).

The **Groundwater Ordinance** (*Grundwasserverordnung – GrwV)* sets the criteria for good chemical status in groundwater bodies. Threshold values for assessing groundwater are based on monitoring data from each groundwater body. Monitoring allows to identify any rise in trends, and authorities are required to act if 75% of the limit value is reached (German Environmental Agency, 2017).

In addition to WHG, OGewV and GrwV, the **Federal Soil Protection and Contaminated Sites Act** (*Bundes-Bodenschutzgesetz – BBodSchG*) is also relevant for protection in mine affected sites. The BBodSchG seeks to establish a link between pre- and post-cautionary soil protection, while the treatment of contaminated sites considering their final use is the main focus (LfULG, 2003). Precautionary measures and requirements for the use of materials are defined in the BBodSchG, to avoid further soil contamination. Any factor that causes an impact on soil capacity must be avoided. The **Soil Protection and Contaminated-site Ordinance** (*Bodenschutz- und Altlastenverordnung - BBodSchV)* defines threshold values for relevant contaminants in soil, hazard prevention tests and measurement values for site contamination and detrimental soil changes and procedures for soil investigation and assessment (UBA, 2014).

The amendment to the Federal Soil Protection Ordinance comes into force in August 2023. The aim is to harmonize the assessment standards for the environmental media soil and water. The revised ordinance which will come into force in 2023 can be found in **Annex 4.**

2.1.4 Saxony Federal State Regulations

Federal regulations for contaminated sites in Saxony were created in 1992 with the **First Law on Waste Management and Soil Protection in the Free State of Saxony** (*EGAB)*, being among the first Federal States in Germany to have its own soil protection law. The EGAB was then renamed as **Saxon Waste Management and Soil Protection Act** (*SächsABG*) in 1991, after the BBodSchG came into force.

The structure and responsibilities in soil protection are defined by the *SächsABG.* The Saxon State Ministry for Energy, Climate Protection, Environment and Agriculture (*SMEKUL*) is defined as the highest soil protection authority, determining the responsibilities for soil protection law enforcement by statutory order. The State Office for the Environment, Agriculture and Geology (*LfULG*) is the technical authority on soil protection, advising and supporting the highest soil protection authority.

2.2 Threshold Values from Peruvian and German Laws

Environmental quality standards in Peru are defined for each category of waters defined in the Environmental Law. Each category is bound to a **specific set of standards for different substances**. Exceptions are specified for water bodies that due to natural conditions (e.g., geological background) present substances exceeding environmental quality standards, without human action.

Table 2-2. *Peruvian environmental quality standards for water in category 3*

Parameter	Unit	Value / range	Parameter	Unit	Value / range
pH	(-)	6.5 – 8.5	As	mg/L	0.1
Temperature	(-)	Δ3°C	Ba	mg/L	0.7
Conductivity	µS/cm	2500	Be	mg/L	0.1
Dissolved oxygen	mg/L	≥ 4	B	mg/L	1
BOD	mg/L	15	Cd	mg/L	0.01
COD	mg/L	40	Co	mg/L	0.05
Cl^-	mg/L	500	Cu	mg/L	0.2
Detergents (MBA)	mg/L	0.2	Cr	mg/L	0.1
WAD cyanide	mg/L	0.1	Fe	mg/L	5
HCO_3^-	mg/L	518	Li	mg/L	2.5
Phenols	mg/L	0.002	Hg	mg/L	0.001
F^-	mg/L	1	Mn	mg/L	0.2
SO_4^{2-}	mg/L	1000	Ni	mg/L	0.2
Oils and fats	mg/L	5	Pb	mg/L	0.05
Nitrates + Nitrites	mg/L	100	Se	mg/L	0.02
Nitrites	mg/L	10	Zn	mg/L	2
Al	mg/L	5			

Source: Supreme Decree 004-2017-MINAM

Considering the study sites studied in this report, category 3 is selected for assessment on water quality. A total of 49 substances are included in this category, including physicochemical parameters, inorganic, organic and microbiological indicators. Environmental quality standards for physicochemical and inorganic parameters from category 3 waters are shown in **Table 2-2.**

Discharge waters from small mining companies must be monitored by the company and shown to regional authorities in a monitoring program document, which must include the location of monitoring sites (must include effluents and receiving water bodies), monitored parameters and monitoring frequencies for each site. It must be approved by local authorities as part of environmental permits and can be later modified, if requested by authorities. Besides the specific parameters determined for every industry, monitoring programs must also include the following parameters:

- Flow rate,
- Electrical conductivity,
- Effluent temperature, and
- Turbidity.

Threshold values can be for a single measurement (i.e., “limit at any given time”), or for annual average. Threshold values for discharge waters in mining activities are shown in **Table 2-3.**

Table 2-3*. Peruvian maximum permissible limits for mining discharges.*

Parameter	Unit	Maximum permissible limit	
		Single measure	Annual average
pH	(-)	6 - 9	6-9
TDS	mg/L	50	25
Oil and fat	mg/L	20	16
Total cyanide	mg/L	1	0.8
Total As	mg/L	0.1	0.08
Total Cd	mg/L	0.05	0.04
Total Cr	mg/L	0.1	0.08
Total Cu	mg/L	0.5	0.4
Dissolved Fe	mg/L	2	1.6
Total Pb	mg/L	0.2	0.16
Total Hg	mg/L	0.002	0.0016
Total Zn	mg/L	1.5	1.2

Source: Supreme Decree 010-2010-MINAM

The OGewV determines the parameters for assessing the ecological status of surface waters. These parameters include species composition and frequency, biomass, and age structure (German Environment Agency, 2017). Ecological status from a water body is determined by the worst assessed biological quality element. Specific pollutants are also included for the assessment of ecological status for surface waters. **Environmental quality standards for 67 substances are included in the OGewV**, including metals, industrial chemicals, and pesticides. Concentrations exceeding 50% of the environmental quality standard are considered significant (German Environment Agency, 2017). In order to achieve a good ecological status, according to the OGewV, the annual average must not exceed the annual average environmental quality standard (AA-EQS), and the maximum value must not exceed the maximum allowable concentration (MAC-EQS).

According to OGewV, chemical status can be “good” or “not good”. **Environmental quality standards for the chemical status of surface water bodies aim to the protection of human health.** A total of 45 priority substances are included in the OGewV and are monitored for annual average values (AA-EQS). A maximum allowable concentration (MAC-EQS) is added for selected pollutants with acute high toxicity (German Environmental Agency, 2017), which may not be exceeded in any individual measurement.

Table 2-4 shows environmental quality standards for relevant parameters, which were selected by Webber et al. (2019) as **related to mining activities in Saxony**. They were selected considering the materials mined in Saxony (lignite, hard coal, silver, uranium, zinc), and their accompanying sulfide minerals, which caused formation of acid mine drainage by mining.

***Table 2-4**. Relevant surface water quality standards in Germany.*

Parameter	Surface water quality standard
As	<40 mg/kg
Cr	<640 mg/kg
Cu	<160 mg/kg
Se	<3 µg/L
Ag	<0.02 µg/L
Zn	<800 mg/kg
Fe	<0.7…1.8 mg/L
SO_4	<75…220 µg/L
pH	5.5-8.5
Cd	<0.08…0.25 µg/L
Pb	>1.2 µg/L
Ni	<4 µg/L

Source: Webber et al. (2019)

As seen in **Table 2-5,** arsenic, chrome, copper, and zinc are regulated in suspended solids (mg/kg) in the fraction <0.063 mm. Therefore, there are no dissolved limits. The **German Environmental Agency (UBA) recommends dissolved limits for different substances**, including arsenic, chrome, copper, and zinc (Wenzel et al., 2015, see **Table 2-5**). Uranium is also included, which is not regulated in the OGewV.

A good quantitative and qualitative status must be met for groundwater bodies in Germany. Assessment on quantitative status is based on groundwater level. A good quantitative status is met when the rate of abstraction is no greater than the available groundwater resource (German Environmental Agency, 2017).

***Table 2-5.** Recommended values for environmental quality standards from UBA,*

Parameter	Recommended value (µg/L)	
	Maximum permissible concentration	Annual average environmental
Arsenic	6.6	1.3
Chrome	3.4	3.4
Copper	2.4	1.1
Zinc	33	10.9
Uranium	3.4	0.44

Source: Wenzel et al. (2015)

For a good qualitative status, **environmental quality standards** are defined in the GrwV, including a total of 10 substances, two of them being defined by the EU Groundwater Directive (nitrate and pesticides) and the rest defined by German regulations (German Environmental Agency, 2017). Environmental quality standards for groundwater are shown in **Table 2-6**.

***Table 2-6**. Relevant German groundwater quality standards,*

Parameter	Groundwater quality standard
Nitrate	50 mg/L
Active ingredients in pesticides and biocide products including relevant metabolites, degradation, and reaction products	0.1 µg/L each; 0.5 µg/L total
As	10 µg/L
Cd	0.5 µg/L
Pb	10 µg/L
Hg	0.2 µg/L
NH_4^+	0.5 µg/L
Cl	250 mg/L
SO_4^{-2}	250 mg/L
Sum total of tri- and tetrachloroethylene	10 µg/L

Source: Grundwasserverordnung – GrwV

Due to the high natural / geogenic occurrence of the metalloids and metals in groundwater and surface waters in some areas of Germany, background concentrations are applied in addition to the environmental quality standards. For surface water and groundwater bodies in these particular areas natural background concentrations have been derived. If these are higher than the environmental quality standards, they replace them. Thus, for example, for the waters in the Ore Mountains (*Erzgebirge*), background concentrations of some water bodies are higher than environmental quality standards presented in the OGewV and GrwV.

2.3 Saxon Methodology for Contaminated Sites Management

In the 1990s, the "**Saxon contaminated site methodology**" was developed, based on the methodology from the federal state Baden-Württemberg for a step-by-step approach to contaminated site management. The manuals and materials produced by the **Saxony State Office for the Environment Agriculture and Geology** (*LfULG*) for the contaminated sites treatments are continuously being updated and can be downloaded from the Saxony webpage (http://www.boden.sachsen.de/). This step-by-step approach for contaminated sites, tested in Saxony and other Federal States, was published in 1999 when the **Law for the Protection against Harmful Soil Changes and for the Remediation of Contaminated Sites** (*BBodSchG*) and **Federal Soil Protection and Contaminated Sites Ordinance** came into effect, and it provides a framework for handling contaminated and suspected contaminated sites **(Table 2-7).** However, it must be noted that each case is set by its individual conditions (Helling, 2014).

***Table 2-7.** Steps and technical guides for the management of contaminated sites*

Processing steps					
Collection		Investigation and risk assessment		Remediation preparation and implementation	
Survey	Historical investigation	Oriented investigation	Detailed investigation	Remediation investigation	Remediation
Technical guides					
1. Principles					
2. Survey and formal initial assessment	3. Groundwater 4. Soil 5. Surface water 6. Air	7. Detailed investigation		8. Remediation investigation	9. Remediation

Source: Produced by LfULG. Modified from Helling (2014)

2.3.1 Principles of the Saxon Methodology

In general, treatment of contaminated sites discussed in LfULG (2003) is based on the following principles:

- Step-by-step concept for treatment
- Pathway-based approach
- Proportionality/appropriateness of measures

Determination of the need for remediation in a specific site will depend exclusively on the results of a proper investigation. A rough sequence of contaminated site treatment procedures is shown in **Figure 2-2.** Contaminated sites and suspected contaminated sites are defined separately. **"Areas suspected of being contaminated"** are defined as follows according to § 2 para. 6 BBodSchG:

“Sites suspected of being contaminated are old deposits and old sites where there is a suspicion of harmful soil changes or other hazards for the individual or the general public.”

In principle, the following criteria apply to the classification of a specific site as a suspected contaminated site:

- Focalized accumulation of pollutants,
- Anthropogenic cause of the contamination,
- Temporary termination of the handling of environmentally hazardous substances,
- Endangerment or damage to objects of protection.

Each step in the treatment of contaminated sites is related to the link between a pollutant source, its pathway and effect on protected goods (receptor, **see Section 2.3.2**).

The existence of concrete hazards or the determination of impacts that have already occurred is always based on *objects of protection*. Measured values from the area of the contaminated site or its surroundings (*pathways*) are to be interpreted in terms of **what concentrations and/or loads will reach a protected good (*receptor*).**

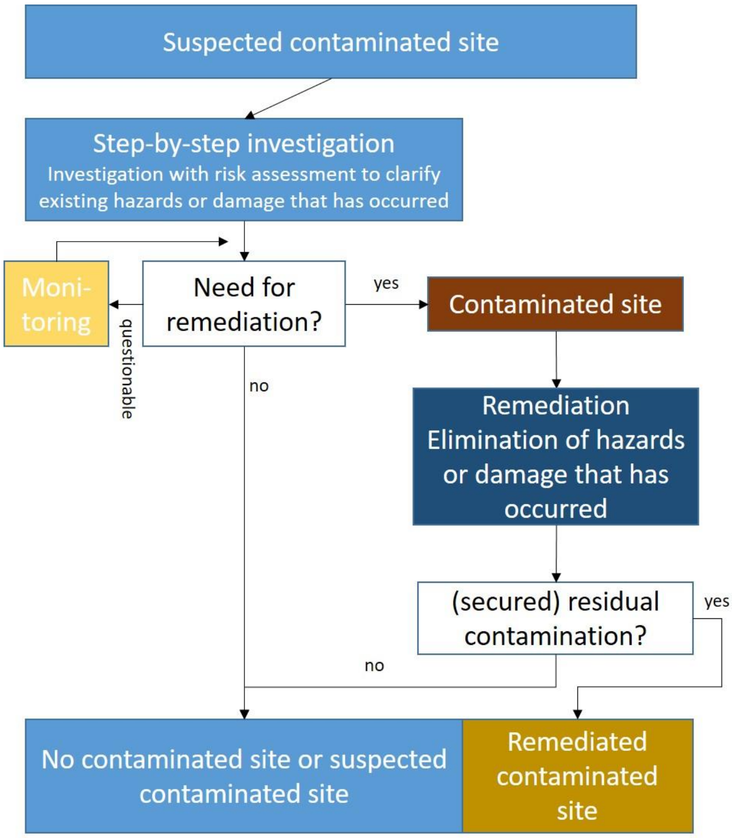


Figure 2-2. *Basic sequence of contaminated site treatment*

Source: LfULG (2003)

The following principles are reflected in the methodology for the treatment of contaminated sites and must be considered in the treatment of individual cases:

- **Danger or damage that has occurred as a basis for action:**

  A sufficient suspicion of the occurrence of a hazard entitles the authority to take an incriminating administrative action against third parties (obligated parties). This requires a determination of the facts (official investigation) by the authority.

- **Appropriateness/proportionality of measures**

  In accordance with the legal requirements and considering the often-high costs and limited financial resources, a gradual approach (alternating sequence of information gathering and decisions) is usually required.

- **Equal treatment of cases**

  The specification of a framework for action for individual case treatment is necessary.

- **Individual case decision for each suspected contaminated site**

  Within the framework of the treatment of contaminated sites, the authority has a duty to exercise discretion in evaluating the necessity and scope of measures under the aspect of proportionality, which is carried out by weighing up the specific situation within the given scope of action (scope of discretion).

In accordance with the legal basis from BBodSchG and BBodSchV (see **section 2.1.3**), the standard procedure for the concept for the treatment of contaminated sites involves of the following **processing stages (Figure 2-3):**

- Data collection, divided into the
  - Survey (with Formal Initial Evaluation FEB*), and
  - Historical investigation (HE*)
- Oriented investigation (OU*)
- Detailed investigation (DU*)
- Remedial Investigation (SU*)
- Remediation (SAN*)
- Monitoring/Aftercare (C*)

**The abbreviations have been unchanged in the original german language.*

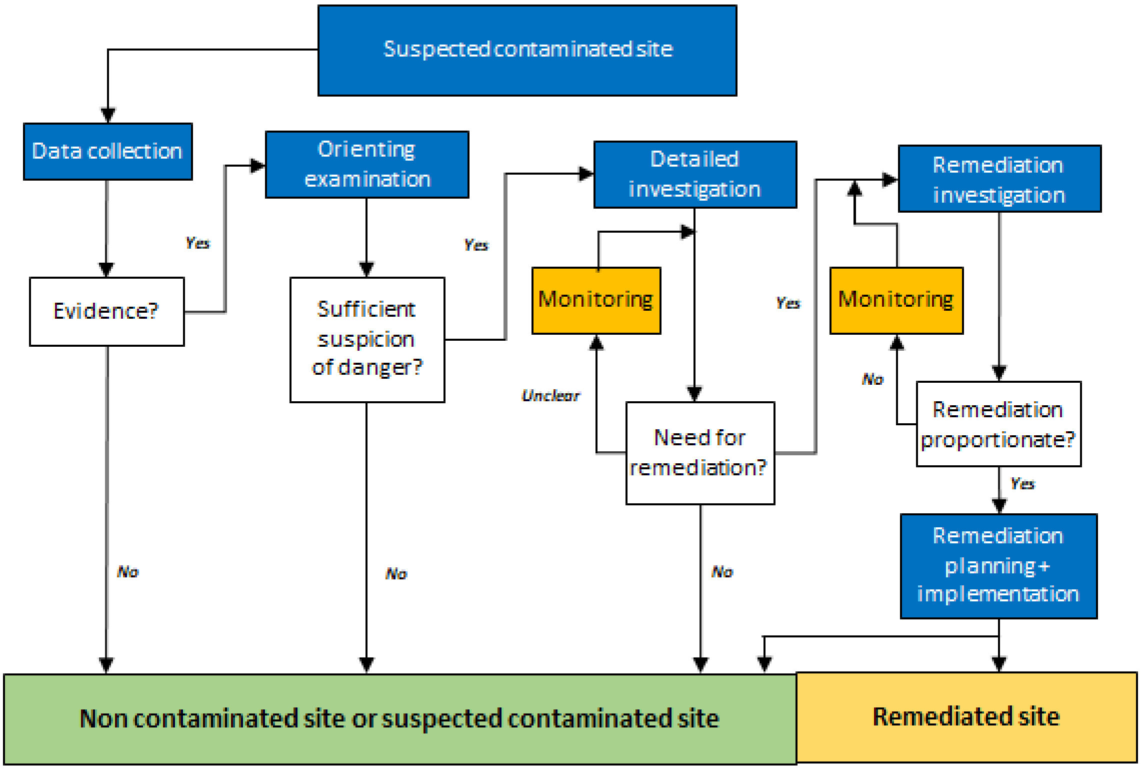


***Figure 2-3.** Standard procedure for assessment of contaminated sites according to the German Federal Soil Protection Act*

Source: modified from LfULG (2003)

Each step is described as follows:

Data collection (with Formal Initial Evaluation FEB)

The objective of this step is to perform a survey of suspected contaminated sites (specifically according to contaminated sites and abandoned waste deposits), obtaining a first rough prioritization. This survey shall be based on historical data from documents, collecting limited but relevant data on the suspected contaminated site (e.g., size, waste type, and industry sector), pollutants dispersion and area use.

Recording, in terms of a Historical investigation (HE)

This step comprises an examination on the evidence on a suspected contaminated site. Relevant and irrelevant pathways and objects of protection are also defined in this step. An initial hazard assessment for relevant transport pathways and protected goods is also part of this step, as is the determination of further need for action and prioritization of the studied site. This step does not include sampling, as it is not a technical investigation. All available data on the suspected contaminated site must be evaluated.

Oriented investigation (OU)

Suspected hazard is proven or refuted on the basis of concrete evidence in this step. Risk assessment for the relevant pathways and protected goods, as well as the determination of the need for further action and prioritization are also included here. A limited number of samplings can be carried out to obtain the necessary information for assessment on the source of pollution, transport pathways and protected goods. A small spectrum on analyzed parameters is also recommended here by LfULG (2003).

Detailed investigation (DU)

This is the final determination of the risk assessment and the need for action. If contamination of the site is proven, preliminary remediation targets to prevent hazards or repair water pollution are defined. Technical investigations including measurements of pollutants and, if necessary, prognosis of substances distribution and contamination plume extent are also recommended. The extension of the contaminated site must be delimited and the impact on protected goods must be predicted.

Remediation Investigation (SU)

The optimal scenario to achieve the remediation goal is selected here. The method for remediation along with the remediation goals is also determined. Environmental and economic criteria is used for assessing and comparing different methods for remediation.

Remediation (SAN)

The goal of this step is the averting of the proven hazards until remediation goals, defined earlier, are achieved. The success of remediation must be assessed through monitoring. Measures for remediation, protection and containment measures are planned and implemented in this step.

Monitoring/Aftercare (C)

In order to assess fulfillment of the defined objectives, the suspected contaminated site / remediated site is monitored. In the case of the latter, usually during protective measures. Technical investigations assessing compliance with hazard-related substances concentrations are performed.

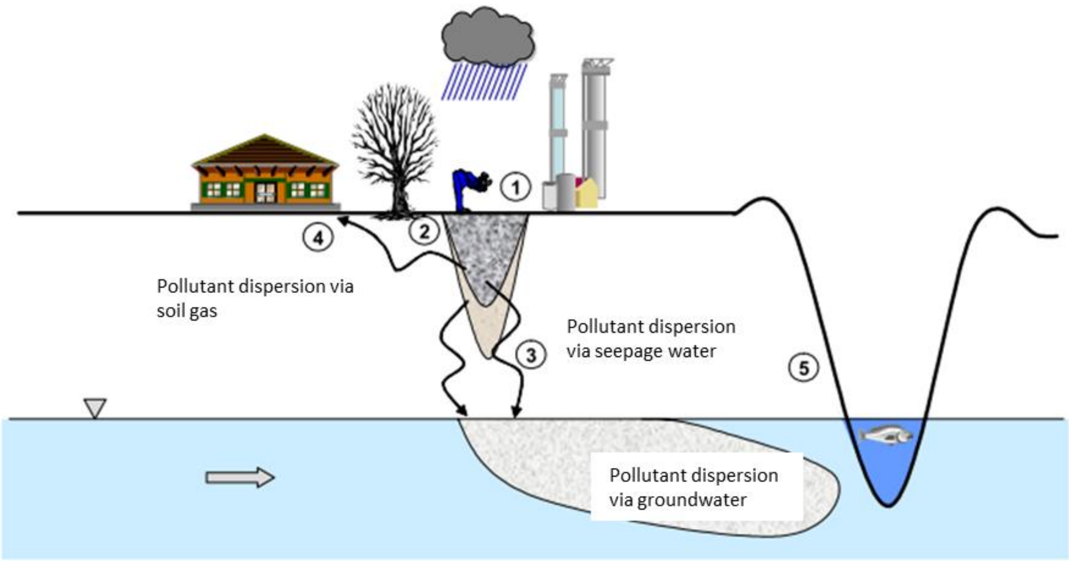
The results of the individual stages are usually presented in the form of an expert report. The data obtained is recorded in the Saxon Register of Contaminated Sites (SALKA). Upon completion of a processing stage, a classification of the need for further action is required. Monitoring involves the time-delayed determination of concentrations, loads and mobility states with an unchanged impact pathway and protected goods.

2.3.2 Source-Pathway-Receptors

Relevant pathways must be considered for investigations on suspected contaminated sites and, if necessary, for remediation assessment. This results in the following basic sequence of considerations:

- Substance assessment
- Site assessment
- Use assessment

Although many suspected contaminated sites and contaminated sites are defined by hazards to groundwater as a protected resource, the other impact pathways and protected resources are not to be neglected. For the treatment of contaminated sites, all relevant impact pathways and objects of protection must first be considered **(Figure 2-4).** Impact pathways and protected assets that are not relevant are excluded from further consideration.



Relevant pathways:

1. Soil – humans (direct contact)
2. Soil – Plants – Humans
3. Soil – air – humans
4. Soil gas – Air – Humans
5. Soil – surface water - humans

Figure 2-4. *Different pathways to be considered*

Source: LfULG (2003)

Source

The source refers to the substances that pose a threat to the receptor. Examples in the context of mining sites are underground mine works which may contain sulfide minerals that have the potential to produce AMD, or tailings which may also contain sulfide minerals exposed to rainwater and oxidizing conditions.

Characterization of the source is indispensable for a proper risk assessment and further solution design. Recommendations for source assessment are presented in LABO (2015).

Estimations on pollutants total mass and discharge must be made due to their influence on temporal and spatial behavior of the pollutant while being transported through the pathway. Therefore, source characterization allows for the prediction of a contaminant pathway.

LABO (2015) recommends including the following information for source characterization:

- Location and extent,
- Pollutant mass,
- Availability (dissolved, fixed, residual, mobile), and
- Discharge rate.

Source control solutions involve the removal of contamination, or any change to the characteristics of the contaminant. Although they may be efficient, consequences of source-oriented methods are the transfer of the problem to another location (e.g., moving the source of contamination to another location).

Pathway

Pathway is the link between the source and the receptors. Examples of pathways are sediment, wind, surface water or groundwater transport. Multiple pathways may be determined for a single source and the correct identification and characterization of these is important.

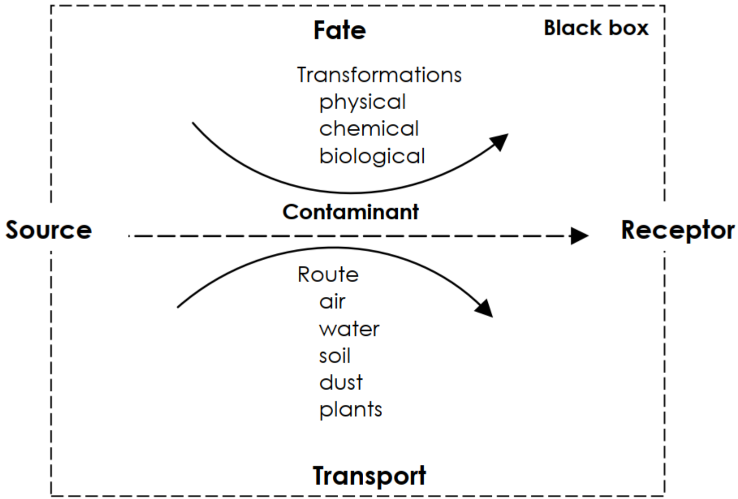


Figure 2-5. *Fate and transport of a contaminant*

Source: Vegter et al. (2002)

Pathway control solutions seek to prevent the migration of contaminants from the source to potential receptors, and it may consist of physical barriers (e.g., bentonite slurry wall) between the source and receptor. Other examples are containment of contaminated waters and treatment techniques, although they may have consequences for land use.

During the transport of a contaminant through a specific route, it may undergo different processes which affect its properties (e.g., toxicity, mobility). These can be chemical, physical, or biological processes (Vegter et al., 2002). Assessment on pathways implies the study of transport and fate of contaminants through these **(Figure 2-5).**

Fate and transport are determined by specific pathway characteristics. For groundwater transport, plume extension and behavior depend on the hydrogeological conditions **(Figure 2-6).** Surface water transport of contaminants depends on other factors, such as river flow regime. Pathway assessment may include:

- Extension of the plume (vertical/horizontal),
- Temporal/spatial prediction,
- Groundwater flow conditions, and
- River flow regime.

Possible pathways are:

- Pollutant uptake by humans (direct contact) = soil-human
- Pollutant uptake by plants = soil-plant-(human)
- Leachate emission to groundwater = soil-groundwater-(human)
- Gas emission to atmosphere/building = soil-air-human
- Emissions from the saturated and unsaturated zone into surface water = soil-surface water-(human)

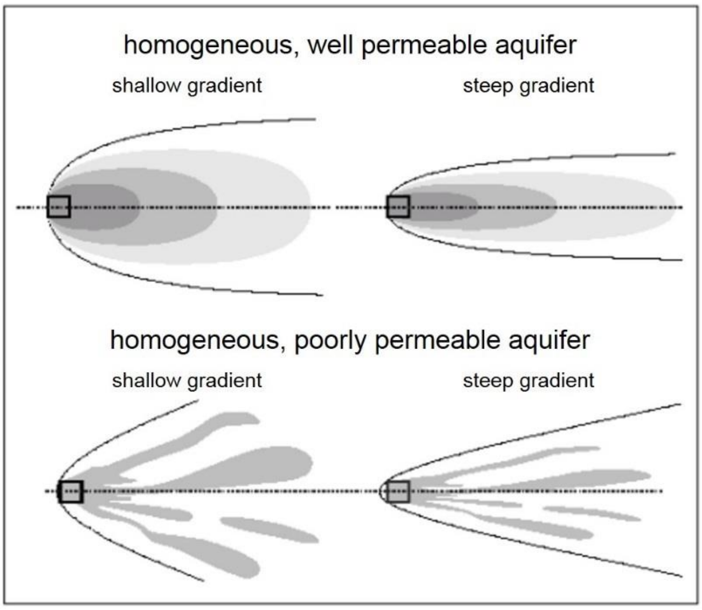


Figure 2-6. *Typical plume contours depending on the hydrogeological conditions*

Source: LABO (2015)

Receptor

Removal or management of receptors is possible, although not preferred. Evacuation of human settlements is unrealistic and could only be considered in the case of emergencies or where source- and pathway-oriented solutions seem unviable. Receptors may not always be humans. Drinking water resources (e.g., extraction well) can also be considered receptors, and in this case, relocation is possible.

2.4 State of the Art in Water Treatment

A review on the state of the art of water treatment techniques is presented in this section. The main processes involved are described, followed by different classifications that apply for water treatment techniques. Finally, criteria for selecting appropriate water treatment techniques are presented.

2.4.1 Main Processes Involved in Water Treatment

Waters affected by mining activity have characteristics such as high concentrations of metal(oid)s, sulfates, and low pH-values. Numerous research has been developed and new technologies have been implemented for the treatment of water affected by mining. Previous projects VODAMIN and VITAMIN presented in-depth research and evaluation of water treatment technologies in the Lusatian lignite region. The following publications will be considered as a basis for this section:

- **VODAMIN project work package 4: "Groundwater and surface water purification process" (DGFZ, 2012)** reviews the existing treatment technologies for mine-affected waters, considering physical/chemical and biological processes. A classification of these processes is presented.
- **VODAMIN project work package 9: "Mine water purification – processes and procedures" (Wolkersdorfer, 2013)** follows the subdivision of processes for mine water treatment by Younger et al. (2002) and also divide them into active and passive methods. Groundwaters, open pit lakes, flowing waters and underground mine waters were considered.
- **VODAMIN project work package 14: "Processes for the capture, discharge and purification of groundwater contaminated by mining activities" (GEOS, 2013)** is focused on the prevention of diffuse substance inputs as a result of groundwater recharge in the Lusatian lignite mining region.
- **VITAMIN project (DGFZ, 2018)** discusses in detail the different (micro-)biological processes for treatment in mine affected waters and their applicability under saxon conditions.

The main processes involved in the water treatment technologies are discussed in the VODAMIN project. The following definitions are from DGFZ (2012), unless stated otherwise.

- **Neutralization** is required because of the acidic character of mine-affected waters. Metal(oid)s are often highly soluble in water, in particular at low pH values, therefore pH needs to be raised into neutral or slightly alkaline range. In addition, iron (usually in high concentrations in mine water) is often precipitated as hydroxide. To achieve this precipitation it is recommended to first oxidize Fe (II) to Fe (III) but the kinetics of iron oxidation are strongly pH-dependent and only proceeds sufficiently rapidly at pH values above 7.0 (Sung & Morgan, 1980).
    - Common neutralization agents are limestone ($CaCO_3$), hydrated lime ($Ca(OH)_2$), quicklime (CaO), magnesium hydroxide ($Mg(OH)_2$, caustic soda ($NaOH$), and soda ash (Na_2CO_3).
- **Oxidation and reduction (Redox)** are defined as the transfer of electrons from one atom to another (Apello and Postma, 2004). As a result of redox reactions, one element or compound is reduced and the other is oxidized. Redox processes play key roles in

the formation and dissolution of mineral phases and control the chemical speciation, bioavailability, toxicity, and mobility of many elements (Tandon & Singh, 2016).

  - Atmospheric oxygen can be sufficient for the oxidation of iron and its input can be carried out for example by aeration cascades. When the load of metals bound in organic complexes is high, or in the case of manganese, the addition of an oxidizing agent can be required. Some common agents are ozone or potassium permanganate.

- **Sorption and ion exchange. Sorption** is a water-solid process in which a water constituent (**adsorptive**) adheres to another water constituent (usually solid, **adsorbent**). The most important mechanisms are adsorption (two-dimensional), absorption (three-dimensional), polymerization (linking of molecules) and complexation (Wolkersdorfer, 2013). In an **ion exchange** reaction, an ion is exchanged for another with similar charge from a water solution to an immobile solid phase (Dahman et al., 2017). Mine water ions (e.g., Ca^{2+}, Mg^{2+}, Cu^{2+}, Fe^{2+}, Fe^{3+}, SO_4^{2-}) are exchanged for ions present in an ion exchanger materia (Na^+, H^+, K^+, Cl^-), thus removing these ions (Wolkersdorfer, 2013).

- **Electrochemical process and membrane technologies.** In **electrochemical** processes, electrical fields or chemical reactions cause the movement of ions, contributing to water purification. **Membrane technologies** on the other hand force water through membranes by mechanical pressure or electrical potential differences, causing the retention of the ionic load.

- **Precipitation and sedimentation.** Precipitation of solids occurs in supersaturated solutions during mine water treatment. These solids may be removed from mine water by coagulation and sedimentation. In active treatment, this can be achieved by the addition of flocculants, high supersaturation, and formation of large solid aggregates. On the other hand, passive treatment requires longer periods of time, increasing the existing solid surface promoting coagulation and separation of the solids.

2.4.2 Classification of Water Treatment Methods

2.4.2.1 Active and Passive Methods

Active methods involve physical or chemical processes for removing pollutants from mine water. Human action is required to keep treatment processes running. (Wolkersdorfer, 2008). In active treatments, volume flows can be controlled or regulated, material flows can be continuously determined, and a continuous, controlled, and regulated supply and removal of materials takes place (DGFZ, 2012). Adjustment of pH or Eh values of mine waters to reduce solubility of metals is common in active treatment plants (Wolkersdorfer, 2008).

Passive methods, on the other hand, rely on natural chemical and biological reactions, which occur without adding nutrients other than compost or energy (Wolkersdorfer, 2008). Only periodic maintenance is required for the operation of these methods, making them less costly than active methods (Younger et al., 2002).

Reactants from **passive treatment** have lower mass transfer rates per area and therefore can remain in site or at most require removal unfrequently. In contrast, **active treatments** require a more periodic removal of material, which also require planning for its disposal (DGFZ, 2012).

A comparison between passive and active methods is presented in **Table 2-8.** Due to the characteristics from each method, **passive methods** are mostly used in closed mines with low and constant flows. **Active methods**, on the other hand, are preferred in active mines with more dynamic conditions (DGFZ, 2012).

***Table 2-8**. Comparison of active and passive treatment methods*

	Passive Methods	Active Methods
Investment and operating costs	Variable: Strongly dependent on the personnel requirement and standing time	High: Strongly dependent on operating resources and personnel costs
Energy use	Low	High
Machine use	Low	High
Use of environmentally hazardous Reagents	Hardly	Frequent
Personnel deployment	Various	High
Maintenance effort	Various	High
Process identification	Elaborate, site-specific; high need for analysis; poor measurement capabilities.	Standardized; little need for analysis; existing design capabilities.
Process control	Bad	Good
Flexibility in terms of inlet water quality and quantity	Low	High
Space requirement	High	Low
Treatable volume flows	Mostly low 10 to 100 m^3 /h	Variable; mostly high: 100 to 3000 m^3 /h
Cleanable material loads	Low	High; adaptable to different inlet conditions
Removal of the products	Remaining in the reaction chamber or discontinuous	Continuous removal necessary
Investment and operating costs	Variable: Strongly dependent on the personnel requirement and the standing time	High: strongly dependent on operating resources and personnel costs

Source: adapted from VODAMIN, DGFZ (2012)

2.4.2.2 On-site and In-situ methods

On-site processes refer to those in which the equipment needed for the treatment of water is located on the surface of the mine, therefore mine water must be transported from the source to the treatment zone. This type of installation allows free access to all technical elements, materials and waste products can be carried out without inconvenience. One disadvantage is the energy used for pumping water from the source to the surface. Therefore, these methods are preferred to treat waters that have already been captured and diverted to the surface (e.g., pit water from active mining) (DGFZ, 2012).

In-situ methods are executed when no uplift is required or desired. The subsurface becomes the reaction space for essential process steps and mass transfer. When the process is set up, necessary reagents for mass transfer are located in the subsurface (e.g., reactive walls), depending on the specific process. In-situ methods are preferred when the load of contaminants is low and waters to be treated should remain underground (DGFZ, 2018).

A brief description is shown in **Table 2-9.**

***Table 2-9**. Water treatment methods*

N°	Treatment Target	Methods	Type	Main technology
		Groundwater		
1	Metal(oid)s - Sulphate - Alkalinity generation - Neutralization	Autotrophic sulphate reduction	Active	Reactor
2	Metal(oid)s - Sulphate - Acidity reduction	Heterotrophic sulphate reduction	Active In-situ	Reaction zone
3	Sulphate – Metal(oid)s	In-situ reactive barriers	Passive In-situ	Reactive barriers
		Surface water		
4	Metal(oid)s	Aerobically constructed wetlands	Passive On-site	Wetland
5	Sulphate - Metal(oid)s – pH increase	Anaerobic constructed wetlands	Passive On-site	Wetland
6	Iron - Sulphate	Schwertmannite process	Semi-active On-site	Reactor
7	Sulphate - Calcium	Membrane process (nanofiltration)	Active On-site	Membrane
8	Iron - Sulphate - Neutralization	Reaction carpets for surface waters inflow treatment	Active In-situ	Reaction carpet
9	Metal(oid)s – Neutralization	Oxidative mine water treatment	Active On-site	Reactor
10	Sulphate - Metal(oid)s - Neutralization	Membrane electrolysis	Active On-site	Membrane
		Surface water (open pit-lake)		
11	Sulphate – increase of alkalinity (reduction of acid load)	Heterotrophic sulphate reduction (In-lake reactors for reductive sulphate separation)	Active	Reactor
12	Neutralization	In-lake process for water neutralization	Active	Reactor
13	Buffer capacity increase	Lake conditioning	Active	Reactor

Source: DGFZ (2012) and DGFZ (2018)

2.4.3 Criteria for Selection of the Treatment Process

Selection of a specific treatment process depends on many factors, and it must be based on results from site investigations and pilot plant tests. DGFZ (2012) discusses the different factors directly determined the treatment process selection, which are:

- Spectrum of dissolved pollutants in mine water to be treated, this defines the available technologies for the immobilization of pollutants.
- Technological and economic capacity. Capital costs and operation costs are relevant factors to be considered.
- Physical conditions defined by climate, geomorphology, geology, and land use that either promote or limit certain remediation options.
- Availability of operational resources: energy, raw materials, space, and personnel.
- Legal framework, which determines the necessary remediation actions by qualitative classification of the water, determination of effluent properties, determination of the measurement site and allocation of responsibilities.

On the other hand, factors that characterize the **source of pollutants** and which indirectly determine the selection of a cleaning process are:

- Source volume (m^3), density (kg/m^3 solid), and mass (kg), and the spatial extent of the contaminated site(s), and, along with the hydraulic flow regime, the course of the transport pathways defining the spatial extent of a possible material sink catchment (catchment system, discharge system, wetland).
- The mobile amount of substance (mol/m^3 solid) within the source, which defines the total amount of substance to be treated (mol) from the source,
- The geochemical release process acting on the source [$mol/(m^3 solid*s)$], which defines the release rate of the substance in a given time.
- The substance load (release rate or source strength) (mol/s) can be defined by the superposition of the source volume [m^3], the initial substance concentration (mol/m^3) and the hydraulic flow regime (m^3/s).
- Sinks along the transport path, which reduce the substance load, the substance concentration, and the dilution processes, which reduces the material concentration.

3. Reference Sites

Three study sites in Peru were selected for the BLP Project Saxony – Peru and are described in this chapter. Sites are located in southern Peru and present water resources problems related to mining industry. Descriptions refer to general background, physical components (geology, hydrology), and mining in the area (operations and tailings). A historical investigation was performed on each study site with the existing information, according to the Saxon methodology for contaminated sites management, described in **Chapter 2.**

In addition, reference sites from Saxony were selected as cases of positive experience in water management at post-mining sites. These are described also in the same way as study sites from Peru.

Finally, a methodology for comparing the saxon reference sites is presented, based on the GKZ (2018) “Support for the development of competencies and capacities in the management of mining environmental liabilities in the Andean countries (project number 81216685)” document. Results from the different saxon sites are presented.

3.1 Peruvian Reference Sites Description

3.1.1 Los Rosales

3.1.1.1 General Background

Los Rosales is located in the Vilque district. Closest city is Puno, 28 km east, capital of the Puno Region, while Vilque is the closest town, 5 km northeast. Since 2009, Los Rosales is owned and operated by Acumulacion Los Rosales Limited Liability Mining Company (*SMRL Acumulación Los Rosales,* from now on Los Rosales Mining Company), since December 2019, reprocessing tailings and waste rock. Los Rosales Mining Company is classified as a small mining producer.

Candelaria mine is an old underground mine located in Los Rosales, with history of copper extraction. Reconditioning and processing of gold bearing veins is planned by Los Rosales Mining Company.

Tailings have been deposited inside the mining properties, as a product of mining activity since almost 40 years. Mining activity in the area by formal companies dates to 1982, while artisan mining is found since 2014, by local miners.

Currently, a leaching and flotation plant with a capacity of 120 MT/day is found in Los Rosales, and plans exist to expand its capacity to 320 MT/day. To this end, a semi-detailed environmental study has been submitted to the local authorities by Los Rosales Mining Company.

Los Rosales Mining Company also seeks to support informal mining in the area, helping to formalize the artisanal miners who work within Los Rosales' mining concessions, as well as stockpile and process their minerals.

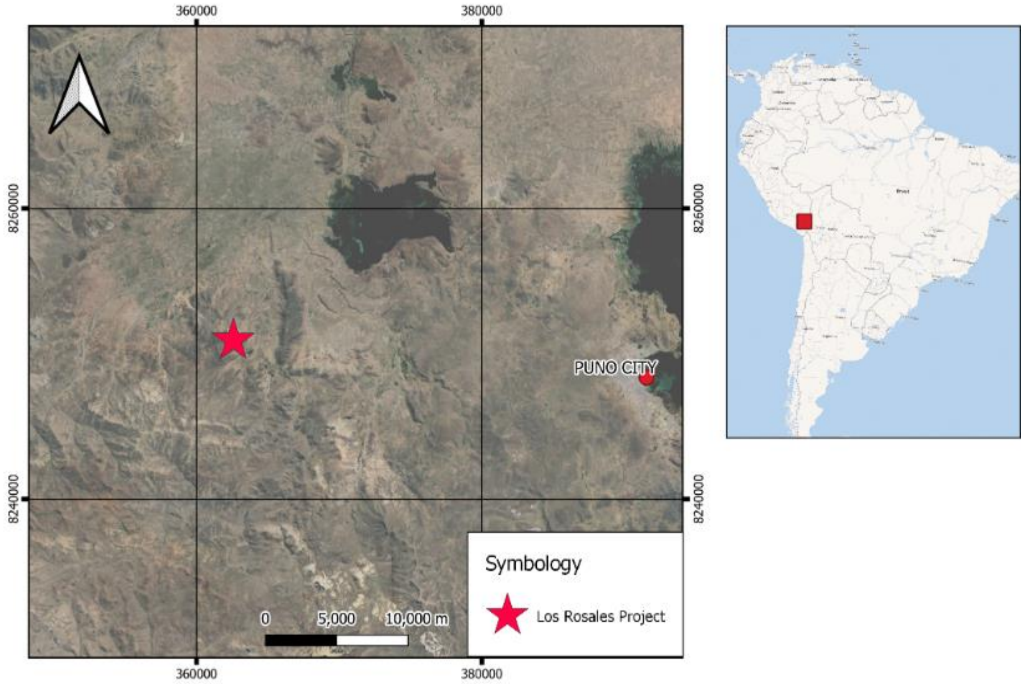


Figure 3-1. *Location of Los Rosales*

3.1.1.2 Geology and Mineralization

Los Rosales is located in the southern Peruvian Andes, which is divided into three main morpho structural units disposed in a SW-NE orientation, from southwest to northeast: *Cordillera Occidental, Altiplano* and *Cordillera Oriental*. Los Rosales lies over the *Altiplano*, 3 km north of the border with the *Cordillera Occidental* (Rodriguez et al., 2020).

The *Altiplano* is a high-altitude plateau in the central Andes, composed mainly by plains and hills with altitudes above 3800 masl (Rodriguez et al., 2020), as seen on the central and northern part of the Illpa Basin. To the south and parts of the east of the basin, more pronounced morphologies arise, mainly controlled by local and regional fault systems (Valencia and Rossel, 2003).

According to Valencia and Rossel (2003), the local geology is characterized mainly by the base of the Puno Group. Diorite – monzodiorite of Neogene age are present intruding the Puno group northwest of the project in the Los Rosales mine sector. Quaternary deposits are spread east of Los Rosales.

Los Rosales is part of a metallogenic district characterized by polymetallic Pb-Zn-Cu deposits with epithermal Au-Ag superposition, which spreads over the western part of the *Cordillera Occidental* unit.

Mineralization in Los Rosales, more specifically in Candelaria Mine is controlled by a vein system with NE-SW direction. Alteration is limited to veins, forming silicified haloes, in some cases with argillic alteration. Disseminated pyrite and specularite are present in argilized zones. Los Rosales Mining Company did a general survey on the small miners working near Los Rosales. Quartz and sulfide mineralization was described in most small mining works.

3.1.1.3 Candelaria Mine and Tailings

Candelaria Mine is an underground mine and was originally exploited for copper extraction. Currently it is under maintenance works for ensuring stability. Historically, it was mined under the "cut and fill" method, due to the good quality of the rock.

Tailings in Los Rosales are widespread in the area and are part of the different mining liabilities found in the area, which also include waste rock dumps and old mining infrastructure. Los Rosales Mining Company is responsible for the adequate relocation of all these liabilities.

Tailings show evidence of erosion and interaction with meteoric waters. All tailings will be processed for extraction of minerals with economic value and will be then deposited in properly sealed dams.

3.1.1.4 Hydrology

Los Rosales is within the Illpa Basin. The main river in the basin is the Illpa River, located north, flowing to Lake Titicaca. Tributaries come from the south and east, where the higher slopes are. Rivers are fed from precipitation occurring during the rainy season (i.e., October to April), and during the dry season they are dry (ANA, 1981).

Vilque River is the closest river to Los Rosales, 2.5 km northeast **(Figure 3-2),** flowing from south to north passing beside the Vilque town, where it merges with several other tributaries to finally become the Illpa River. SENAMHI (2019) estimates mean flow rates for Vilque River reaching up to 23 m^3/h in February and as low as 1 m^3/h, evidencing the strong dependence on rainfall.

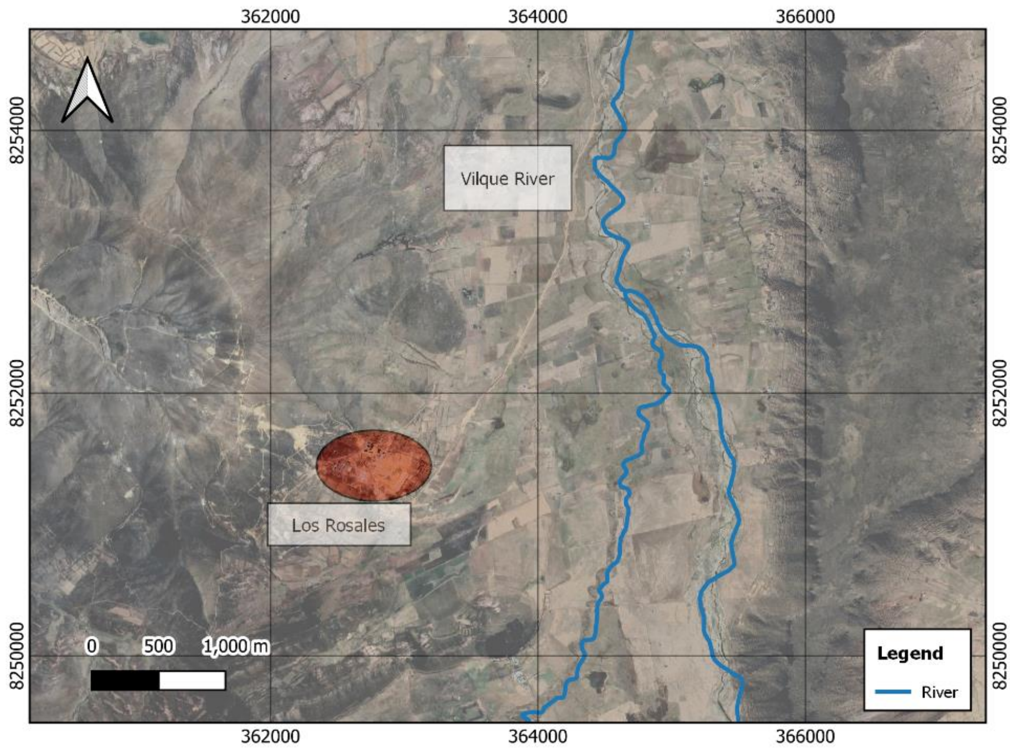


Figure 3-2. *Vilque River*

Historical rainfall data was obtained from PISCO (Peruvian-interpolated data of the SENAMHI's climatological and hydrological observations): a monthly data set based on the rain gauge network data from SENAMHI (National Hydrology and Meteorology Survey), available for the period 1981-2018 with a spatial resolution of 0.05° x 0.05°. Data from Mañazo weather station, located 7 kilometers west of Los Rosales (***Figure 3-3***), was extracted from the PISCO database. Total annual precipitation is shown in **Figure 3-4**. For the 1981 - 2018 period, annual precipitation ranges from 286 mm in 1983 to 1000 mm in 1984.

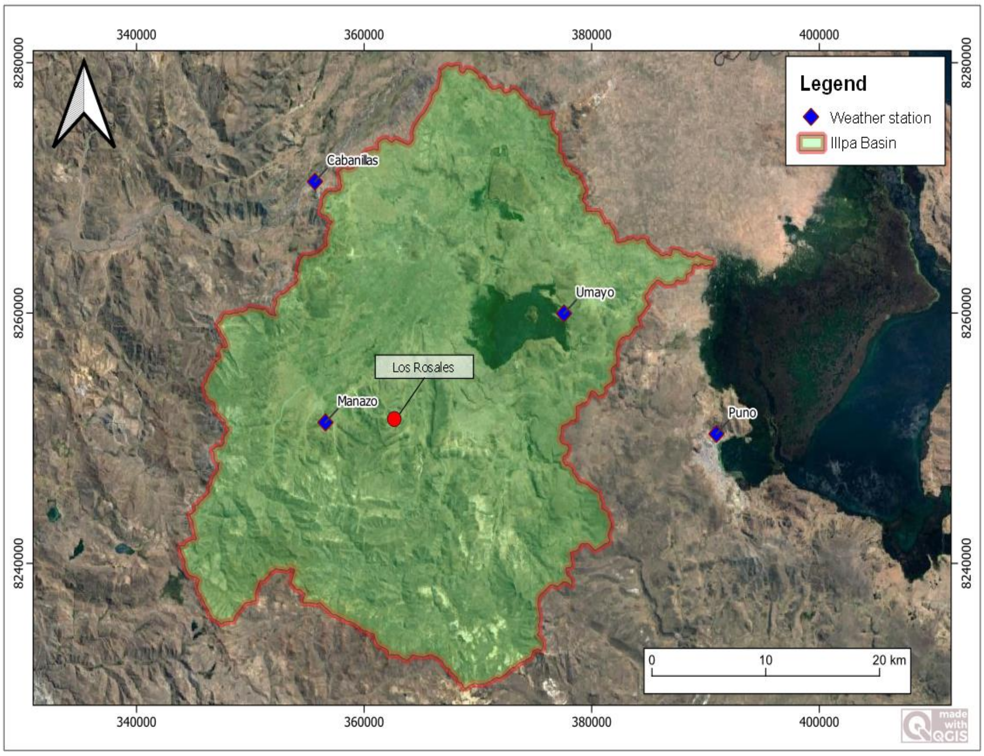


Figure 3-3. *Location of Mañazo weather station*

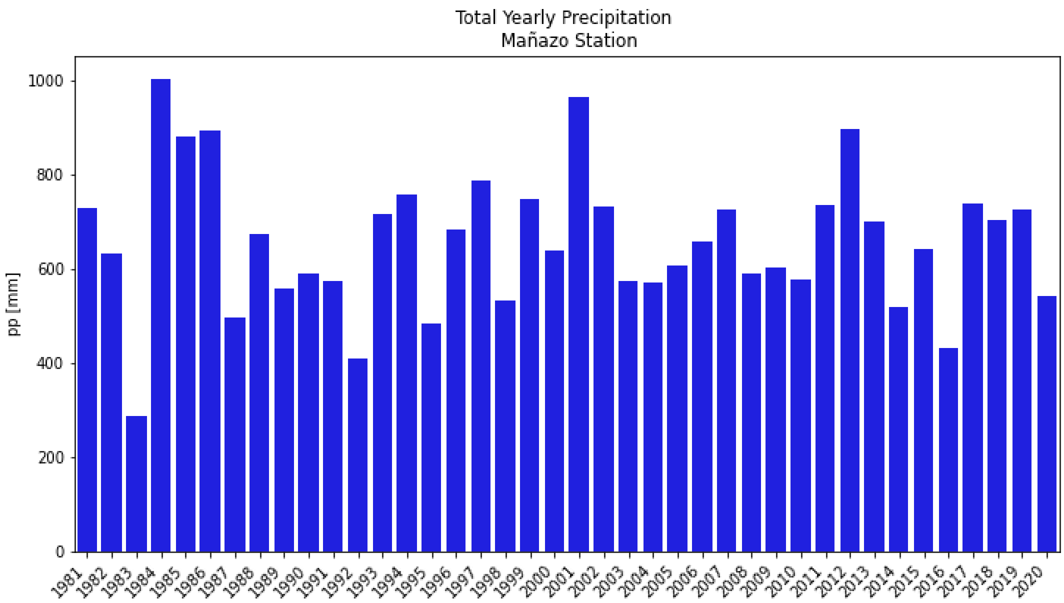


Figure 3-4. *Total annual precipitation in Mañazo station*

Source: PISCO

Figure 3-5 shows the average monthly precipitation for the same period. It is possible to identify two very distinct seasons, a rainy season from November to April with almost 90 % of the total annual precipitation, and a dry season from May to October.

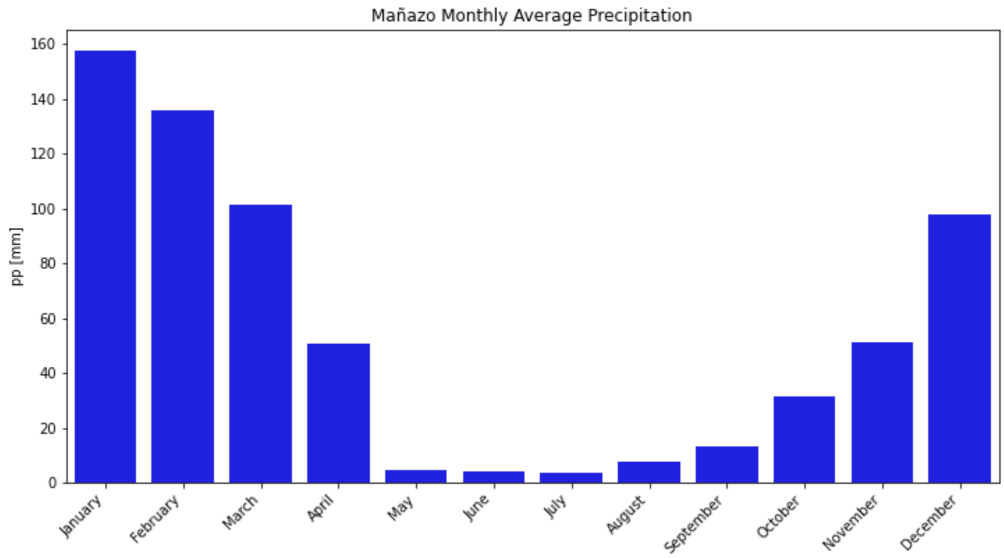


Figure 3-5. *Monthly average precipitation for 1981-2018 period*

Source: PISCO

3.1.1.5 Historical Exploration

Historical information from Los Rosales was studied in order to determine pathways and protected goods for hazard assessment. The necessary information was obtained from the following reports and sources:

- **Two monitoring campaigns** in March 2020 and 2021 (Quantum MVA, 2020; Sesam-Peru, 2021). These reports included soil, water, and noise analyses.
- **Hydrogeological study** from October 2020 (Golden Growing, 2020a). Chemical results from four sampling sites are presented, including mine water and groundwater samples from exploratory excavations.
- **Hydrological study** from October 2020 (Golden Growing, 2020b). Basin characterization and maximum expected precipitations and runoffs were calculated from meteorological data.
- **Geological exploration report from October 2020** (Canllahui Duran, 2020). A general survey of the Los Rosales properties, the Candelaria Mine and miners extracting material without machinery in the area focused on mineralization in the area.
- **Personal communications** with Los Rosales Mining Company's permits chief, Mr. Oliver Huaman.

The following results were obtained from the historical exploration:

- Mine water from Candelaria Mine reported low pH, high concentrations of sulfate, fluoride, aluminum, copper, manganese, nickel, and zinc (**Table 3-1**). Copper, iron, and zinc concentrations exceed maximum allowed limits for water discharge in mining sites determined in the Peruvian regulations.

Table 3-1. *Historical chemical data on mine water in Los Rosales*

Date	pH (-)	SO_4 mg/L	Al mg/L	Cu mg/L	Fe mg/L	Mn mg/L	Zn mg/L
March 2021	4.4	-	-	-	-	-	-
March 2020	5.2	-	9.35	7.98	117.01	11.56	2.34
October 2020	4.3	985	8.75	6.99	128.7	12.89	2.249

- Groundwater from exploratory excavation reported low pH, and high concentrations of sulfate, aluminum, cadmium, cobalt, copper, manganese, and zinc **(**
- **Table 3-2).** These concentrations exceed the environmental quality standards from Peruvian regulations.

Table 3-2. *Historical chemical data on groundwater in Los Rosales*

Date	pH (-)	SO_4 mg/L	F- mg/L	Al mg/L	Cu mg/L	Mn mg/L	Zn mg/L
October 2020	3.8	1968	7.81	14.25	61.38	44.43	9.58
October 2020	4.5	1375	3.11	3.57	21.01	24.42	6.85

- There is no permanent surface water runoff in Los Rosales water catchment. Water courses are seasonal and related to precipitations during the rainy season (October – April).
- Mineralization in Candelaria Mine and small mine works in the area is present in veins, with sulfides mineralization present in all the surveyed mining works (e.g., pyrite, chalcopyrite).

Based on results from historical investigation in Los Rosales, the following pathways were identified: Surface water and Groundwater.

Further investigations (oriented investigation) are required for these specific pathways. As part of the BLP Saxony-Peru project, groundwater and surface water characterization were planned in Los Rosales and activities took place in November 2021. Results are presented in **Chapter 4.**

3.1.2 Madrigal

3.1.2.1 General Background

Madrigal mine is located in the province of Arequipa Region. It is part of the upper part of the Colca River Basin. Madrigal town is the nearest settlement, located southeast of the mine **(Figure 3-6).** Madrigal mine is a polymetallic deposit (Cu-Ag-Zn-Pb) with arsenopyrite, chalcopyrite, galena, quartz, and sphalerite mineralization. It is located in the Caylloma epithermal vein district, a scale mineralized region in southern Peru with silver and base metal mineralization (Echavarria et al., 2006).

Mine operation began in 1972, producing copper, zinc, and lead concentrates until 1991 via underground mining operations. Mine properties are currently owned by Mountain Minerals Peru S.A. Approximately 2.2 MT of tailings from the Madrigal mine are found on the Chimpa River, a tributary of Colca River without impoundment walls at circa 75 meters from the left bank of the river.

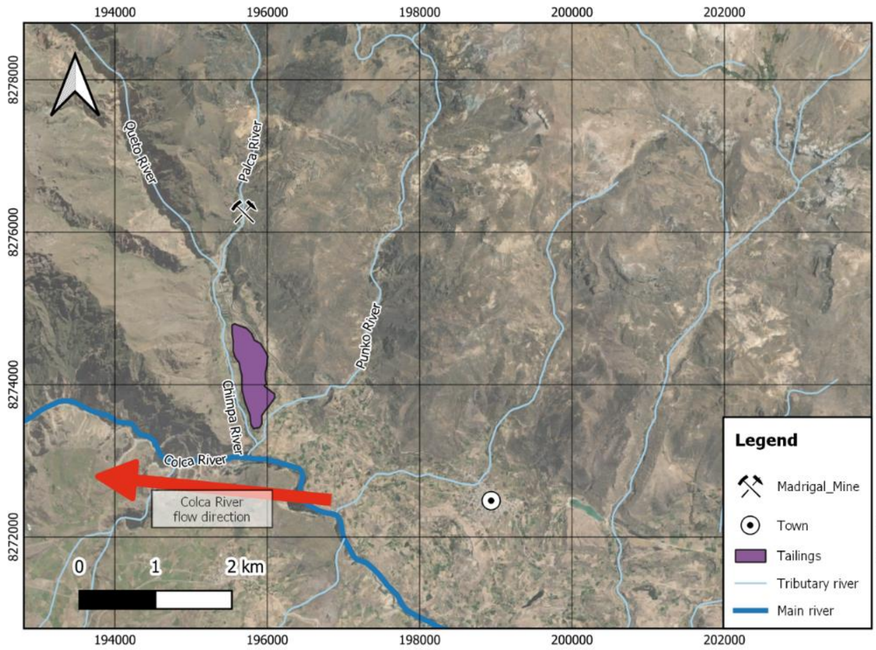


Figure 3-6. *Madrigal town, Madrigal mine and tailings*

3.1.2.2 Geology and Mineralization

Madrigal is located in the Neogene volcanic arc, southern Peru, which is part of the Cordillera Occidental structure. The main lithologies found are Plio-Pleistocene volcanic rocks and tuffs, Miocene dacite domes, and Jurassic sedimentary rocks (Echavarria et al., 2006).

Over a 245 km strike length there is a Zn-Cu-Ag vein. The structures strike N80°W and dip 72°NE and range in thickness from 0.9 to 19 m in a main mineralized nail zone. The bedrock consists of quartzites and slates of the Jurassic Yura Group, which underlies in discordance the volcanics of the Tacaza Group; outcrops of this group show alteration aureoles such as propylitization, silicification and pyritization (Chira et al., 2011; **Figure 3-7**).

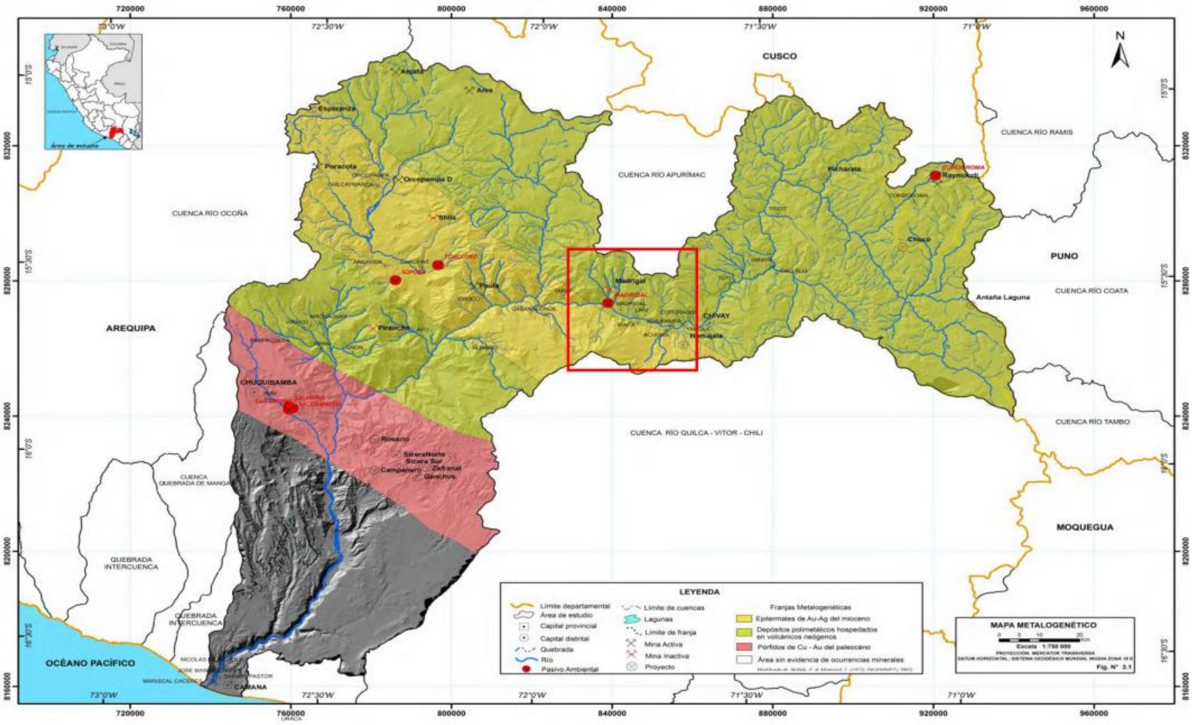


Figure 3-7. *Metallogenic map in the Madrigal area*

Source: Chira, et al. (2011)

3.1.2.3 Hydrology

Historical rainfall data was obtained from PISCO (Peruvian-interpolated data of the SENAMHI's climatological and hydrological observations): a monthly data set based on the rain gauge network data from SENAMHI (National Hydrology and Meteorology Survey), available for the period 1981-2018 with a spatial resolution of 0.05° x 0.05°. Data from Madrigal weather station, located near the Madrigal Town, was extracted from the PISCO database.

Total annual precipitation is shown in **Figure 3-8.** During the 1981-2018 period, annual rainfall ranged from 70 mm in 1992 and 813 mm in 2012.

Figure 3-9 shows the average monthly precipitation in Madrigal for the same time period. It is possible to identify two very distinct seasons, a rainy season from December to April with almost 93 % of the total annual precipitation, and a dry season from May to November.

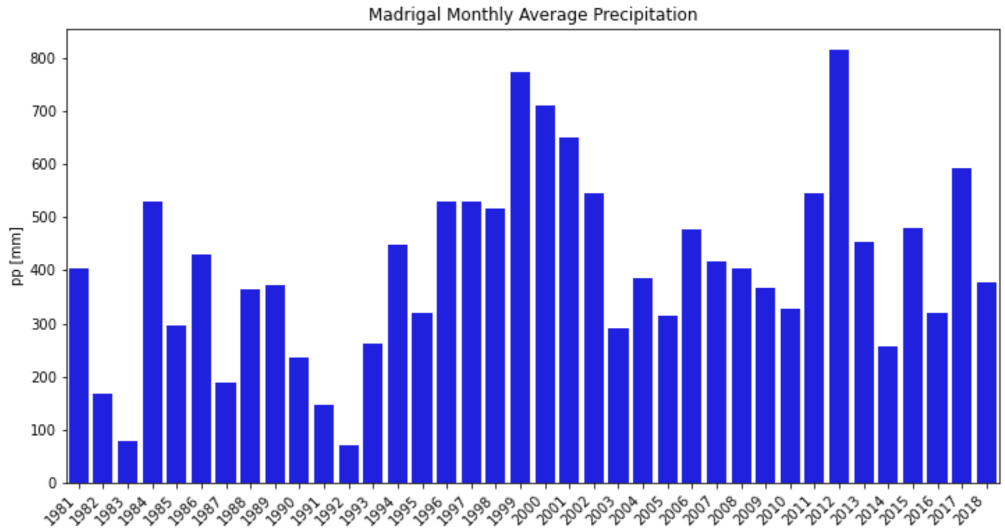


Figure 3-8. *Total annual precipitation in Madrigal*

Source: PISCO

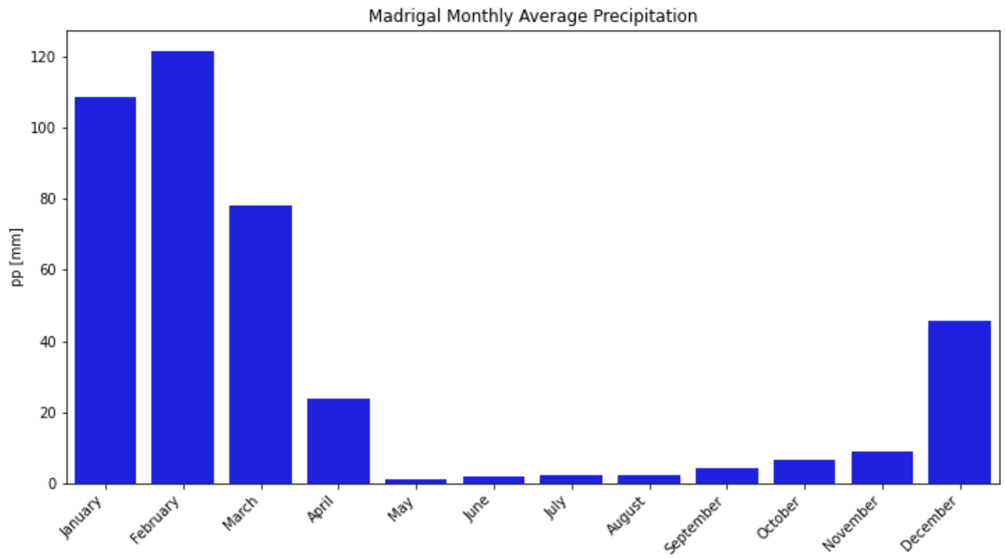


Figure 3-9. *Monthly average precipitation in Madrigal*

3.1.2.4 Madrigal Mine and Tailings

The Madrigal mine is located in the study area at an altitude of 3000 meters above sea level. The Madrigal mine began operating in 1972, with a production of 30,000 [MT] of copper, zinc and lead concentrates, until 1991. The mineralization at Madrigal is polymetallic: Cu-Ag-Zn-Pb **(Figure 3-10),** and the minerals or other materials present in the mine are: arsenopyrite, chalcopyrite, galena, quartz, and sphalerite. Mine operations consist of underground workings. Subsurface length extends for a maximum of 10,000 m. The mine used the cut-and-fill mining method with subsequent selective flotation of copper, lead and zinc, respectively. The final residues from the last selective flotation (zinc) were conveyed by gravity through an iron pipe to a dam located south of the beneficiation plant. Mountain Minerals Peru S.A. is the current owner of the mining area.

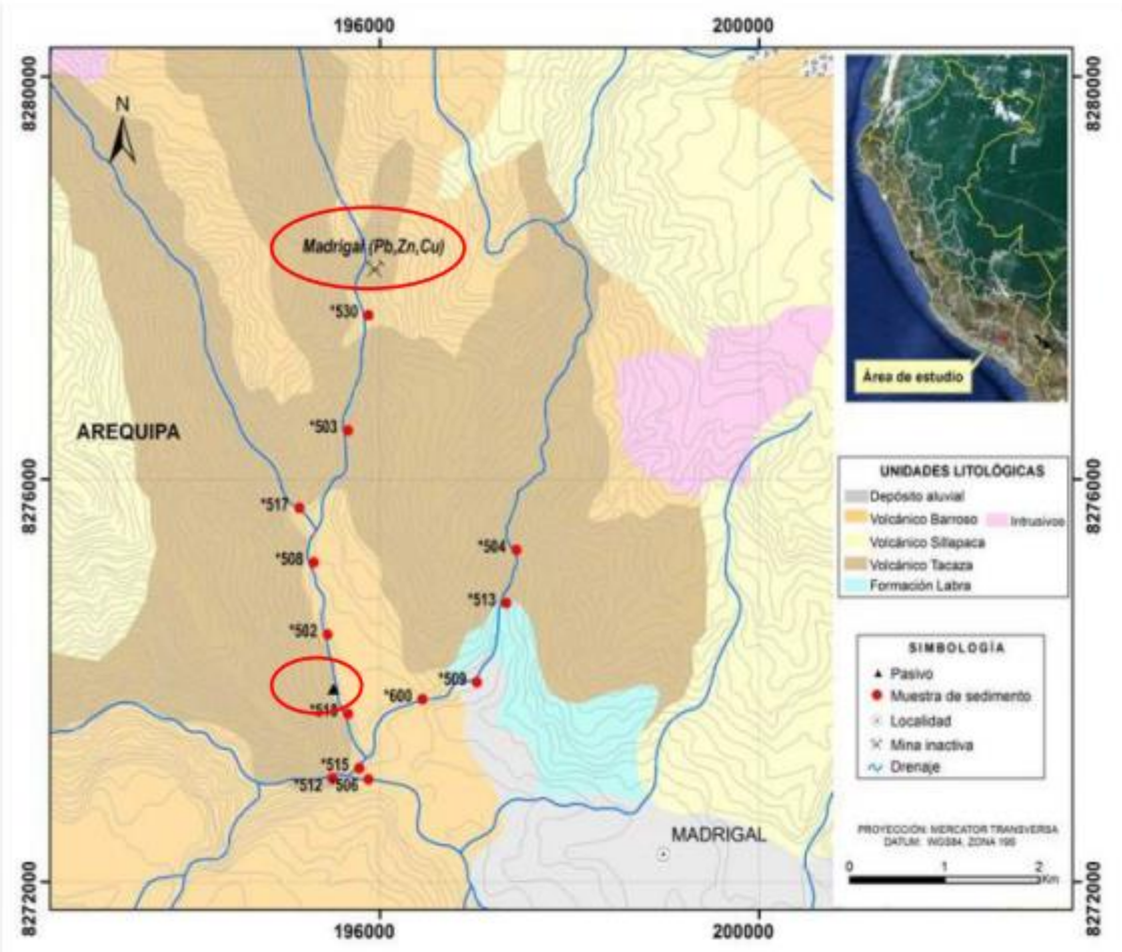


Figure 3-10. *Madrigal Mine and tailing's location*

Source: Guillén et al. (2013)

As a product of 19 years of mining operations there is a tailings pond of approximately 2,200,000 tons located on the left bank of the main creek. The mining waste was deposited in a natural environment without the construction of retaining walls. This waste is located approximately 75 meters from the left bank of the Cahuira River, which is one of the sources of irrigation for nearby crops and is one of the tributaries of the Colca River.

Precipitation, generally occurring between December and March, facilitated plant growth, which again generated a layer of soil on top of the tailings. When the tailing material is dry, however, it is transported by wind and then deposited in the environment. For example, also on the nearby fields.

3.1.2.5 Historical Exploration

Historical information from Madrigal Mine and tailings was studied in order to determine pathways and protected goods for hazard assessment. Data was limited due to the Mining Company not being able to participate in the project, because of COVID crisis related problems. The following sources of information were consulted as part of the historical exploration:

- **Geochemical characterization of sediments** near Madrigal mine (Guillén and Vasquez, 2013). 13 sediment samples were analyzed to determine the distribution of metals and metalloids in sediments of rivers near the Madrigal Mine.
- **Peru metallogenic map** (Chira et al., 2011). Peru hosts many metallogenic districts with distinct features. This document was studied in order to obtain a regional characterization of the area.
- **Environmental geochemistry of the Camana-Majes-Colca River Basin** (Chira et al., 2011). General information about the Madrigal Mine and associated tailings were found in this document. Sediment samples were also analyzed for this study.
- **Geo-environmental study on the Colca River Basin** (Zavala et al., 2014). Historical and general information about the Madrigal Mine and its tailings is discussed.
- Doctoral thesis from Martinez (2018), presenting an **assessment on the conservation status of the contaminated soils by the Madrigal Mine Tailings and a proposal on phytoremediation**.

The following results were obtained from the historical exploration:

- Madrigal Mine is located in the Caylloma metallogenic district, characterized by silver and base metal mineralization.
- Sediments in the Madrigal Mine area reported high concentrations of zinc, copper, and lead, related to the sulfur mineralization in Madrigal Mine.
- Waters in Madrigal are calcium sulfate, unlike most of all waters from that part of the basin, which are dominated by calcium bicarbonate-sulfate and sodic.
- Madrigal Mine tailings are identified as one of the main environmental liabilities in the Colca Basin, with high concentrations of arsenic (307.1 mg/Kg), zinc (3485.7 mg/Kg) and mercury (42.9 mg/Kg).
- Tailings are located next to the Palca River, without any top cover to prevent wind transport or interaction with meteoric waters.
- There are reports of collapses and landslides near the tailings.

3.1.3 Salinas y Aguada Blanca National Reserve

3.1.3.1 General Background

Salina y Agua Blanca National Reserve is located in the southwest of Peru, It occupies 366,936 ha among Arequipa and Caylloma provinces in Arequipa Region and General Sanchez Cerro province in Moquegua Region. It is located at 4,300 masl.

This National Reserve was created by Supreme Decree 070-79-AA on August 9 of 1979. As a National Reserve, its main objective is to preserve biological diversity, especially for the recovery of vicuna populations, and it also allows for the sustainable use of the reserve's flora and fauna. Since its creation, Salinas y Agua Blanca was overseen and administered by the National Institute of Natural Resources and Protected Areas (INRENA), which was later replaced by SERNANP. Under INRENA's public administration policies, in 2007 the RNSAB was ceded to DESCOSUR under a 20-year administrative contract. (RNSAB; 2019)

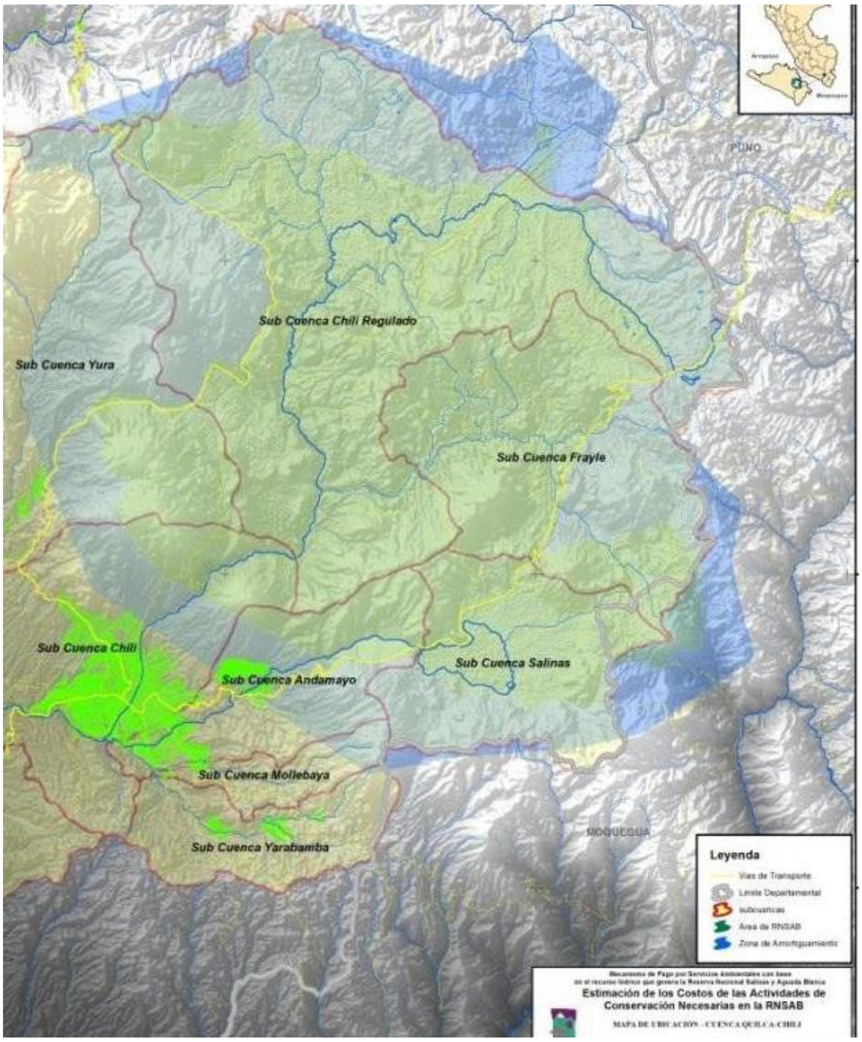


Figure 3-11. *Location of Salinas y Aguada Blanca National Reserve*

Source: Poma (2022) DESCOSUR.

Currently, the main productive economic activity within the Agua Blanca National Reserve is raising South American camelids such as llamas and alpacas. In addition, the reserve's water management influences the water supply for the city of Arequipa and surrounding areas, contributing approximately 350 million cubic meters of water from its network of reservoirs (regulated system of Chili Basin). (Poma, 2022)

More than 1.300.000 inhabitants, 17.000 hectares of agriculture, the second largest copper mine in Peru (Minera Cerro Verde), and some industries, including hydroelectric power generation, are supplied by water from the National Reserve. A large part of waters in the RNSAB show a naturally elevated level of metal (oid)s because of the hydrogeological structure of the region. Also, there is a still unidentified number of ongoing informal (gold) mining activities inside the reserve. These are performed by local population of the rural communities as well as by private land owners (total of about 7,000 persons) and they are based on poor local living conditions. Environmental water contamination due to mining activities are risky for the water supply of the local population itself and for the agriculture activities. Monitoring of local water quality and / or treatment of drinking water is rather uncommon.

3.1.3.2 Hydrology

There are two watershed systems in the RNSAB area: the Chili River watershed and the Salinas Lagoon watershed. The Chili River basin occupies approximately 300,000 ha and the Salinas Lagoon endorheic basin occupies approximately 50,000 ha. (Zeballos et al., 2008).

On the other hand, the reserve covers the entire headwaters of the Quilca Chili watershed, the area with the highest rainfall in the basin. The basin's water management is responsible for supplying water to the city of Arequipa through rainfall, the capacity of the natural water regulation infrastructure, and a system of small and medium-scale reservoirs built within the National Reserve.

Construction of micro reservoirs: Its purpose is to store and infiltrate water to supply the aquifers. Its implementation promotes the diversity of flora and fauna and is also used as a source of water for irrigating natural pastures. According to the water management report, 315 "Qohas" rustic water reservoirs were built in the last 5 years, with a storage capacity of 600,908 m^3 of water.

***Figure 3-12**. Front view of the micro reservoir “Mamaqocha”*

Source, Poma (2022). DESCOSUR.

3.1.3.3 Social responsibility

The creation of the national reserve contemplates objectives and action plans to promote the productive-social development of the communities through the improvement of environmental conditions, for which the RNSAB considers the following strategies:

- Training and development of technical capacities of local populations to self-control local water resources (storage and quality) and to adapt to climate change.
- Consolidation of local organizations and governments including registration of informal mining.
- Support for natural resource management (e.g., planting and water harvesting).

3.2 German Reference Sites Description

3.2.1 SAXONIA Freiberg

The contaminated site project SAXONIA (SAXONIA Site Development and Management Company Ltd.) ran from 1993 to 2013 with 400 measures at about 50 sites. The aim of the project was to remediate contaminated sites in the Freiberg area in order to prevent or significantly reduce the transfer of pollutants via the air and water pathways. Remediation measures include, for example, the deconstruction of contaminated buildings and the covering and sealing of polluted smelter sites and dumps. The main pollutants are arsenic and metals such as lead, cadmium, copper, and zinc. The effectiveness of the implemented measures could be proven via the still ongoing water monitoring.

The sludge dump site Davidschacht was one of these sites. The site is still under investigation and many proposals were made for remediation but also for further use as a research place.

3.2.1.1 General Description

Mining started in 1168 in Freiberg when large silver discoveries were made. In 1835 the Davidschacht was excavated as one of the main shafts in the mine field with a maximum depth of 736 m. After the closure of the mine, the shafts were flooded. Today, numerous commercial and industrial enterprises are located in this area.

The site is located at the eastern part of the city Freiberg in Saxony (Germany). The Davidschacht complex itself represents a dump complex consisting of three sub-areas: the coarse tailings pile with the open-cast facilities of the Davidschacht and two sludge dumps. The sludge dump Davidschacht is located in the north and the sludge dump Hammerberg is located in the south **(Figure 3-13).**

The sludge dump Davidschacht has an extension of about 6.3 ha and a volume of 760.000 m³. The highest difference in height between plateau and surface of the original underground is 42 m. Soil was applied after the abandonment for re-vegetation.

The measures carried out after the end of mining to recultivate the slurry dump were only very rarely successful in the long term, partly due to the very low pH values. Nevertheless, large areas are now overgrown again (natural succession). Due to the extreme abiotic site factors (high heavy metal content, low pH values, low soil moisture), the biotopes developed on the flushing dump are unique. The slag heap is thus not only worthy of monument protection for cultural-historical reasons, but also worthy of nature conservation.

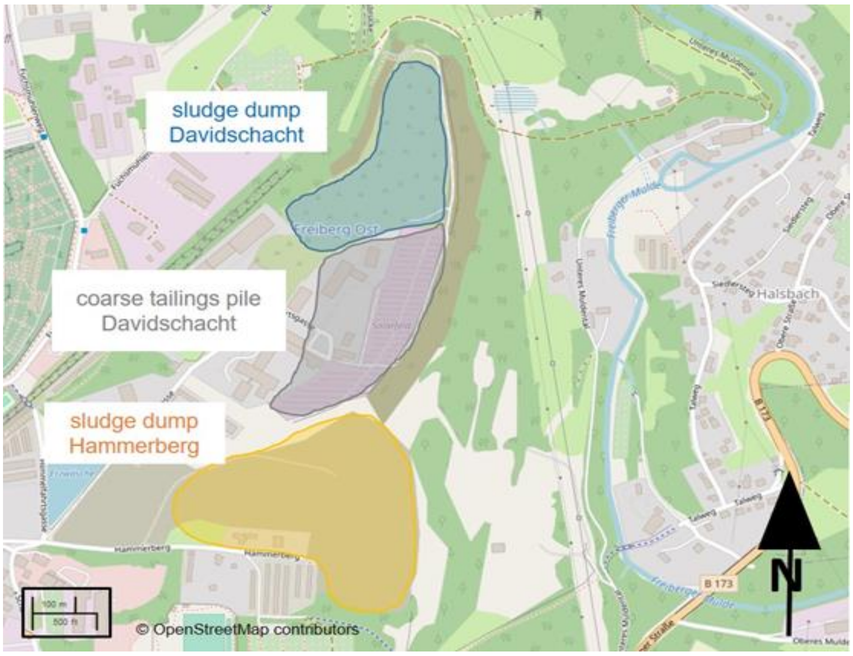


Figure 3-13. *Location of the complex of the Davidschacht dumps*

3.2.1.2 Climate

The following climatic conditions are present in the study area:

- Main wind direction: west
- Mean annual precipitation: 831 mm
- Mean annual temperature: 8°C

3.2.1.3 Geology

The Freiberg deposit district is in the north-eastern part of the Ore Mountains. The area around Freiberg consists of grey orthogneiss, the so-called Freiberg gneiss dome. This is a medium to coarse crystalline biotite-double feldspar gneiss. Educts of this gneiss were magmatic rocks with granodioritic composition intruded in the Late Proterozoic. Metamorphism and tectonic overprinting occurred in connection with the variscan orogeny in the Lower Carboniferous and the alpidic orogeny in the Cretaceous.

3.2.1.4 Hydrology

The Davidschacht sludge dump was created by closing off a valley leading to the east, to the Freiberger Mulde, by means of a heaped-up dam made of coarse rock material. The precipitation catchment area of the flushing dump has an area of 0.166 km².

The Freiberger Mulde is the main receiving water of the area with a long-term mean discharge of 4.10 m³/s. The precipitation water seeping into the rinsing dump flows hypodermically on the surface of the solid rock or through fissures in the rock to the Freiberger Mulde following the gradient. Water pathways continue to exist due to old mining operations beneath the flush dump.

One of three main galleries draining the Freiberg mining district is the "Königlich Verträgliche Gesellschaft Stolln" (KVGS). It drains into the "Roter Graben" (Red Ditch), which also collects water from other mines and drains into the Freiberger Mulde in several sections.

The average rate of groundwater recharge is 200 L/(m²*a) or 0.67 L/s. In total, the real water volume flowing out of the catchment area of the flushing dump is 0.95 L/s on average. (Water balance details see Martin et al. (2012))

3.2.1.5 Mining

Mineralogical composition

Almost exclusively ores from the Freiberg mining district were processed in the Davidschacht processing plant. Accordingly, the rinsing dump contains quartz (approx. 70 %), feldspar, mica, fluorspar, barite, calcite, lead sulphide, iron sulphide, zinc, manganese, arsenic, cadmium, and copper. The following average substance contents of the treatment residues have been documented: lead 0.14 %, zinc 0.3 %, copper 0.04 % and sulphur 2.3 %.

Remnants of flotation reagents are also contained in the tailings. The reagents mainly used in the Davidschacht flotation were xylenol as frother and xanthate (isoamyl xanthate) as sulphide collector. From 1952, sodium cyanide was used to press the zinc blende. Flotation therefore had to take place at pH > 7 to prevent the development of hydrocyanic acid. The addition of copper sulphate served to bind the released cyanide. Furthermore, chlorinated lime was added to the flotation effluents.

Methods/Working Process

Since 1936 the processing plant on the Davidschacht site worked with the principle of foam processing (flotation). The ore was subjected to the following **process steps** during its extraction until it was processed: After railroad and shaft haulage, the ore was taken from the mine tubs via a revolving tipper to the jaw crusher, where it was first crushed to a grain size of < 60 mm. However, even smaller grain sizes were necessary for ore processing, which is why it then went through several more stages of crushing and screening until it had a diameter of about 0,2 mm. From the sludge produced from the ore meal, copper-containing PbS, a ZnS and a strongly arsenic-containing FeS_2 concentrate were obtained successively during flotation.

The two sludge dumps of the complex of the Davidschacht are described as follows **(Figure 3-13).** These belong to the processing plant working in the 20th century.

- After the exhaustion of a small clarifier which had been put into operation in 1944, the **Davidschacht sludge dump** was approached. It was the sole sludge dump from 1951 to 1964 and served as a reserve dump for the new Hammerberg sludge dump from 1964 to 1969. It is located north of the processing plant and the former small clarifier and represents the northern dump of the entire tailings pile.
- From 1964 to 1969, the **Hammerberg sludge dump** was used as a clarifier. The small settling basins for fine sludge located in its northern section were used to dispose of the finest grain fraction of the flushed material in the first months after the flushing dump was put into operation, to keep the new central basin capable of percolation.

A special bottom sealing of the dump body does not exist. The eastern coarse clay dumps were filled directly on the natural slope after partial removal of the root soil. The stratification of the subsoil probably roughly corresponds to that of the coarse clay heap. A "clay apron" served to protect the base of the embankment. There was no targeted sealing of the flushing dump on its surface.

Quantities

A total of 39 pile core tests were carried out (18 in the area of the dump base and 21 on the dump surface). Furthermore, 135 solid samples (69 samples in the area of the dump foot, 66 samples on the dump surface) were taken. Likewise, 6 leachate samples (3 dump foot, 3 dump area) were taken. Element contents of As, Pb, Cd, Cu, Zn were determined in the solid samples. Water eluates were prepared with the same solid samples and analyzed for As, Pb, Cd, Cu, Zn, chloride, sulfate, fluoride, electrical conductivity; and pH value **(Table 3-3).** The same analysis spectrum was also used for the 6 water samples. (G.E.O.S., 1993)

Table 3-3. *Investigation data of solid matter and eluate for the sludge dump Davidschacht*

		Max.	Min.	Mean value
Solid				
Arsenic	mg/kg TS	16.300	50	4161
Lead	mg/kg TS	10.480	460	1213
Cadmium	mg/kg TS	62	2	17,1
Copper	mg/kg TS	2760	60	218
Zinc	mg/kg TS	24.000	130	1197
Eluate				
pH	-	9,4	1,9	5
Conductivity	µS/cm	2330	65	895
Arsenic	mg/L	2	0,04	0,13
Lead	mg/L	2,8	0,02	0,19
Cadmium	mg/L	0,75	0,004	0,08
Copper	mg/L	3,9	0,02	0,3
Zinc	mg/L	34	0,046	2,42

Source: G.E.O.S. (1993), depicted in G.E.O.S. (2012), Table 10

3.2.1.6 Source-Pathway-Oriented Analysis and Risk Assessment

According to the “Saxon Methodology for Contaminated Sites” of the free state of Saxony (see section 2.3), the investigation stages have also been carried out for the Davidschacht sludge dump. An **oriented investigation** (OE) as a first risk assessment has been done in 1993 with an exploration program in which extensive boreholes and soil and water samples were taken. In 1995, the **historical investigation** of the object was carried out. The result of the **detailed investigation** (2009-2018) was the final confirmation of the suspected contaminated site and the recommendation for action to remediate the sludge dump.

The remediation options were then discussed in the **remediation study** that began in 2013. Due to the extensive nature conservation concerns that had to be taken into account, a processing time of several years had to be planned. The final results, including a proposal for the preferred remediation option, will be available at the beginning of 2017. After that, the rehabilitation planning is to be started, which is to be followed by a building law approval procedure.

The source-pathway-protected good analysis has been carried out of the former mentioned investigations (G.E.O.S. 1993; BIUG, 2009; G.E.O.S., 2012; G.E.O.S., 2016). The **contamination pathways** for the sludge dump Davidschacht are:

- Formation of dust/wind dispersal:
    - Direct uptake by humans and animals via the lungs,
    - Deposition on agricultural land/entry into the food chain of humans and animals,
    - Leaching of pollutants from the dust-laden material by precipitation and entry of the substances into the water/ground or surface cycle.
- Washing off of tailing material at unstabilized places
- Dissolution of pollutants by precipitation/slope leachate and their entry into slope leachate/near-surface groundwater/surface water (Freiberger Mulde)

A danger prevention system must prevent the following:

- Blow-off of dusty tailings pile components
- Rinsing of flushing sands by precipitation water
- dissolution of pollutants by precipitation water and slope leachate
- Input and transport of dissolved pollutants into slope leachate, near-surface groundwater and surface water

3.2.2 Major Ecological Project: Dresden Coschütz/Gittersee

3.2.2.1 General Background

This chapter describes the major ecological project "Dresden Coschütz/Gittersee". The remediation work at this site and the following site "Königstein" (described in **Chapter 3.2.3**) differs not only because of the different timings of their operating histories, but above all in terms of their mining and extraction processes and thus in the entire subsequent technical facilities and technological processes.

The sediment filling of the Döhlen Basin, which forms the subground of Dresden Coschütz/Gittersee, contains mainly sandstones, conglomerates and pyroclastics, originates from the upper Upper Carboniferous and the lower Permian and is placed partly in the Rotliegend, partly still in the Stefanium. The Döhlen Basin thus belongs to a series of post-Variscan relict basins, to which the Vorerzgebirge depression in the Chemnitz area, the permocarbonic series of the Thuringian Forest and the Saar-Nahe depression with the northern part of the Palatinate Forest can also be attributed. The sedimentation in the Döhlen

Basin was controlled by the activity of the basin edge disturbances of that time. The cumulative sediment thickness is more than 800 meters

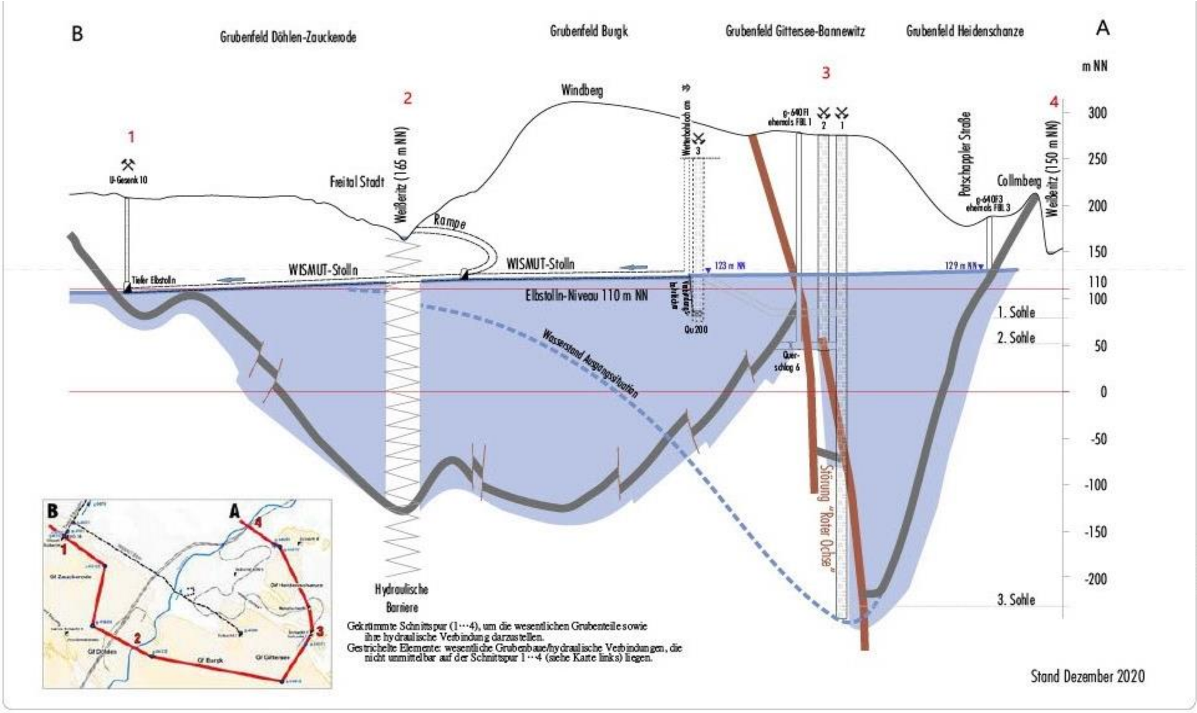


Figure 3-14. *Hydrogeological cross section of the Döhlener Basin with the Dresden Coschütz/Gittersee location.*

[The upper horizontal red line indicates the location of the two mine drainage tunnels, source: Environmental Report of the Wismut GmbH 2020]

Of economic importance were the coal seams of the Döhlen Formation, whose occurrences had been known since the 16th century and caused intensive mining activity, especially in the late 19th and early 20th centuries. Since the hard coal contains uranium, the Döhlen Basin was explored from 1947 with regard to uranium deposits and production began shortly afterwards. From 1968, mining was limited to the mining of uranium ore-bearing hard coal on the northwest edge of the Döhlen Basin by the mining company “Willi Agatz”.

On land formerly used for agriculture in Dresden-Coschütz and -Gittersee, above the popular Kaitzbach valley, the Soviet joint stock company (Sowjetische Aktiengesellschaft) SAG Wismut or Wismut AG built the “Uranium Factory 95” (Uranfabrik) on an area of about 42 hectares between 1947 and 1950. Together with the industrial tailings ponds (Halde A and Halde B), the site covered a total area of about 76 hectares. The mining activities continued after re-organisation as Soviet-German joint stock Company (Sowjetisch-Deutsche Aktiengesellschaft) SDAG Wismut in 1954.

Uranium extraction at the Dresden Coschütz/Gittersee site had been discontinued shortly after the German re-unification in 1989, and preparatory work was initiated for the closure of that mining operation. The SDAG Wismut was transferred into a limited liability company Wismut GmbH, which to this day plans and carries out the rehabilitation measures on the remains of the GDR uranium mining.

Figure 3-15. *The Gittersee tailings in the south of the city of Dresden*

left: View from Gittersee tailings to the "Uranium Factory 95" of the Wismut in 1958
right: Rehabilitated mining waste dump site Gittersee in 2015

[sources: https://www.wismut.de/de/pressefotos.php, https://www.dresden.de/de/stadtraum/umwelt/umwelt/boden/altlasten/stillgelegte-deponien/coschuetz-gittersee.php]

Structural Damage from Mining Activities

The area used over the entire period of mining in the Döhlen Basin was about 25 km², of which about 2.1 km² were used for uranium ore coal extraction by SDAG Wismut (Note: The uranium is partly bound to the hard coal.). The mining areas used by the SDAG Wismut as well as by the coal extracting companies of the 19th and early 20th centuries is monitored by constant measurement.

The subsidence on the surface caused by underground mining have subsided long ago. Possible future ground movements may occur as a result of the flooding of the pit cavities. The mining damage is mainly small to medium-scale cracking on structural objects.

Safekeeping of Underground Mine Workings

The safekeeping work of the underground mine workings has been completed at the end of the 1990ies. The necessary work was carried out to eliminate water pollutants (fats, oils, chemicals) and to backfill near-surface pits – especially shafts – to avoid subsidence of the ground surface. The flooding of the pit was initiated by those measures.

Current Situation

The core remediation of the Gittersee site has been completed since 2017; the transition to the long-term tasks of Wismut GmbH has been completed in full (source: Environmental Report of the Wismut GmbH 2020).

Treatment of mining water is no longer required at the Dresden-Gittersee site. The Gittersee underground mine workings are drained into the Elbe River via the Wismut-Stolln and further over the Tiefer Elbstolln. The monitoring of the water levels of recent years in the former working panels of the pit has shown that at intervals of several years, the connecting boreholes between the pit and the Wismut-Stolln must be cleared of incrustations in order to prevent accumulation of mine water in the flooded pit. For this purpose, the condition of the boreholes is regularly examined by means of camera inspections.

The condition control and the cleaning of the connecting boreholes are long-term tasks, as well as the maintenance of both mine drainage adits and tunnels. The latter requires the clearing of sludge at intervals of several years. In 2020, it was not necessary to clean the connecting boreholes and also not to remove sludge from the Wismut-Stolln or Tiefer Elbstolln.

A post mining environmental monitoring of surface and ground water, soil, air/dust, and radiation is ongoing on behalf of the Office of Environment of the Administration of the City of Dresden (LH-DD UA). The rehabilitated former operating area and mining waste tip in Dresden Coschütz/Gittersee, which has been transformed into a secondary biotope since the end of the remediation, is a very interesting area for observing rare animal and plant species due to its location on the outskirts of the city and the protective fence. As part of a project of the Nature Conservation Union Germany (NABU) and the City of Dresden with the aim of creating a breeding bird atlas for the city, for example, a bird count was carried out in the area with an ornithologist at the beginning of May 2020.

3.2.3 Wismut Sites Experiences

3.2.3.1 Königstein

General Background

The so-called remediation operation Königstein („SBK Sanierungsbetrieb Königstein“) of the Wismut GmbH comprises two locations, Königstein and Dresden Coschütz/Gittersee. Both sites had been included as reference locations in the BLP project. After summarizing the situation at the Dresden Coschütz/Gittersee site in **Chapter 3.2.2** here some key figures of the Königstein site are listed – in order to give the reader an overview of both locations.

In **Figure 3-16** is shown the Königstein site (black dot KS) which is placed in sandstones of the Cretaceous (light green). The Dresden Coschütz/Gittersee site described in **Chapter 3.2.2** (black dot CG) is placed in sedimentary rocks of the Carboniferous and Permian (orange with circles)

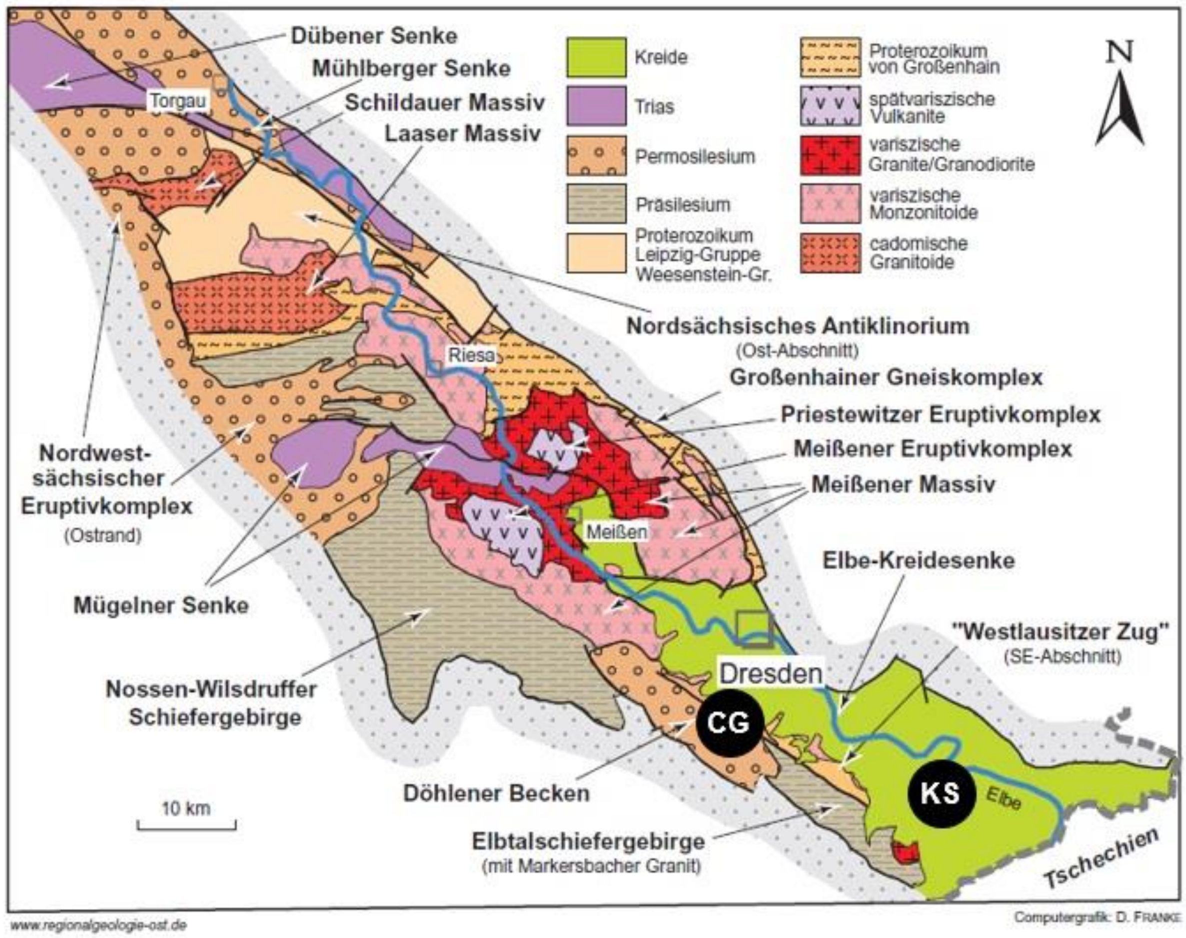


Figure 3-16. *Geological map of the Elbe valley in Saxony.*

Source: FRANKE, D. (2018)

In 1961, SDAG Wismut began exploratory work in the area of the saxon Elbe Valley Cretaceous sediments. From 1967, conventional uranium ore mining was carried out here. The uranium ore deposit, located in various sandstones of the Cretaceous sediments, was developed over an area of about 6 km² and mined in the area of the villages Königstein – Bielatal – Langenhennersdorf (Note: The Bielatal site will by described separately in **Chapter 0** The village of Leupoldishain, located in the immediate vicinity of the main shafts at the Königstein site, was almost completely influenced by underlying workings. Decisive for the entire mining and the subsequent rehabilitation of the pit are the local and regional hydrogeological conditions.

In **Figure 3-17** is shown a schematic geological cross section with vertical exaggeration through the Königstein pit. Sandstones of the Late Cretaceous (cream-colored) dipping flat towards the Elbe River and overlying Lausitz granodiorite (light red), hydraulic conditions before and after flooding of sub-area I.

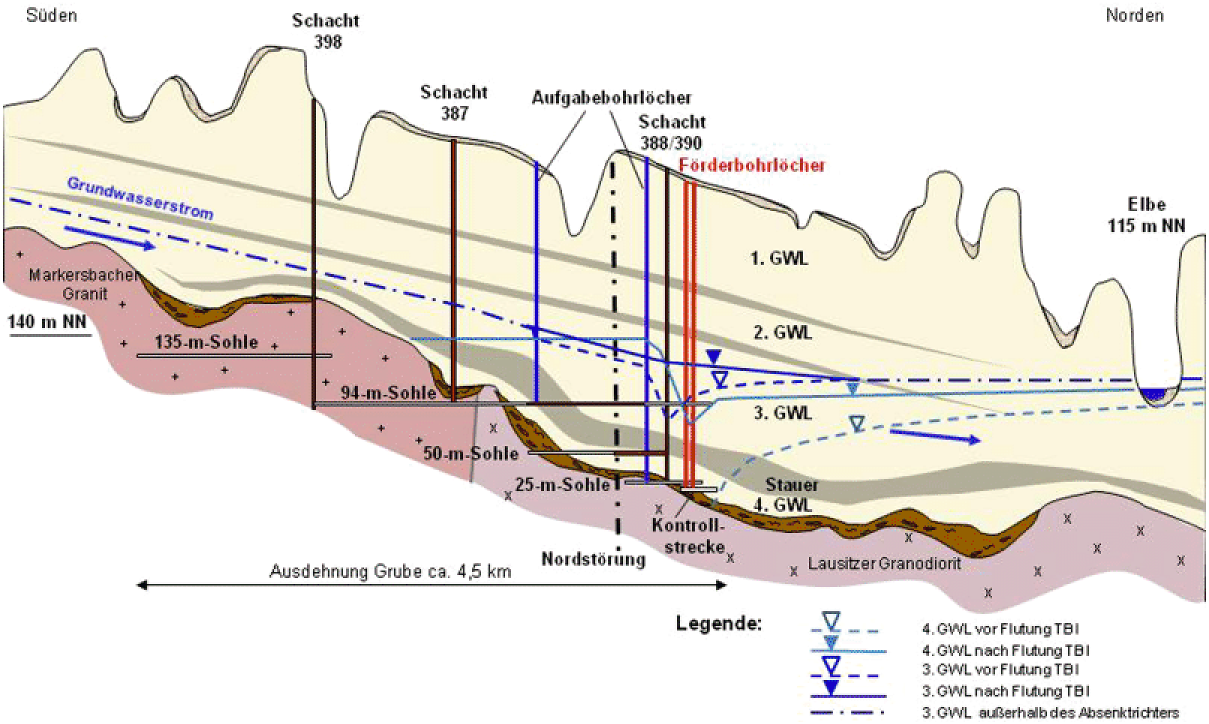


Figure 3-17. *Schematic geological cross section of the Königstein pit*

Source: WEDEKIND, C. (2017)

Uranium Extraction by Leaching – Königstein Site

The geologic total resources of the Königstein deposit amounted to a total of around 30,000 tons of uranium. In the period from 1967 to 1983, the mining method “chamber pillar working” with self-hardening backfill was used. From 1 January 1984 on, the mining method changed: Underground leaching was introduced as an alternative extraction method.

The mine has a special feature that is particularly important regarding safekeeping and subsequent flooding. Due to the relatively low uranium content in the sandstone, investigations into more effective chemical processes for obtaining the raw material began in the early 1970s. In 1984, the underground mining of uranium was converted to the chemical extraction process. Water mixed with sulfuric acid was used as part of various leaching technologies. This was pressed into prepared sandstone blocks via boreholes or was filled into blown-up underground chambers. After the leaching process, the solution was to get hold of and pumped over ground. Finally, the uranium was selected in a processing plant. Through this technology, more than 55 million tons of rock came into contact with sulfuric acid-containing solution by 1990. Part of the solution remained as pore water in the sandstone and led to the further mobilization of uranium and heavy metals. In the event of uncontrolled flooding of the mine, these elements would have entered the aquifers or receiving waters uncontrollably.

Structural damage from mining activities – Königstein Site

The area affected by uranium mining has been and still is monitored regularly by measurement. Due to underground mining work, the ground surface was affected in different ways. Ore extraction caused surface deformations, such as subsidence and tilt. Explosive effects as a result of shrinkage stopping blasts caused seismic vibrations, which led to small-scale cracks on structural objects.

Safekeeping of Underground Mine Workings and Adits – Königstein Site

The rock mechanical reports carried out on the underground mine workings and adits (surface openings) demanded a complete backfilling of these mine workings with cohesive filling material in order to avoid relevant effects on the adits for rock mechanical reasons and to ensure permanent safe storage. The areas of the aquifers had to be sealed.

The backfilling of the mine adit/ ventilation boreholes and shafts could not take place immediately depending on the confirmed flooding program of the pit cavities. In fact, this work was only carried out in the final phase of safekeeping (up to 2021) and is still not one hundred percent complete in 2022. The surface installations showed in **Figure 3-18** were needed over almost the entire remediation period – even longer than during the mining period - and only dismantled in the last phase

Figure 3-18. *Königstein mine installations*

Left: Headframes of shafts. Right: 50-m-level before the start of the flooding.

Source: https://www.wismut.de/de/pressefotos.php, 22.07.2013 and 14.10.2010

Removal of Pollutants from the Groundwater – State of Rehabilitation Achieved

At the time of the cessation of uranium extraction of SDAG Wismut (December 1990), there were still about 1 million m³ of leaching solution in circulation in the Königstein pit due to the chemical extraction process used, which could not be disposed of abruptly. In order to carry out this process in an environmentally friendly manner, special facilities and plants had to be built for each task; some of them are still in use or available for use up to the present day. Particular differences in the remediation at the respective location are highlighted.

For the decommissioning of mines in which chemical uranium extraction took place, there was little usable experience nationally and internationally. Therefore, the process of underground leaching could not be stopped immediately. Extensive research and development work was required to develop solutions for orderly closure for the specific pit conditions. In addition to the destruction of the acid solution, the geological and hydrological conditions of the pit had to be taken into account in order to avoid surface mining damage and not to allow excessive and inadmissible ingress of pollutants into the existing and used aquifers (Note: The associated works are presented in more detail in **Chapter 4.2**).

The concentration of uranium in the flood water is now so low that the process stage uranium disposal is no longer necessary in the converted extraction plant AAF. The last uranium extracted in the water cleaning process was sold to a customer in the USA in 2021 – thus ending the uranium production in Germany. This means that all technical facilities and areas associated with uranium disposal can now be dismantled and remediated – the headframes and other surface installations had already been dismantled in 2014 and 2015.

The goal is still the complete flooding of the pit. Together with the authorities, a technologically feasible and approvable solution is being sought.

In 2020, 1 ha on the company premises and 1.6 ha on the Schüsselgrund mining and production waste tip were made usable again or renovated. However, as provided for in the planning approval decision for the management of the Schüsselgrund waste tip, the area on the tip is not yet in the aftercare process. Thus, as in 2019, 18 ha of the total area of 32 ha are in the aftercare. **Figure 3-19** shows an overall view of the Königstein operating area with the water treatment plant in the upper center of the picture and the Schüsselgrund mining waste heap to the right. The two shafts were located on the free sandy area to the right of the white building complex.

Figure 3-19. *Aerial view of the Königstein operation plant.*

Source: https://www.wismut.de/de/pressefotos.php, 16.11.2015

Outlook – Königstein Site

The dismantling of the uranium disposal facilities at the Königstein site, which had begun in 2021, is a particularly demanding task, as the technical systems contain radioactively contaminated residues. The water treatment plant AAF has been transferred to regular operation, after the trial operation proved to be successful (see **Chapter 4.3.1**).

The waste disposal facility (AEE) Schüsselgrund waste tip will continue to be managed as planned. This applies to the special storage area as well as the design and long-term security through the hydraulic construction and the construction of paths on the already covered areas of the waste tip.

The goal of complete flooding of the Königstein pit is being pushed forward. In November 2020, a hydrochemical test was started to influence the flood water, which was continued in the following year. In addition, a new feed well for fluid introduction has also planned a drilled in the southern field of the pit in 2021, which will help the flooding process significantly.

For the second quarter of 2021, the acceptance of the converted water treatment plant AAF under water law by the Saxon Mining Authority and the Saxony State Directorate as well as by the State Office for the Environment, Agriculture and Geology (LfULG) regarding radiation protection law was applied for. Approval is expected to take place in 2022.

Effects of Remediation on People and the Environment – Königstein Site

At the Königstein site, a long-term stable state has not yet been reached. This is mainly due to the flooding situation of the pit, which in turn is caused by the in-situ leaching practiced at that time and its effects on the groundwater. In order to protect the groundwater, the approved level of the impoundment level remains below the naturally occurring conditions. Maintaining the level of impoundment can only be achieved by continuously extracting the mine water and reintroducing the treated water. In 2020, approximately 2.8 million m³ of water were extracted from the pit and treated in the AAF. For this purpose, the old and new systems were used depending on the test phase. Both plants pursue the same goal: the best possible separation of uranium – now finished – and other heavy metals. The resulting residues are stored in the Schüsselgrund waste tip.

3.2.3.2 Seelingstädt and Crossen

General Background

The Seelingstädt remediation business of the Wismut GmbH was founded in 1991 by merging the former processing plants Seelingstädt (Thuringia) and Crossen (Saxony), which originally worked separately. The distance between the two parts of the business is about 30 km. The headquarters of the management was set up in the newer part of the company, in Seelingstädt.

These plants have been carefully selected as additional reference locations, because they are major projects of Wismut GmbH, where, for example, the safekeeping of very large settling basins and the complete relocation of larger mining dumps can be traced. In contrast to the reference sites presented so far, they belong to the uranium mining districts in the western part of the Ore Mountains (western Saxony) and around Ronneburg (eastern Thuringia).

For the processing of the ores, SAG/ SDAG Wismut operated several processing plants, which in most cases it had taken over from other industrial companies. In the early years, smaller plants were usually in operation near the deposits. Later, the processing was concentrated on the Seelingstädt and Crossen sites.

From the 230,400 tons of uranium extracted by the SAG/ SDAG Wismut mining operations, the processing plants produced 216,300 tons of uranium by the end of 1990. This included the mechanical concentrates sent as chemical concentrates as well as other products.

Seelingstädt Operative Plant

The largest and most modern processing plant of SDAG Wismut was placed in Seelingstädt (object 102, from 1968 processing plant 102), adjacent to the Culmitzsch deposit in eastern

Thuringia. The plant was commissioned in 1961 as a result of the growing importance of the Ronneburg mining district, which is located about 15 km north of the plant.

Figure 3-20. *Seelingstädt with sludge settling basin and tailings facility Culmitzsch, 1993*

Source: https://www.bergbautraditionsverein-wismut.de/ehemaliger-aufbereitungsbetrieb-102-seelingstaedt.html

The mineralization in the Ronneburg mining area is hosted by Paleozoic meta-black shales and Meta-basalts. Uranium mineralization occurs in irregular shaped bodies of highly variable size and uranium content (in average 70 tons of uranium per body). The uranium minerals (mainly pitchblende) occur as impregnations, thin veinlets or in breccia zones in these bodies. The deposit was formed by remobilization of uranium already enriched in the black shales by synsedimentary processes. Remobilization was caused by hydrothermal and supergene processes leading to the further enrichment of uranium. The background uranium content in the black shales is 40 to 60 ppm. Like the major vein-style uranium deposits in the western Ore Mountains, the Ronneburg deposit is located on the Gera-Jachymov fault zone, which is called the Crimmitschau fault zone in this particular area.

The uranium ore deposit had an average uranium content of approximately 0.065 to 0.07%. There were individual mining blocks with average grades around 0.3% and few areas where the grade was sometimes 1%, but this was the absolute exception. The fact that the Ronneburg uranium ore deposit was mined at all with such a low average grade is solely due to the special political situation at that time and the pursuit of nuclear balance after the end of the 2nd World War and during the Cold War. Even without the political change in 1989, uranium ore mining would have been stopped by the year 2000, which was already a done deal. From a purely economic point of view, the Ronneburg deposit would never have been mined. (Mineralienatlas, N.d.)

Over a period of almost 40 years, 40 shafts were operated in the Ronneburg ore field, whose mine building reached a depth of almost 1000 m and an extension of 74 km^2. At times, mining was also carried out in opencast mining.

The Seelingstädt plant was the central facility for processing the uranium ore – with the highest deliveries from Ronneburg, but also from all other SDAG Wismut deposits of the Ore Mountains and beyond (see map and list in **Figure 3-21**). By 1991, the plant had processed 108.8 million tonnes of ore as well as products from leach mining in Königstein and Schmirchau and produced 86,273 tons of uranium in concentrate. Two different chemical processes were used for uranium extraction, depending on the geochemistry of the ore. These were a process with soda-alkaline leaching and a process with sulfuric leaching. Both processes delivered concentrates with significantly different uranium contents and the propagation of uranium from the ore. On average, the concentrate content was 60 % uranium, and the output was 92%. The last barrel of so-called yellow cake (the uranium concentrate in dried condition) was bottled in 1996.

From 1991 onwards, a disposal of ores and intermediates from remediation mining as well as residual ores from stockpiles and from the treatment process respectively for the recycling of residual lye solution was carried out during that last production campaign, and at the end of 1991 the entire ore processing was discontinued. Only the disposal of the liquid concentrates resulting from the water treatment of the Königstein remediation plant (see **Section 3.2.3**) took place until 1996 (Chronicle Wismut).

Figure 3-21. *Seelingstädt operative plant*

(left: view 1962, right: processing hall with evaporators for uranium concentrates 1991)

Source: https://www.bergbautraditionsverein-wismut.de/ehemaliger-aufbereitungsbetrieb-102-seelingstaedt.html

On the premises of the processing plant, technical plants and facilities continued to work immediately after the German reunification, which had to fulfill central tasks for the entire operative plant or still produced products for sale. Examples were:

- The sulphuric acid factory, which produced its own sulphuric acid requirements but used the larger capacity shares for the production and sale of oleum.
- The industrial power plant, which not only covered the electrical energy, the technological steam and the heat demand, but at the same time had to feed electrical energy into the network system for the Thuringian mining companies in the event of an accident.
- The special workshops to produce rubberized pipes and other special materials.

In 1991/1992, these technical capacities were greatly reduced in their scope of services in accordance with the demand requirements and then taken out of operation, dismantled, and demolished depending on the progress of the remediation.

Crossen operative plant

The Crossen site was previously a paper mill, which was converted for the new purpose. The so-called Object 101 with factory 38, which went into operation in 1951, developed into one of SAG/ SDAG Wismut's two central processing plants. It was located in Crossen on the northern edge of Zwickau in Saxony and was renamed "Aufbereitungsbetrieb 101" in 1968. It processed ores from all major SAG/ SDAG Wismut deposits and produced a total of 77,000 tons of uranium from 74.7 million tons of ore. In Crossen, both mechanical concentrates from Ore Mountains (mainly from the Aue mining operation) and chemical concentrates were produced by soda-alkaline leaching. In the mid-1980s, tests were also carried out for the tin ore processing of ores from Pöhla-Hämmerlein and an experimental silver ore processing for ores from Pöhla and Niederschlema-Alberoda was put into operation. In 1989, the processing plant began to be shut down because many of its plants were outdated and the declining production of SDAG Wismut led to capacity utilization difficulties. The concentrate from the last year of production had a uranium content of 75% with a uranium recovery from the ore of 93.3%.

Uranium ore processing was discontinued in 1989 and then the dismantling of plants began in part. Partial capacities of laboratory facilities and production facilities continued to be used for investigation work for the processing of ores from deposits in the region of the western Ore Mountains for tin and silver (see **Figure 3-22).** This short-term work came to an end in 1990 (Wismut, 2010).

Figure 3-22. *Facilities of the operative plant Crossen with the dump of mining residues*

Source: https://www.wismut.de/de/pressefotos.php, 1991

3.2.4 Bielatal closed tailing site

The headwaters of the Biela creek origin from the Eastern Ore Mountains Region not far from the capital Dresden. The creek forms a local valley (Bielatal) of about 40 km length and the water flows towards the Elbe river. The Elbe catchment is one of the three largest river systems in Germany. The Biela creek region is in contact to the protected area of the so-called “Saxon Switzerland”. This is at the same time a National Park (reserve of nature protection) and a touristic region of national prominence.

The post mining rehabilitation of the tin ore mine in Altenberg, which was shut down in 1991 is shaped by the mining legacies of the Altenberger Pinge mine with the associated drainage tunnel and an industrial tailings facility. The IAA plant and the tailings deposit area are situated in contact to the Saxon Switzerland protected zone. The plant started in 1967 the discharge and storage of residues and operated until 1991. Flushing of a total of approx. 10.5 million m³ of tailings used from tin ore mining took place there. A tailing area of about 1 km² has been placed into the valley and the Biela creek has been deviated. The final dam is of 90 m height and of 1 km length. The surface of the tailing area has been sealed and re-greend after 1991. To guarantee of permanent stability expensive water protection and rehabilitation work was required. Construction of a spillway channel along the main dam became necessary as a measure for flooding prevention. This work was finished in 2014.

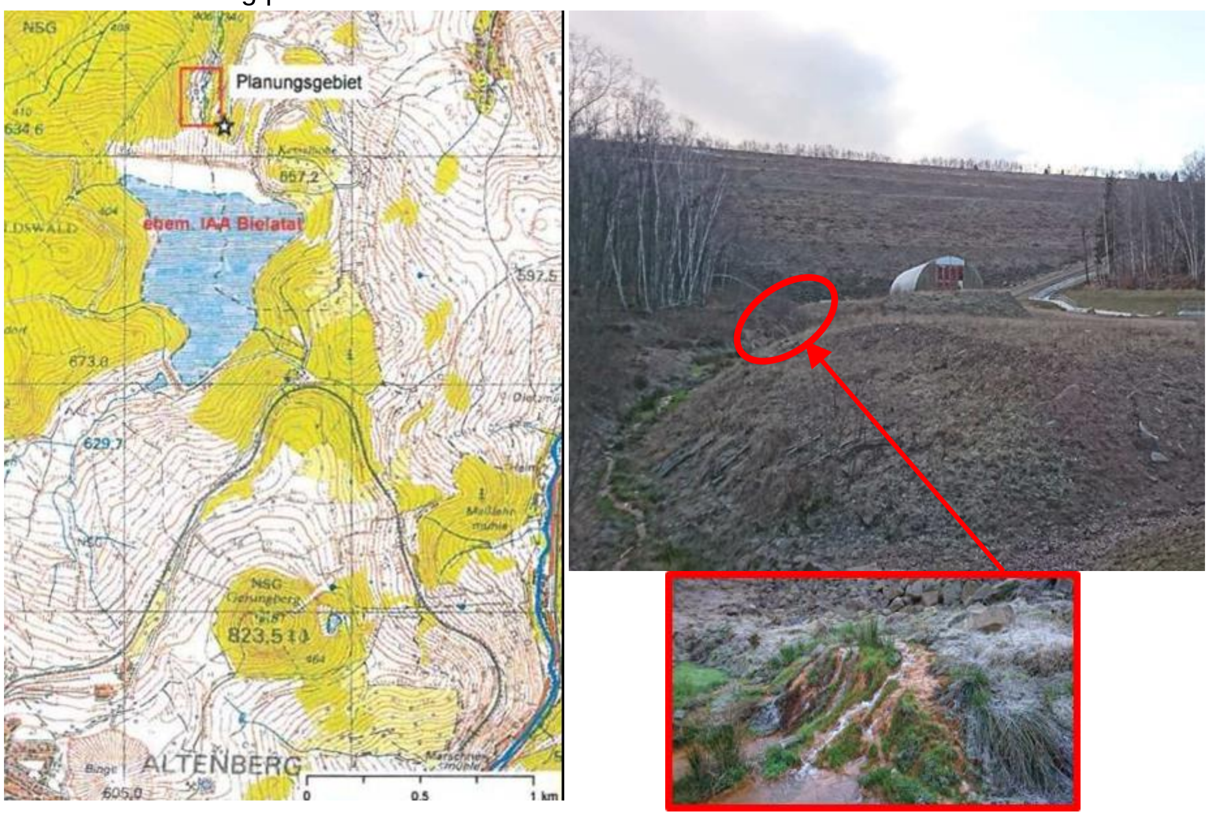


Figure 3-23. *Bielatal tailing area near Dresden, Saxony*

left: Map view of Bielatal site in the Ore Mountains,
right: Tailing dam of Bielatal and water leakage with As accumulation at dam basis.

Beside of all measures implemented, leakage and seepage waters at the foot of the tailing dam did not cease sufficiently. The leakage filtrates to the downstream Biela valley accumulate in their flow path arsenic and heavy metals and form a serious risk for the touristic and nature protection zones.

3.3 Sites Comparison Concept

In order to compare the reference sites, a methodology that allows to quantitatively assess and compare sites from different backgrounds (e.g., social, economic, technological) must be used.

Figure 3-24. *Relevant UN SDGs for post-mining remediation study sites*

GKZ (2018) in the context of the GIZ project “Support for the development of competencies and capacities in the management of mining environmental liabilities in the Andean countries (project number 81216685)” developed a methodology for assessing different post-mining remediation study cases from South America (Chile, Peru) and Europe (Germany, Ireland, and Montenegro) based on UN’s sustainable development goals (SDG). At first, relevant SDG were selected for mining environmental liabilities remediation were selected, shown in **Figure 3-24.**

A list of indicators to measure the SDG implementation was presented by the UN in 2016. Nevertheless, these indicators are mainly focused on their impact on macroeconomic and macrosocial development on countries. Remediation of mine affected sites have positive impacts on a local and regional scale, but these are not sufficient to impact on the macro level of a nation (GKZ, 2018).

The methodology presents a pragmatic approach on the contribution to the relevant SDG. The quantitative assessment criteria and evaluation is presented in **Table 3-4.**

Table 3-4. *Relevant indicators for assessment*

N°	Criteria	Indicators	Measurement value
1	Preparatory works	Restoration and reclamation plan	Acceptance by the authorities
2	Main actors	Professionalism of parties involved	Evaluation based on a 5 points scale
3		Management of parties involved	Evaluation based on the complexity of decision making
4	Time required	Overrun time	Difference between estimated time and final time
5	Organization model	Cooperation between authorities: experts – promoters – contractors	Evaluation based on a 5 points scale
6		Internal control of the reclamation plan	Evaluation based on deadline management, budget and project development
7	Financing model	Suitability or adequacy for the restoration and reclamation project	Budget volume, finance sources, capital costs, funding and expenditure planning
8	Effective costs	Exceeding or non-compliance with budget	Difference between estimated budget and final cost
9a	Success factors	Restoration and reclamation success	Report evaluation. 5 points scale
9b	Risk factors	Restoration and reclamation success	Report evaluation. 5 points scale
10a	Application of German environmental and social standards on contaminated sites management	Acceptance and fulfillment	Evaluation based on legal and administrative demands
10b	Application of international environmental and social standards on contaminated sites management	Acceptance and fulfillment	Evaluation based on legal and administrative demands

Source: GKZ (2018)

Each criterion is evaluated with a 1 – 5 scale, with 1 being very high relevance and 5 being barely relevance.

4. Technical Tool-Box for Mine Water Management at Post-Mining Sites

Based on experiences from Saxony study sites, a technical tool-box for mine water management at post-mining sites is presented.

This is a technical-methodological guide, containing a summary of technical know-how and exemplary data evaluations from Saxony reference sites, as well as applied investigations and proposed solutions on Peru study sites. The detailed recommendations were given during the trips to Peru (Annex 1, Annex 2, and Annex 5).

The tool-box is structured in five parts:

- **Technical site investigations:** Based on the Saxony methodology for contaminated sites management presented in **Chapter 2**, detailed investigations were conducted on both study sites from Peru and results are presented.
- **Remediation closed mining Areas and water catchment rehabilitation:** Based on the experience from Saxony reference sites and remediation of mining installations and catchments are presented.
- **Remediation of mine-affected waters:** Based on the state of the art of water treatment techniques presented in **Chapter 2**, the different techniques are evaluated and compared in order to propose appropriate water treatment techniques for applying in Peru. Also, experiences of water treatment plants from Saxony reference sites are presented.
- **Protection or containment measures:** Based on the experience from Saxony reference sites, protection or containment measures are presented.
- **Monitoring the effects of site and local watershed remediation:** Based on the experience from Saxony reference sites, water monitoring strategies are presented. Also, a proposal of a water monitoring strategy for Los Rosales is presented.

4.1 Technical Site Investigations

4.1.1 Los Rosales: Oriented Investigation (OU)

Based on the results from the historical investigation, an oriented investigation was planned and carried out during October and November 2021, when a DGFZ team visited Los Rosales for field work. Historical investigation indicated the presence of mine water with AMD characteristics and affected groundwater in Los Rosales. The objectives for the oriented investigations were the following:

- Groundwater characterization in Los Rosales, downstream of the tailings area.
- Further characterization of mine water from Madrigal Mine and treated water.
- Determine a general water scheme in Los Rosales, identifying the different water pathways in the area and their pathway.

The following field activities were carried out for the fulfillment of the objectives:

- Installation of three shallow monitoring wells downstream of the tailings area for qualitative and quantitative monitoring of groundwater.
- Sampling of mine water from Candelaria Mine and treated water.
- A general survey on the different waters found in Los Rosales, with measurements of pH and electrical conductivity.

A detailed description and discussion on results from these activities can be found in **Annex 1.** Results obtained from the oriented investigation were the following:

- Results from analyzed parameters in Los Rosales revealed low pH values and high concentrations of sulfate and metals in mine water and groundwater. Highest concentrations in groundwater were reported in the tailings sector. These results are consistent with previous data from historical investigation and suggest the presence of AMD affecting groundwater in Los Rosales **(Table 4-1).**

Table 4-1. *Chemical results from Los Rosales oriented investigation*

	pH	**SO4-2**	**F-**	**Al**	**Cd**	**Co**	**Cu**	**Fe**	**Mn**	**Zn**
	(-)	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Mine water	3.91	1006	0.34	3.37	0.02	0.86	4.78	102	12.8	2.06
Treated water	6.19	1018	0.23	0.08	0.01	0.50	0.52	15.2	10.8	0.81
PZ-1*	4.17	1050	2.30	7.97	0.08	0.77	14.3	0.02	15.8	4.39
PZ-2*	4.18	772	1.77	7.53	0.08	11.40	10	0.11	15.1	4.66
PZ-3*	5.64	1552	0.12	0.211	0.002	0.04	0.014	0.15	2.68	0.14

**: Groundwater sample*

- Los Rosales mine water treatment increased pH to accepted values for Peruvian regulations, and decreased iron, copper, and zinc concentrations. Nevertheless, iron and copper concentrations from treated water exceeded Peruvian regulations on water discharge for mine industries **(Figure 4-1).**

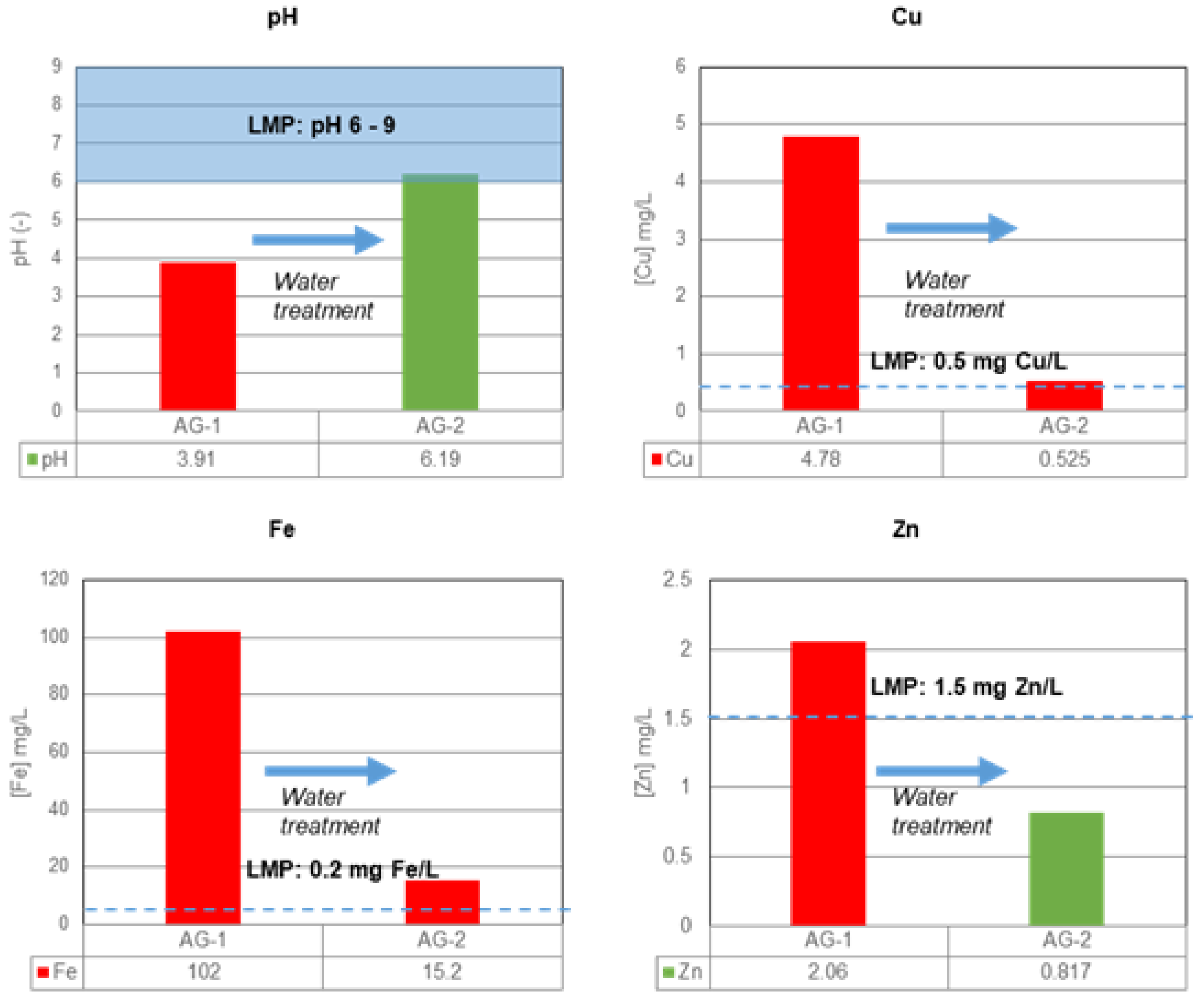


Figure 4-1. *Water parameters that exceed Peruvian permitted values (LMP) in Los Rosales mine water (AG-1) and treated water (AG-2).*

NOTE: Red bars mean results exceed limit. Green bars mean results comply with regulations
Source: Supreme Decree 010-2010-MINAM

- Concentrations of cadmium, copper, nickel, cobalt, manganese, selenium, and zinc from groundwater samples in Los Rosales exceeded environmental quality standards from Peruvian regulations **(Figure 4-3).**

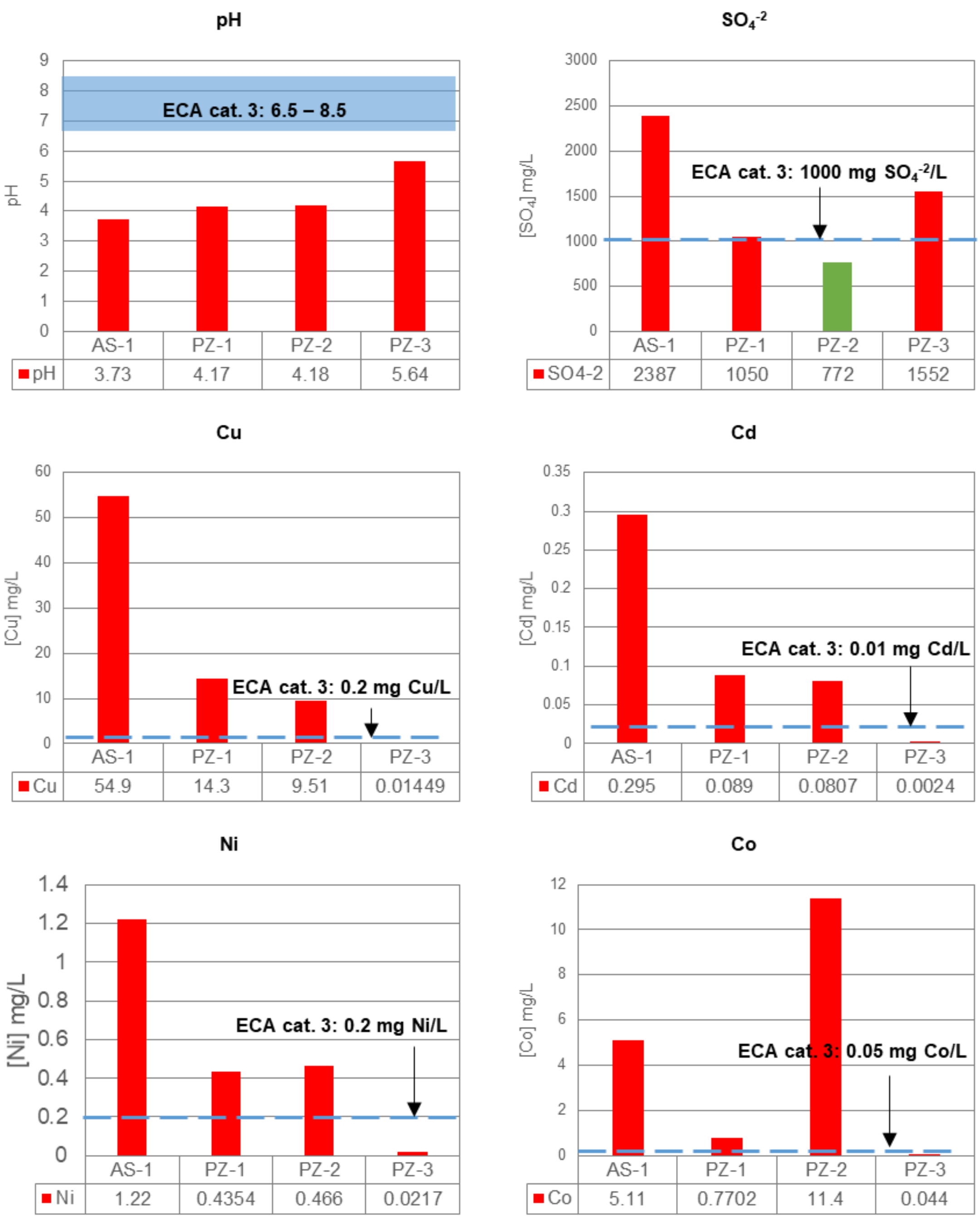


Figure 4-2. *Water parameters that exceed Peruvian environmental quality standards (ECA category 3) in Los Rosales groundwater samples, Part I.*

NOTE: Red bars mean results exceed limit. Green bars mean results comply with regulations

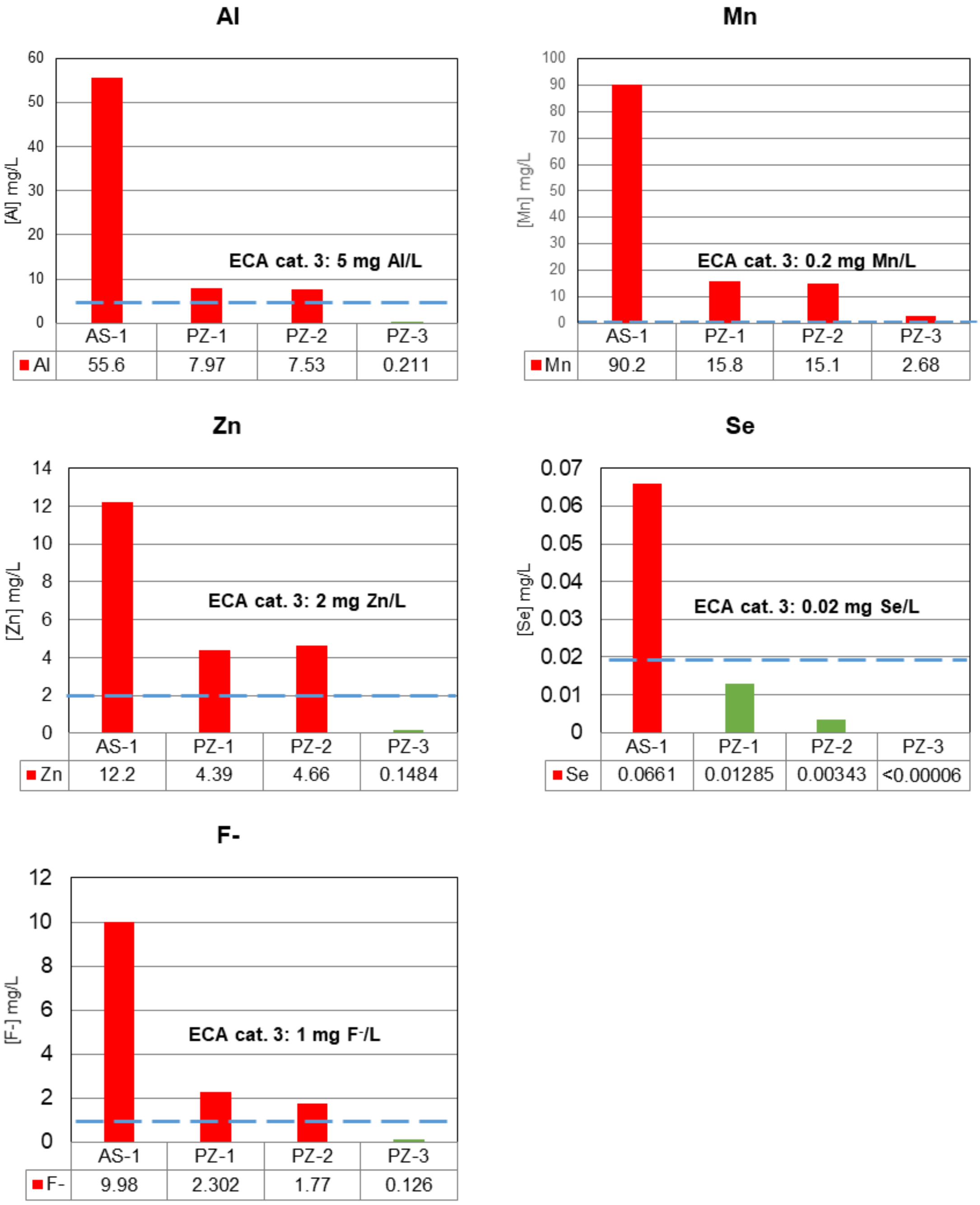


Figure 4-3. *Water parameters that exceed Peruvian environmental quality standards (ECA category 3) in Los Rosales groundwater samples, Part II.*

NOTE: Red bars mean results exceed limit. Green bars mean results comply with regulations

Source: Supreme Decree 004-2017-MINAM

- Installation of shallow wells in Los Rosales during this project allows groundwater monitoring (water levels and sampling). Geological information obtained during installation is consistent with alluvial deposits described in public geological maps. Groundwater level measurements show an increase in levels since November 2021 **(Figure 4-4).**

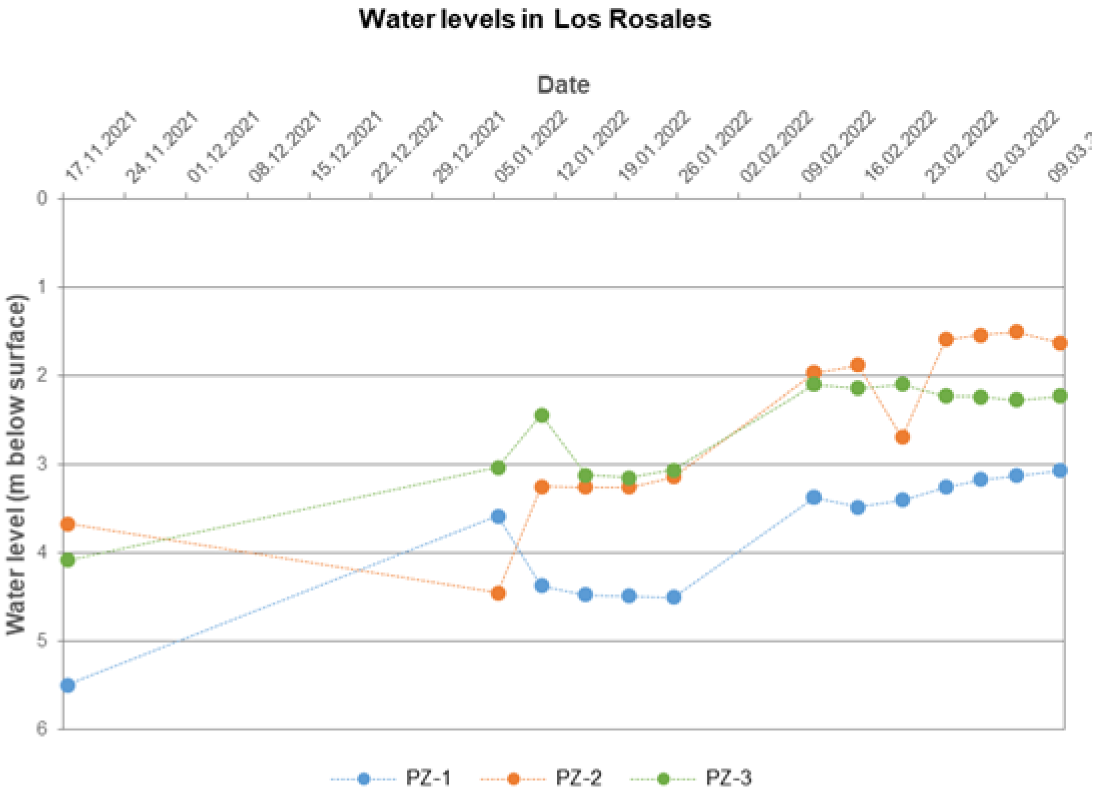


Figure 4-4. *Water levels measured in Los Rosales monitoring wells.*

NOTE: Dotted line does not imply measured values.

- Water survey in Los Rosales allowed for the determination of the following water courses in Los Rosales **(Figure 4-5):**
    - **Mine water:** Water discharged from Candelaria Mine which is then treated by Los Rosales. Treated water is finally discharged to a collecting channel downstream of Los Rosales.
    - **Runoff water:** Two NW-SE creeks are found limiting the tailings in Los Rosales. These creeks are only active during the rainy season, transporting runoff water from the elevated zones to a collecting channel downstream of Los Rosales.
    - **Spring water:** Two water springs are found SW of Los Rosales. Water from these springs is used by Los Rosales Mining Company for hygiene purposes in their facilities. After being used, water is discharged in an unsealed pond downstream of the facilities.
    - **Los Rosales discharge water:** A collector channel was constructed by Los Rosales Mining Company and located downstream of Los Rosales, collecting water from the two creeks, treated water from Candelaria Mine and sporadic discharges from small miners located upstream of Los Rosales.

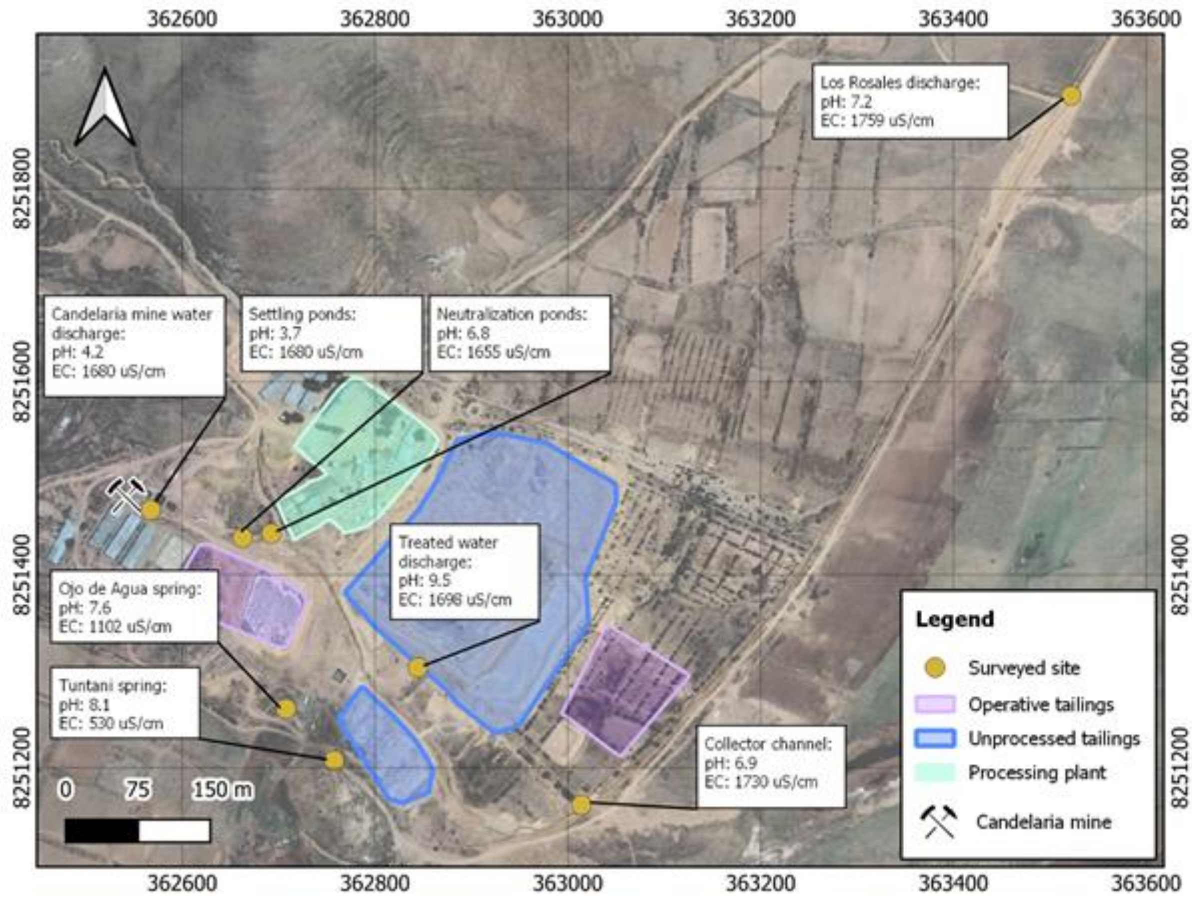


Figure 4-5. *Results from water survey in Los Rosales.*

4.1.2 Madrigal: Oriented Investigation (OU)

Based on the results from the historical investigation, an oriented investigation was planned and carried out during November 2021, when a DGFZ committee visited Madrigal for field work. Historical investigation indicated distinct water quality in the Madrigal Mine area, different from the Colca River, and also the presence of tailings without top sealing and reports of collapses in the area. The objectives for the oriented investigations were the following:

- Obtain a water quality characterization in the different rivers located near the Madrigal Mine, to assess the impact of the Madrigal Mine and tailings on the water quality, and to assess the results on Peruvian regulations.,

A detailed description and discussion on results from these activities can be found in **Annex 1.**

For this purpose, the following activities were done:

- Sampling in 8 locations, including the drinking water in Madrigal Town. Sampling sites are shown in **Figure 4-6.**

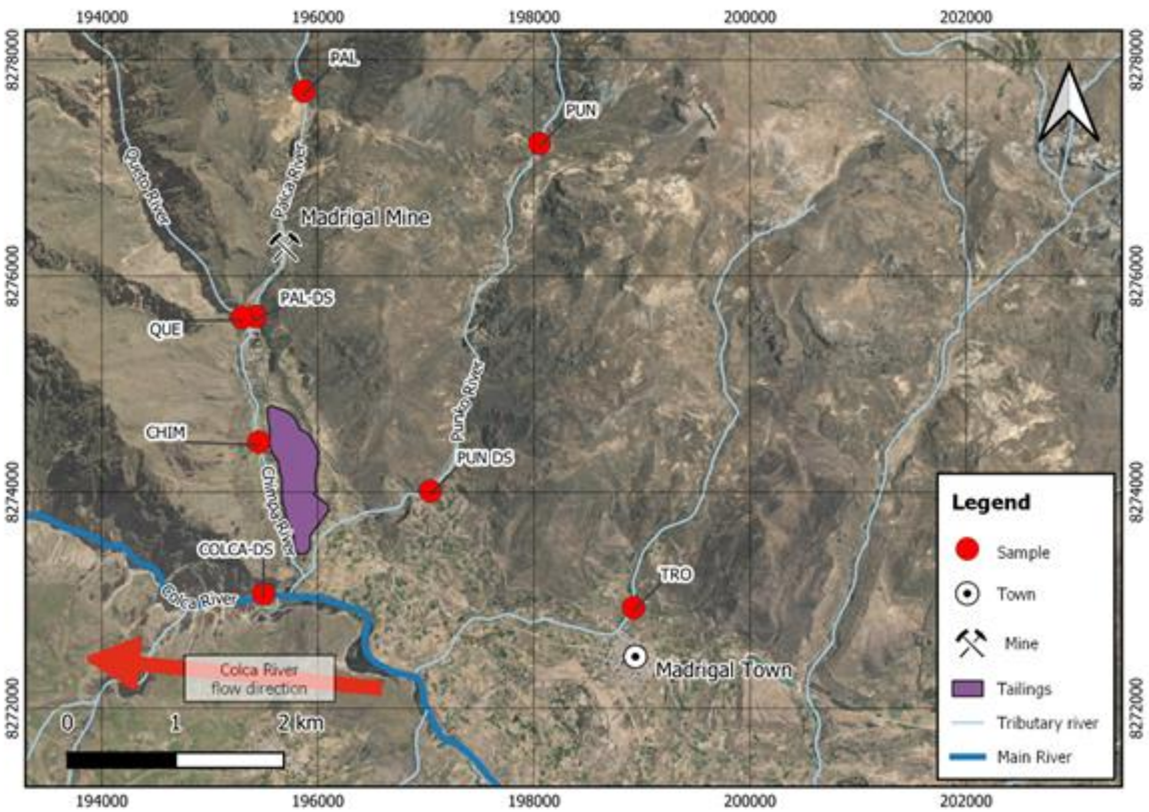


Figure 4-6. *Sampling locations in Madrigal's detailed investigation.*

Results obtained from sampling in Madrigal were the following:

- Results from analyzed parameters in rivers Punko (downstream and upstream) complied with category 3 environmental quality standards from Peruvian regulations. Rivers Chimpa, Queto and Palca downstream didn't **(Figure 4-7).**

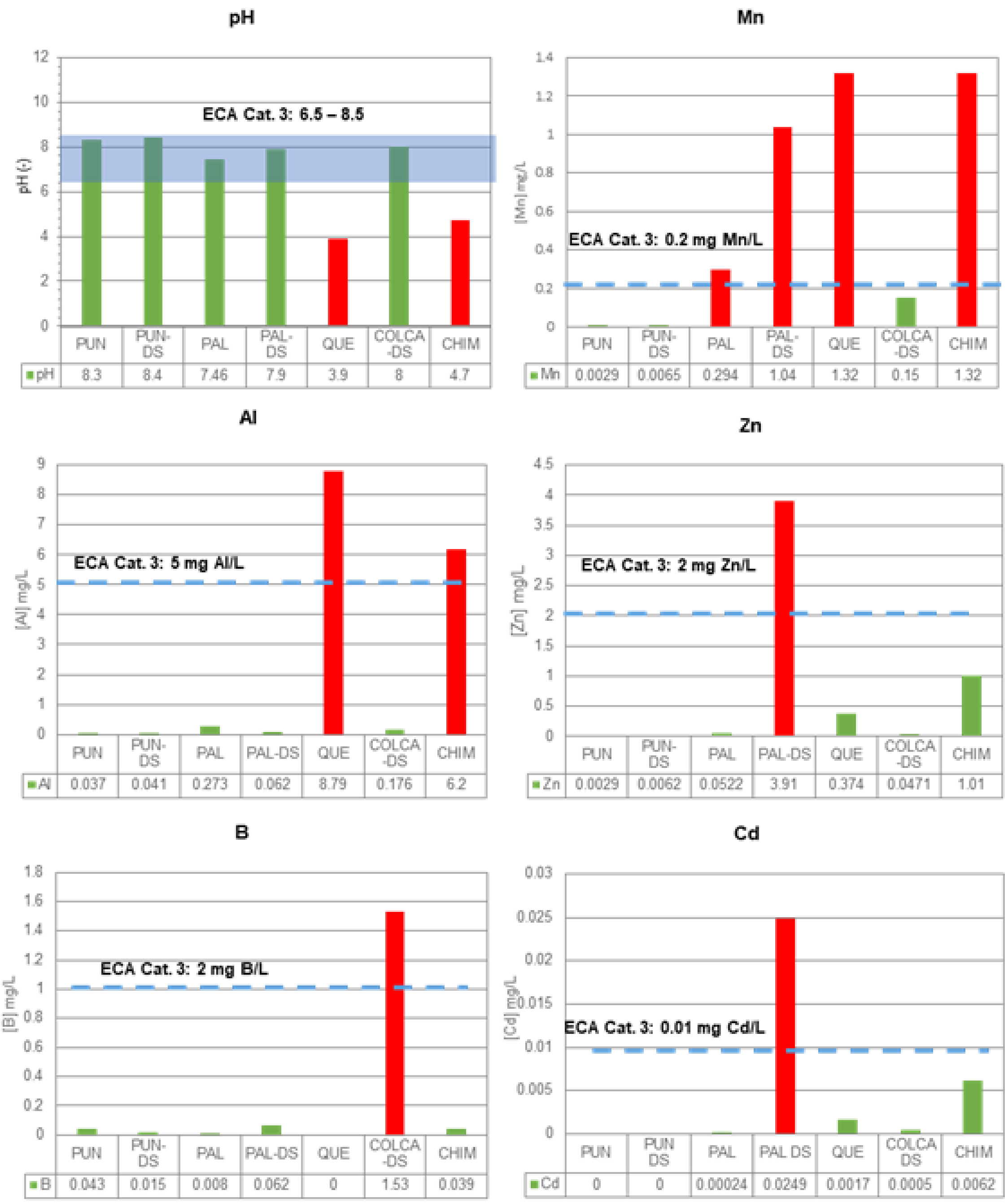


Figure 4-7. *Water parameters that exceed Peruvian environmental quality standards in Madrigal groundwater samples.*

NOTE: Red bars mean results exceed limit. Green bars mean results comply with regulations

Source: Supreme Decree 004-2017-MINAM

- Results from analyzed parameters in Punko River upstream and Palca River upstream complied with category 1 environmental quality standards from Peruvian regulations (for drinking water source), while rivers Queto, Chimpa, Colca, Punko downstream and Palca downstream didn't comply with them. Therefore, Palca River is another potential source for drinking water for Madrigal **(Figure 4-8).**

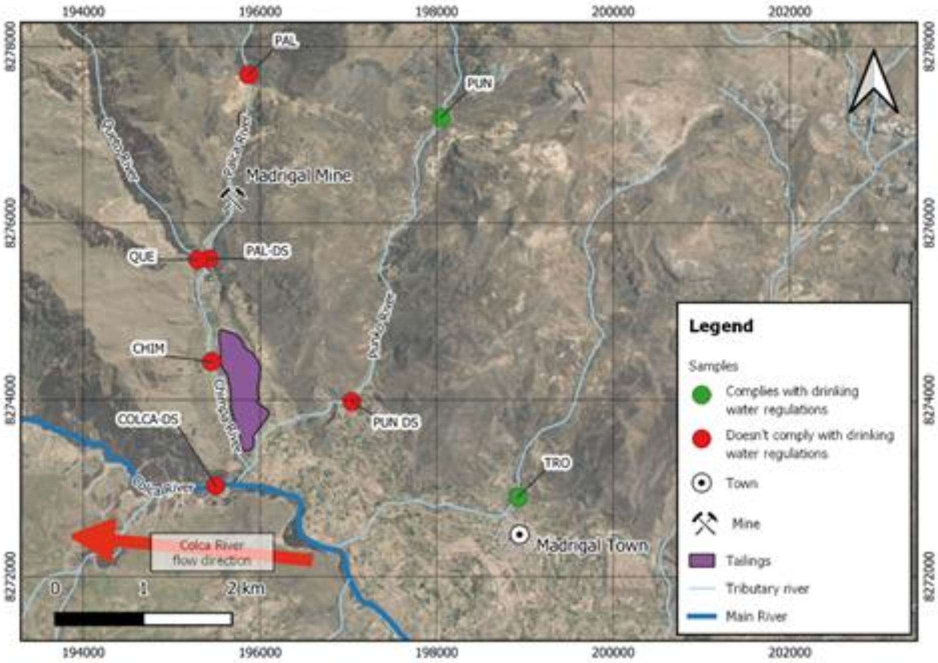


Figure 4-8. *Madrigal samples compared to drinking water standards from Peru*

- Water quality from Colca River tributaries was lower than Colca River. Although an increase in sulfate, manganese and zinc concentrations was observed in Palca River, downstream of Madrigal mine, other old underground mines were seen during the visit upstream of the Madrigal Mine with water draining out to the river and may also contribute to this increase in concentrations. Rivers Queto and Chimpa showed low pH and high concentrations of sulfate, aluminum, and manganese, while Punko River showed high sulfate concentrations downstream **(Table 4-2).**

Table 4-2. *Chemical results from Madrigal detailed investigation.*

	SO4-2 mg/L	Al mg/L	B mg/L	Cd mg/L	Mn mg/L	Zn mg/L
Madrigal drinking water	62	0.048	0.043	<0.00005	0.0082	<0.00004
Punko River	50.8	0.037	0.043	<0.00005	0.0029	0.0029
Punko River downstream	628	0.041	0.015	<0.00005	0.0065	0.0062
Palca River	248	0.273	0.008	0.00024	0.294	0.0522
Palca River downstream	399	0.062	0.062	0.0249	1.04	3.91
Queto River	335	8.79	<0.002	0.0017	1.32	0.374
Colca River	151	0.176	1.53	0.0005	0.15	0.0471
Chimpa River	374	6.2	0.039	0.0062	1.32	1.01

4.1.3 SAXONIA Project: Detailed Investigation (DU) of the Davidschacht Sludge Dump

The approach of the investigation is explained step by step in this chapter. The tasks of the detailed investigation of the water pathway were the modeling of the groundwater recharge and the runoff conditions for the area of the Davidschacht sludge dump and the development of a water balance. On this basis, estimates of the pathways of pollutants, a hazard assessment, remediation options and initial statements on a remediation target were determined.

Information in this chapter is from G.E.O.S. (2012). Please find basic knowledge about the Davidschacht Complex in **Chapter 3.2.1.**

4.1.3.1 Conceptual Model and Water Balance Estimation

On the basis of a conceptual model **(Figure 4-9)** of the sludge dump and its surroundings, a qualified water balance estimate was made and verified by a plausibility check. For the plausibility check, the amount of water leaving the catchment area of the flushing dump (downstream) was subsequently analyzed. This was done by driving shafts, water outlet measurements of shaft water, determination of drip water points in shafts, outcrops of fissure aquifers.

Because of the complicated hydrologic conditions, this estimate was made for the sludge dump catchment. The sludge dump is composed of the following hydrological units:

- Sludge dump Davidschacht
- Coarse tailings dam
- Northern part of the coarse tailings dam
- Remaining catchment area in the upstream of the tailings pile complex

Hydrotopes were formed from these units. The area calculation of the catchments and the hydrotopes was done with a GIS program.

When analyzing the water balance of the study area, the following water flows must be considered in principle:

Inflow

- Groundwater recharge from the various tailings pile areas of the catchment
- Groundwater recharge from the rest of the catchment
- Additional water flowing into the catchment (inflow of "foreign" surface water, here: rainwater channel)

Run-Off from the Tailings Pile Areas

- Run-off near the surface in old mines
- Run-off in deeper levels in old mining operations
- Run-off out of the drainage basin in old mining operations
- Run-off out on the top of the rock or in the fissure GWL

Based on the researched data, site findings and investigation results, a model of the structure of the flushing dump as well as the water pathways and heavy metal dispersion paths was developed. This is shown in **Figure 4-9.**

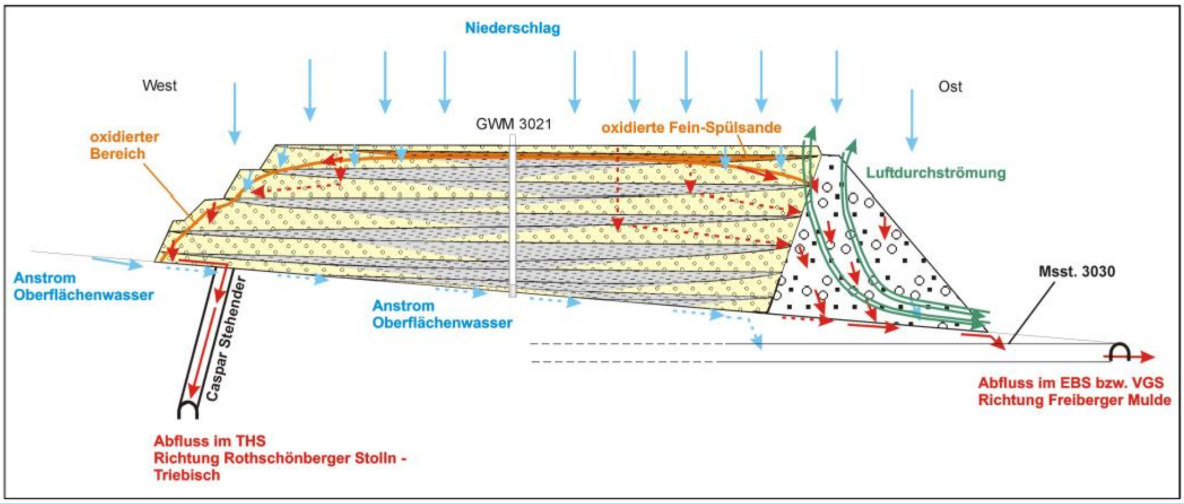


Figure 4-9. *Conceptual model of the sludge dump Davidschacht, metal pathways are shown as colored arrows*

NOTE. blue: slight contamination, red: high contamination

The results of the investigation show that

- Precipitation seeps onto the flushing heap.
- The seepage water flows off sideways on low-permeability layers.
- The waters absorb heavy metals, especially Cd, as a result of oxidation.
- Oxidation creates pathways for water and air.
- The seepage waters contaminated with heavy metals are discharged by the coarse tailings dam.

4.1.3.2 Load Considerations

An exact calculation of the discharged loads was not possible, since no reliable discharge measurements were possible. However, these could be estimated in different ways via balance calculations: Estimation from the oxidation depth, estimation from the water balance and estimation from the real discharged water quantities.

The calculations not only provided a plausible value of the Cd load, but the comparatively good agreement of the individual results also showed that a good understanding of the processes taking place had been achieved with the previous considerations. Comparison of the individual cadmium loads showed that the coarse tailings dam is the largest source of Cd. Emissions from the flushing tailings are slightly lower and those from the coarse tailings dam are much lower. A total of 187 kg of cadmium is discharged annually from the entire David shaft complex.

For details on the calculation, see G.E.O.S. (2012).

4.1.3.3 Dispersion Pathways and Affected Objects of Protection

***Surface Water*:** A model of the structure of the sludge dump as well as the water pathways and heavy metal dispersion paths was developed. It could be proven that the spreading of the pollutants occurs mainly with the leachate. Transport pathways include drifts from old mining operations, natural fissures and fault zones, and the gneiss replacement zone. Due to these conditions, most of the elements dissolved in the seepage water reach the Freiberg syncline and, to a lesser extent, the river *Triebisch* via the shaft *Rothschönberger Stolln*.

Thus, it can be stated that the protected resource surface water is affected by the spreading of the pollutants mobilized in the sludge dump. With the surface water, the pollutants are further transported in dissolved form and as suspended matter and finally deposited in the river or floodplain bound to the sediment. The effects of the heavy metal discharges from the saxon old mining legacies can be detected as far as the port of Hamburg.

***Groundwater*:** In the immediate downstream of the sludge dump, there are also impacts on groundwater as a protected resource. The transport of the seepage water formed in the area of the sludge dump initially takes place in the weathering zone above the solid bedrock. In this process, the shafts of the old mine act as drainage systems that absorb a noticeable portion of the polluted seepage water. The remaining part of the seepage continues to migrate in the percolation zone, drains in sections into the ditch *Roter Graben* or underflows it and then reaches the Freiberg syncline via the fluviatile sediments deposited in the floodplain. In this way, the entire pollutant load is released into the surface water, partly selectively and partly diffusely. In the downstream area of the Davidschacht site complex and in a partial area of the floodplain, a localized endangerment of the groundwater as an object of protection can be determined due to the present heavy metal contamination.

***Other Dispersion Paths*:** A dispersion of pollutants by soil erosion and wind drift can be excluded as far as possible.

4.1.3.4 Hazard Assessment

Substance hazard: The seepage waters forming in the area of the sludge dump, the coarse tailings dam and the coarse tailings pile are mainly contaminated with As, Al, Cd, Zn and some other heavy metals. Cadmium occupies a dominant position because of:

- its toxicity,
- the high concentrations and loads found in seepage water, as well as
- the behavior of this element in the environment.

The load calculations were used for the risk assessment and discussed for all water pathways. From the considerations, the derivation of the need for action is as follows:

- The Cd loads discharged into the river *Freiberg Mulde* are detectable in the entire river system, apparently as far as the port of the city Hamburg. From the substance danger of the Cd and its transport in the river system results the necessity to reduce the input.
- By remediation of the sludge dump, a noticeable reduction of the discharged Cd loads is possible. The need for remediation thus arises as a consequence of the necessary load reductions that must be achieved in the river *Freiberg Mulde* by law.

4.1.3.5 Remediation Options for the Davidschacht Sludge Dump

The following remediation options are to be discussed conclusively in a subsequent remediation investigation.

The results of the investigation show that the Davidschacht sludge dump is a significant source of heavy metals, especially cadmium. Cadmium emissions from the sludge dump material are caused by a combination of two processes:

- Oxidation of the residual ores in the tailings pile material by oxygen and water influx.
- Leaching and removal of the mobilized heavy metals with the outflowing seepage waters.

Thus, heavy metal emissions can be reduced by preventing oxygen access on the one hand and water access on the other. In addition, remediation can basically attack at two points:

- Remediation of the pollutant source (tailings pile)
- Remediation of the dispersion pathway (water pathway)

Remediation of the Spring:

- Preventing precipitation water from entering via the storm sewer.
- Covering or sealing of the western slope and the plateau to reduce groundwater recharge. Furthermore, this largely prevents the penetration of oxygen and thus also the process of pollutant release. According to the state of the art, the sealing can be achieved by the following measures:
  - Profiling of the plateau, alignment with the plateau of the coarse tailings dam (approx. 8 m) by application of suitable materials (construction waste, excavated earth) and creation of the necessary slope.
  - Backfilling to the western slope and creation of a suitable slope.
  - Application of a sealing.
  - drainage layer
  - cultivation layer
  - suitable recultivation
  - regulated drainage of surface water, integration into the drainage system Davidschacht.

Remediation of the Propagation Path:

In addition to remediation of the source, remediation can also be performed on the water pathway. In this case, the partial streams of mine water should be disentangled in advance:

- Separation of weakly contaminated partial streams, discharge into the river *Freiberg Mulde.*
- Combining the partial streams with the highest pollutant load.
- Treatment of these partial streams.
- Construction of a reactive wall below the coarse tailings dam and the coarse tailings pile, which binds down to the in-situ gneiss and collects the near-surface groundwater run-off in the replacement zone.

4.1.3.6 Remediation Targets

***In general*:** Remediation objectives must generally be based on the technical feasibility of the remediation measures and on the principle of proportionality. Proportionality is not a scientific or technical issue, but primarily a legal category that encompasses the appropriateness, suitability, adequacy, and necessity of a measure. Because there is no generally and easily applicable methodology for determining proportionality, the process of determining remediation targets is usually a multi-step and iterative process.

The preliminary remediation target value derived from the detailed investigation for the sludge dump Davidschacht is a reduction in Cd emissions (load) of ≥ 80%). This reduction is achieved by using cover group "B" with an insulating layer of mineral building materials (kf-value << 10-7 m/s, corresponding to a reduction in permeability compared to the flushing sand by at least a factor of 100; see also **Chapter 4.2.2)**, which on the one hand reduces the amount of leachate and on the other hand prevents oxygen access. This eliminates the two most significant major components for contaminant release from the sludge dump.

The remediation target value is to be specified by a remediation investigation and verified by modeling as well as special experimental investigations (e.g., leachate prognosis).

4.1.3.7 Recommendations for Water impacts and for a Remediation Monitoring

Remediation of the sludge dump is primarily aimed at reducing water and oxygen inflows. If these are reduced, this can affect heavy metal emissions in several ways. If oxidation processes continue to act, the diluting effect of seepage water inflow is eliminated, i.e., concentrations increase and loads decrease. If various water paths are shut down, the diluting effect is also eliminated there and the concentrations remain the same or decrease slightly, the loads also decrease. **Thus, it is essential to monitor the heavy metal loads.** It can take several years until these loads are visibly reduced. A monitoring should be done at monitoring sites as close to the surface as possible, where both heavy metal concentrations and flow rates are measured. **The remediation monitoring should begin two years prior to the start of the remedial action in order to obtain sufficient data on the baseline condition.** A semi-annual measurement cycle (wet and dry periods) is suggested.

4.2 Remediation of Closed Mining Areas and Water Catchment Rehabilitation

“Remediation within the meaning of this Act are measures that prevent or reduce the spread of pollutants in the long term without removing the pollutants (safeguards).”
[BBodSchG, §2 (7) No. 2]

Safeguarding procedures prevent the release (emissions and transmissions) of gaseous, liquid or solid pollutants or direct human contact with the contaminated site. In contrast to decontamination, however, the contaminants remain (secured) at the site. Examples are:

- Sealing of the surface (to prevent the emission of gas, direct contact with humans, or to prevent water from entering the site),
- Immobilization procedures (admixture of binding materials to fix the pollutants),
- The construction of barrier wells in the groundwater, as well as
- The construction of vertical sealing systems (e.g., diaphragm walls).

Safeguards are often more cost-effective in the short term than decontamination. However, there remains a residual risk that must be monitored. If the securing effect diminishes, it must be restored as part of aftercare. The long-term measures and costs must be taken into account in the development of remediation scenarios (LfULG, 2003).

4.2.1 Uranium mining site Königstein

4.2.1.1 Controlled Flooding

Due to the complex situation of the uranium extraction by leaching, immediate flooding was too great an environmental risk. For this reason, a concept for flooding the Königstein mine was developed from 1991 onwards. Ten years later, the controlled flooding of the mine could be started.

In January 2013, the flooding of the previously approved sub-area I – damming of the pit up to a maximum of 140 m above sea level – was completed with a flooding level of 139.5 m above mean sea level. At present, the flood level must be maintained at < 140 m above sea level. This means that so far only about half of the total pit volume has been flooded. The flood water level is controlled by withdrawal of flood water over two 300 m deep wells.

The flood water is treated in a treatment plant. After separation of the dissolved uranium, the water is fed to a water treatment plant before it is released into the Elbe River. This process is necessary until no significant influence on the aquifers and on the Elbe River can be expected.

Due to the current approval situation, the treatment of flood water of the same order of magnitude as before will remain necessary for an indefinite period of time. The long-term goal is the complete flooding of the pit to a level of about 200 m above mean sea level as before mining.

4.2.1.2 Flooding of underground works

When uranium leaching was discontinued, both preliminary scientific investigations and approved limit and discharge values for pollutants into the groundwater and receiving waters were missing. Under these circumstances, the protection of the 3rd aquifer had top priority for Wismut GmbH in agreement with the public in the remediation concept of 1991.

This basic objective should essentially be achieved by extensive restoration of the 4th aquifer and the greatest possible prevention of the rise of flood water into the 3rd aquifer. At the same time, both constant control and constant active influence on the flooding process should be possible.

In the Königstein pit there is a considerable pollutant potential, which is mobilized in the course of certain storage variants and can leave the current pit space. As a result of this release of substances from the pit space, it may be possible to cause a condition in the underground area around the pit over a longer period of time (several generations) that corresponds neither to the actual state nor to the state before the start of uranium ore mining. For these reasons, immediate flooding or backfilling of the pit was generally not possible. For the safekeeping of the pit, various basic variants were developed over several years through research work based on local experiments and expert recommendations. This approach led to constantly improved technical, ecological, and business solutions.

The general consensus of Wismut, the authorities involved, and their experts is, that the rehabilitation of the Königstein deposit can only be achieved by flooding. In the course of the approval and assessment process, the considerations focused, among other things, on investigating ways of accelerating the flooding process while maintaining the basic objective of "avoiding unacceptable contamination of the 3rd aquifer".

After extensive discussion of variants on the basis of Wismut GmbH's rehabilitation concepts with the authorities involved and their experts, six basic variants for the safekeeping of the pit were derived:

- Variant 0 Uncontrolled immediate flooding,
- Variant A Uncontrolled immediate flooding with hydraulic short circuit to the Elbe River,
- Variant B Stage-controlled flooding up to the impoundment height of 190 m above mean sea level,
- Variant B 1 Stage-controlled flooding up to the impoundment height of 250 m above mean sea level,
- Variant B 2 Controlled flooding up to the impoundment height 140 m above mean sea level,
- Variant C Controlled flooding up to the impoundment height of 140 m above mean sea level with water treatment on the company premises and long-term drainage via an Elbe tunnel.

Based on the comparison of the basic variants, the available expert and official statements as well as the coordination discussions conducted for this purpose, implementation variants were considered and evaluated, which are in principle capable of approval and technically and technologically feasible in consensus with the parties to the proceedings. With the help of a multi-attribute assessment, an attempt was made to take into account all possible influencing parameters, available information, existing uncertainties, risks, different time periods, health risks and publicity-relevant aspects. In the multi-attribute evaluation, the expected consequences of the custody variants with regard to the evaluation criteria were expressed in cost units using tradeoffs (exchange relations, compensation values). The comparison of the variants with each other was thus based on their equivalent costs.

The basic variant of immediate flooding does not contemplate any further precautionary measures with regard to the prevention or reduction of contaminants respectively element outflow from the pit during flooding. The aim of the other variants is to achieve a reduction in element outflow from the pit using different technical processes. These different variants can also be subject to certain requirements aimed at complying with guideline or limit values. In order to ensure comprehensive comparability of the variants, relapse variants were defined. This refers to measures which, following flooding of the Königstein mine, result from an exceedance of tolerable loads on the protected assets and which represent a technical influence on the hydraulic or geochemical regime of the mine that goes beyond the originally planned flooding variant.

As a result of the coordination talks in 1997 between Wismut GmbH and the authorities involved and their experts on the status of the flooding of the Königstein mine, it can be stated:

- The general necessity of flooding the Königstein mine is not in doubt,
- The existence and effectiveness of the control routes are practically recognized, the control route system had to be completed,
- The flooding must be stoppable,
- Flooding can initially be approved up to such a level of impoundment at which contamination of the 3rd aquifer does not yet occur,
- In order to increase knowledge and perfect the parameters and data, a second extended flooding experiment with accompanying field and laboratory investigations including the storage of scrap and the step-by-step washing of each block of rock material and subsequent immobilization shall be carried out. Substantial improvements shall be made to describe the millieu-dependent development of the pollutant potential, its effects and the selection and justification of supporting measures,
- Water cleaning capacity had to be maintained for the acidic mine water,
- The flooding of the pit planned after the flooding experiment required a new separate permit. During the same period, Wismut GmbH could apply for a new water treatment plant.

The basic variants 0, A, B and B 1 are less favorable in the variant comparison compared to the basic variants B 2 and C. The variants B 2 and C as variants of a controlled flooding are almost identical in the first years of flooding, so that in any case a controlled flooding of the pit can be started. The decision to build a direct discharge of flood water into the Elbe River had to be made later.

A special underground flooding monitoring system was developed for the chosen method “controlled flooding with control route system”. The main focus was/is on the collection of quantitative and qualitative data from the water and air path as well as from geohydraulic, geotechnical and geochemical conditions in the course of flooding.

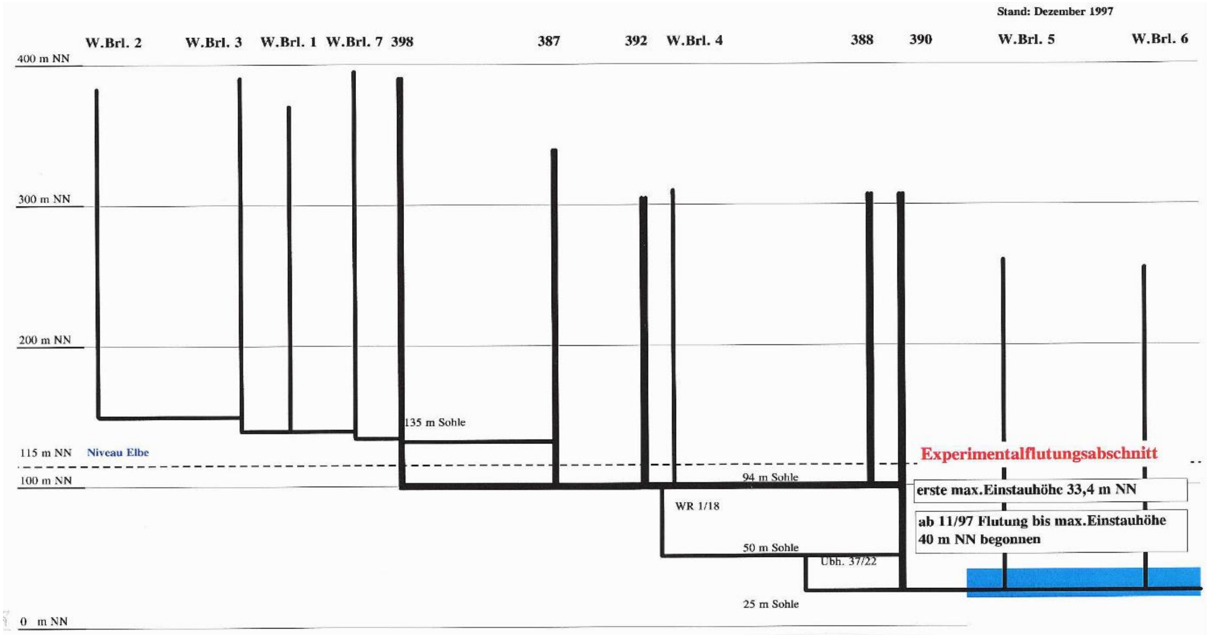


Figure 4-10. *Overview of the shafts and flooding sections in the Königstein pit (as of 1997).*

Source: Chronicle Wismut

4.2.1.3 Remediation of the mining and production waste tips

The creation of the mining and production waste tip in the Schüsselgrund was carried out in accordance with the requirements of the Saxon Switzerland Landscape Conservation Area. After that, no cone heaps could be built in this area. The construction of the waste tip had to be carried out in such a way that at the beginning of the filling on a higher section of the respective waste tip plateau, the lower berms had been covered in accordance with confirmed regulations and made reusable for forestry use by planting.

The mining and production waste tip has a contact area of 24.5 ha, of which 7.8 ha are embankments, and a volume of approx. 3.3 - 3.4 million cubic meters. Mainly rock from mining and leached poor ore as well as other radioactively contaminated materials (filter cakes, sludge, soil excavation, and demolition masses) were transferred to the waste tip. The radioactive materials resulting from the further underground and surface remediation were and still are also deposited on the Schüsselgrund waste tip.

According to an additional project related to the Schüsselgrund mining and production waste tip from 1988, about 16,000 to 20,000 trees have been planted so far, so that the lower berms already have a pre-forest character. At the waste tip, the embankments, and berms, including water catchments, were profiled, and rebuilt to the intended final height, the embankments were covered and greened. Towards the company premises, the roadways for transporting covering material were redesigned to achieve a clear separation between contaminated waste tip area and uncontaminated company premises.

The seepage waters from the Schüsselgrund tip were/are collected via the foil-lined basin at the foot of the tip. Via an acid-resistant underground pipeline to a borehole and another acid-resistant pipeline – sealed to the rock with special concrete – the tip seepage waters were/are discharged underground into the designated mine working and fed to the underground mine water to be cleaned.

Smaller mining and production waste tips, which were mainly deposited with the sinking of shafts, were already made reusable before the cessation of uranium extraction in 1990 and handed over to the council of the district of Dresden.

Table 4-3. *Scope of the remediation works on mining waste tips of both operative parts of the remediation operation Königstein*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
Removal of material	10^3 m^3	167	9	36	7	7	---	---	108	167
Filling of material	10^3 m^3	1,526	140	180	20	86	56	82	140	704
Covering, capping	10^3 m^3	667	28	22	-	10	11	7	1	79
Profiling	10^3 m^3	307	---	74	13	46	24	13	19	189
Area rehabilitating	ha	45	9	---	---	1	1	1	---	12
Seepage or leachate water collection systems	10^3 m^3	300	26	26	20	19	25	22	12	150

Source: Chronicle WISMUT

4.2.1.4 Safekeeping of underground mine workings

A large number of safekeeping facilities for underground mines were developed, evaluated and assessed by authorities as well as national and international teams of experts. After several years of scientific and technical investigations and experimental work carried out, the option "Controlled and phased flooding with underground monitoring by a control section system" was examined by the authorities and confirmed in its main features.

The application of Wismut GmbH to dispose of the ores produced in the southwestern pit field as a result of necessary shrinkage stopping blasts using the previous leaching method in order to avoid later major pollution in the flood water due to the easily soluble uranium compounds, was rejected by the authorities.

The special feature of the choice of the safekeeping method of the underground mines was to substantially complete the possible release of pollutants in the context of the flooding process before final flooding. Therefore, existing connections between the pit field and the aquifer have been and still are prevented by sealing. Within a control section system, dam structures were built in order to control the water path nature of the flood water and to avoid possible outflow of flooding water contaminated with pollutants. The control section system is separated from the rest of the underground mine workings in order to influence the flooding process from a still accessible and secured mine structure.

Of the total volume of the deposit of approximately 247 million cubic meters, approximately 55 million cubic meters of rock were actively influenced by sulfuric acid leaching. About 120,000 tons of sulfuric acid of different quality were used for the leaching of the rocks. The sulfuric acid concentration in the circulating solution was about 2 to 3 g/L. Calculations showed that in the existing pore volume of the rock were about 1.9 million cubic meters of acidified water, which were introduced by the leaching process.

The flooding experiments carried out since 1993 in a sub-area of the deposit confirmed the predicted parameters. By damming inflowing geological waters into the pore volume of the rocks, the accumulation was regulated in such a way that the flow conditions are analogous to the situation as they will occur with the total flooding of the pit. The contaminated water is fed to the water treatment.

Parallel to the construction of facilities for controlled flooding, further work was carried out on the disposal of hazardous substances of grease and oil contamination as well as by backfill insertion in pits for rock mechanical stabilization in the area of geological weakness zones (sand and basaltoid zones).

Depending on the existing technical capacities and the concrete underground possibilities, between $80 \cdot 10^3$ m³ and $100 \cdot 10^3$ m³ acid solution were disposed of.

Further focal points of the underground rehabilitation work were the safekeeping/tamponing (= clogging) of the very high number of boreholes as well as the tapping of drainage holes in the control section system for the intended flushing of the underground mine workings.

4.2.1.5 Dismantling of the operating facilities and rehabilitation of the operating areas

The dismantling of operating facilities after the cessation of uranium extraction at this site was directly determined by the process of destruction of the acid solution in the cycle and the flooding method of the deposit to be used.

The dismantling of equipment and the demolition of buildings and plants that were radioactively contaminated took place in parallel with mining rehabilitation work.

For example, mainly operating facilities and buildings that were not related to the chemical cycle and the flooding of the deposit could be dismantled and demolished at first. Due to the size and complexity of the buildings, plants and facilities, the dismantling and demolition work was put out to tender and carried out by specialist companies. The radioactive contaminated material was/is stored in the Schüsselgrund mining waste tip with the permission of the authorities.

The plants of the chemical cycle were reduced according to the annual necessary capacities or rebuilt and adapted for technical measures from official requirements. The annual destruction of acid solution and the necessary cleaning of radioactive mine water resulted in a uranium-containing intermediate that was handed over to subsequent treatment. The scope of the estimated water treatment/cleaning is shown in **Table 4-4.**

Table 4-4. *Water treatment and discharge at the Königstein site*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
water treatment	10³ m³	163.340	7.520	7.463	7.316	6.823	6.040	5.255	4.823	45.240
water discharge	10³ m³	94.815	6.473	6.654	6.303	6.064	5.498	4.812	5.641	41.445
sludge formation	m	23.960	3.357	5.157	2.219	1.224	664	892	394	13.907
sludge disposal	m³	429	48	50	29	34	25	23	25	234

Source: Chronicle WISMUT

The operating area of the Königstein site covered a total of 160 ha, and consisted of:

- Mining and production waste tips: approx. 38.5 ha,
- Settling basis: approx. 2.3 ha,
- Operating facilities including sand opencast mine Struppen-Nauendorf as well as areas for boreholes, for backfill injection: approx. 120.0 ha.

All areas were examined, sampled, and evaluated by measurements of the local dose rate within the framework of the Wismut environmental register created. In particular, the areas of the operating facilities in the main operating area at shaft 388/390 and at Rottwerndorf station, which were used for mining and processing activities with their diverse processes, are radioactive and/or multiple contaminated. For selected areas, such as within the ore leaching and water treatment complex, the soil path was explored by dynamic window sampling or bearing rod drilling to determine the depth range of the radiometric and chemical conditions of the contaminants.

Table 4-5. *Scope of remediation of areas for both sites*

definition	measure unit	extent, total	1991	1992	1993	1994	1995	1996	1997	sum 91/97
removal of material	10^3 m^3	480	18	48	18	16	11	19	5	135
filling of material	10^3 m^3	375	4	20	9	11	16	13	4	77
profiling	10^3 m^3	95	---	22	7	---	1	5	3	38
area rehabilitating	ha	74	---	1	1	1	---	1	---	4

Source: Chronicle WISMUT

The work begun on land rehabilitation in the 1990ies is carried out in accordance with the radiation protection principles of the Radiation Protection Commission and in accordance with the regulations of the Saxon Switzerland Landscape Conservation Area. Preparatory work has been started to rehabilitate the settling basins and their areas.

Figure 4-11. *Left Demolition of the shaft complex 388/390 (Königstein, 2014); right dismantling of the headframe of shaft 388 (2015).*

Source: https://www.wismut.de/de/pressefotos.php, 13.10.2014 and 11.11.2014

4.2.1.6 Storage and disposal of pollutants

All residues and materials produced in the process of safekeeping, liquidation and remediation have been checked for the possibility of recovery before disposal has been carried out. The basis for the pollutant disposal were the legal regulations for the respective pollutants as well as the disposal companies approved by the Dresden Regional Council.

The residues and materials to be disposed of from the decommissioning process of ore extraction, the dismantling of operating facilities and the demolition of buildings were collected and taken to an interim storage facility or stored in a mining waste tip in accordance with the official approval. The pollutants collected in interim storage facilities were/are mainly oils, fats, acids, varnishes, paints, organic and inorganic laboratory chemical residues, NC accumulators, dry batteries, alkaline cartridges, solvents, paint and chemical containers as well as metal containers with harmful residual contents. Very small amounts of these pollutants were deposited in special waste containers. Materials and equipment that were particularly in need of monitoring, such as e.g., enclosed artificial radioactive radiation sources, were temporarily stored in separate storage facilities, e.B. isotope bunkers, until they were disposed of.

The radioactive asbestos cement waste generated by dismantling and demolition work was placed in the Schüsselgrund mining and production waste tip at the Königstein site and in the Gittersee waste tip at the Dresden-Gittersee site following official approvals.

Non-radioactive asbestos cement waste at the Königstein site could be transported to the Nauendorf sand opencast mine after approval by the Office for Waste and Water Management at the Pirna District Office. In the period from 1991 to 1997, pollutants amounting to 183 m³, 321 t and 703 pieces (drums, containers, etc.) were disposed of by special companies.

4.2.1.7 Demolition and area redevelopment

In 2020, an external company demolished the entrance buildings, fire brigade buildings including hose tower, MED/laboratory building, former kitchen and several smaller facilities. The planned demolition of the administration building, including the south and north wings of the shower combine, has been postponed to 2022. The reason for this was a species conservation examination of the building complex. This resulted in a high population of quarters and habitats for bats and house swallows (house martins) as well as possible breeding grounds for European songbird species. In order not to endanger the animals, replacement quarters are created before demolition. The implementation of the measures will continue until 2021.

The focus of the redevelopment was the completion of sub-area 7 of the so-called Südfeld. The maintenance of the already renovated areas and facilities represented another major area of work.

4.2.1.8 Flooding water treatment plant

Since May 2018, the AAF has been rebuilt and adapted to the requirements of the achieved remediation progress. The particular challenge was to implement the necessary measures in parallel with the ongoing operation of the old plant. The most important change is the elimination of the process stage uranium disposal. Since the concentration of uranium and heavy metals has decreased significantly during the remediation in recent years, further separate separation and processing of the uranium is no longer necessary. The new AAF takes over the complete treatment of the flood water, with the main steps of neutralization/precipitation, sedimentation, demanganization and sludge dewatering, before discharge into the Elbe River.

Figure 4-12. *Treatment plant for flooding water Königstein in the state of 2015, which was modernized in 2020.*

Source: https://www.wismut.de/de/pressefotos.php, 16.11.2015

In spring 2020, the first trial operation with a capacity of 200 m³/h was successfully carried out in the partially converted AAF. Subsequently, the completion of the conversion of the AAF could be realized. In November 2020, the second trial operation for the exceptional operation with a capacity of 650 m³/h started as planned.

The aim is to test the completely rebuilt system for the maximum throughput required to be able to lower the flooding water level again in the event of unacceptable environmental effects in the event of further flooding. Trial operation 2 will continue until the first quarter of 2021. Parallel to the trial operation, residual work and technological adjustments were carried out.

In the Königstein pit, the dammed level was kept constantly below the approved flood level of 140 m above sea level. For this purpose, about 2.4 million m³ of flood water had to be pumped. Some of the flood water was plunged back into the pit untreated. This circular operation was necessary in the trial operation of the new AAF in order to coordinate the individual processes. In the converted AAF 1.24 million m³ were treated, in the old AAF only 0.69 million m³. This includes 0.37 million m³ of surface water. The treated water was discharged into the Elbe River (1.81 million m³), and a very small proportion was released into the pit (0.09 million m³).

4.2.1.9 Mining and production waste tip Schüsselgrund

In 2020, work was carried out in construction phases 2 and 3 at the Schüsselgrund waste disposal facility. No further contaminated material was stored in construction phase 2. Here, the covering layer of inert material was then applied to an area of 1.62 ha for safe storage. For this purpose, 16,000 m³ of material were delivered and installed. A total of 32,000 t were moved. This completely covers construction phase 2. In 2021, the construction of water and paths will take place. In the course of the construction of the Pirna road bypass, Wismut GmbH was able to acquire further covering material for the next few years. It is temporarily stored on the company premises and the stockpile until it is used.

In the year under review, contaminated material was stored exclusively in construction phase 3 of the stockpile. In a special storage area within this construction phase, scrap, and liquid residues from the water treatment, which were classified as hazardous waste, were safely stored. The scrap is stored in prepared areas and filled with sludge and concrete. Also in 2020, more of these so-called dry beds were prepared.

The materials newly stored on the Schüsselgrund waste tip included removal masses from surface remediation, demolition material, scrap, and residues from water treatment. The new AAF changes the name for their residues. So far, the resulting sludge has been decanted and generally referred to as residues. In the converted AAF, the residues are dewatered in a filter press. What remains is the so-called filter cake. This results in the following list for the year 2020:

- Removal masses from surface rehabilitation: Approximately 11.800 m³
- Demolition and disassembly material: Approximately 758 m³
- Scrap: Approximately 710 m³
- Residues from the flooding water treatment plant: Approximately 218 m³
- Filter cake from the converted respectively rebuilt AAF: Approximately 178 m³
- Material from basin and street cleaning: Approximately 95 m³

During the management of the waste tip, roads must be created for the transport of materials to the storage area; last year that was 240 m. For this purpose, about 20,500 m³ of diabase gravel had to be procured from the Ottendorf quarry. Further work on the AEE at the beginning of the year was the removal of wind and snow breakage, the maintenance of the already rehabilitated areas and the maintenance of the existing path and ditch system.

4.2.2 Large Ecological Project Dresden-Coschütz/Gittersee

4.2.2.1 Safekeeping of surface adits

The safeguarding of the surface adits at the Dresden-Coschütz/Gittersee location was carried out according to confirmed special operating plans. Accordingly, these pits had to be completely backfilled. In order to prevent the leakage of the liquefied filling material from the mine construction, partial dams had to be built in the area of the filling locations. In order to avoid possible contamination by rising mineralized mine water into existing aquifers, dams were built, and special requirements were placed on the backfills. The safeguarding work of the surface galleries at this location had been completed. A special feature in the implementation of the custody work was, that the winding tower of the Marienschacht in Bannewitz, a so-called Malakoff tower, built in 1886, was included in the state monument list of Saxony, as this building is one of the last of its kind and had to be preserved and restored (see **Figure 4-13**).

Figure 4-13. *Shaft building of the Marienschacht with Malakoff winding tower, 1886 and in the 1990th*

Source: Chronicle Wismut 2010; photo: R. Jentzsch, https://www.marienschacht.de/galerie.html

Table 4-6. *Scope of remediation on surface adits of mine workings of Gittersee in the 1990th*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
Miner's shoring works	m	1,165	-	-	-	260	355	50	-	665
Disassembly operations	t	1,253	-	-	-	-	5	-	-	5
Boreholes, drilling	m	6,834	-	-	-	377	78	79	-	534
Water-retaining structures	piece	50	-	-	-	6	4	2	-	12
Scope of the safeguarding	10^3 m^3	78	-	2	8	-	16	1	1	28
Plate carrying traffic load	piece	6	-	-	-	1	-	1	4	6

Source: Chronicle Wismut 2010

4.2.2.2 Safekeeping of underground mine workings

The safeguarding work of the underground mine workings was completed at the end of the 1990s. The necessary work was carried out to eliminate water pollutants (fats, oils, chemicals) and to backfill near-surface pits – especially shafts – to avoid subsidence of the ground surface. The flooding of the pit was initiated afterwards.

4.2.2.3 Remediation of the mining waste dumps

At the Dresden-Coschütz/Gittersee site were the Gittersee mining waste tip and the mining waste tip at the Marienschacht with a waste tip contact area of approx. 14 ha and a volume of approx. 1.3 million cubic meters.

Scientific and technical studies have shown that the waste tips pose environmental risks due to the long-term pollutant potential. Of the remediation variants examined, the option "Profiling and covering of the waste dump on site" was assessed as the most suitable and confirmed by the authorities (Wismut, 2010).

The Gittersee mining waste tip had been created by the so-called dumping on a slope on a flank of the valley Kaitzbachtal. At the Gittersee mining waste tip, the plateau and the eastern flank were completely profiled and covered, the west flank was re-profiled towards residential development, covered and the contaminated tip area was demarcated to the private areas by a newly created roadway with seepage and surface water intake. On the northern flank, a waste tip extension (approx. 2.3 ha) was carried out to absorb residues from the hard coal mining industry, which were incurred in the context of municipal and private construction activities.

The mining waste tip at the Marienschacht had to be partially removed, profiled, covered and greened. The waste dump embankment had to be redesigned using existing troughs and sinks for the placement of contaminated materials. The collection of seepage waters infiltrating into the tip and their controlled discharge to the beek Boderitzgraben, which is the receiving water, was established.

The area of the mining waste dump at the Marienschacht in connection with the listed monument complex in the shaft area (e.g. Malakoff winding tower) was redesigned in the following years into a versatile recreation and excursion center of the municipality of Bannewitz.

Table 4-7. *Scope of the remediation works on mining waste and residues tips of Gittersee*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
Removal of material	10^3 m^3	167	9	36	7	7	---	---	108	167
Filling of material	10^3 m^3	1,526	140	180	20	86	56	82	140	704
Covering, capping	10^3 m^3	667	28	22	-	10	11	7	1	79
Profiling	10^3 m^3	307	---	74	13	46	24	13	19	189
Area rehabilitating	ha	45	9	---	---	1	1	1	---	12
Seepage or leachate water collection systems	10^3 m^3	300	26	26	20	19	25	22	12	150

Source: Chronicle Wismut 2010

4.2.2.4 Storage and disposal of pollutants

All residues and materials produced in the process of safeguarding, liquidation and remediation have been checked for the possibility of recovery before disposal has been carried out. The basis for the pollutant disposal were the legal regulations for the respective pollutants as well as the disposal companies approved by the Dresden Regional Council.

The residues and materials to be disposed of from the decommissioning process of ore extraction, the dismantling of operating facilities and the demolition of buildings were collected and taken to an interim storage facility or stored in a mining waste tip in accordance with the official approval. The pollutants collected in interim storage facilities were mainly oils, fats, acids, varnishes, paints, organic and inorganic laboratory chemical residues, nickel cadmium accumulators, dry batteries, alkaline cartridges, solvents, paint and chemical containers as well as metal containers with harmful residual contents. Very small amounts of these pollutants were deposited in special waste containers. Materials and equipment that were particularly in need of monitoring, such as e.g., enclosed artificial radioactive radiation sources, were temporarily stored in separate storage facilities, e.B. isotope bunkers, until they were disposed of.

The radioactive asbestos cement waste generated by dismantling and demolition work was placed in the mining waste tip at the Dresden-Gittersee site following official approvals and after that tip had been prepared to store additional waste.

In the period from 1991 to 1997, pollutants amounting to 183 m^3, 321 t and 703 pieces (drums, containers, etc.) accrued both at the Dresden-Coschütz/Gittersee and the Königstein operative parts of the remediation operation Königstein during the first decade and were disposed of by special companies (Wismut, 2010).

4.2.2.5 Dismantling of the facilities and rehabilitation of the operating areas

With the takeover of part of the Dresden-Coschütz/Gittersee deposit for uranium extraction in 1968, typical mining buildings and facilities were also taken over from the former Zwickau hard coal combine, some of which already had a corresponding age value at that time. For uranium extraction, therefore, only technological operating facilities for quantitative and qualitative uranium determination in the uranium ores were built on the surface area.

With the cessation of uranium extraction in 1989, a first evaluation of the buildings and facilities with regard to possible reuse, necessary dismantling or demolition took place. As part of the Wismut environmental register, all buildings and facilities were re-examined and evaluated regarding their contaminants and contamination. Based on this environmental assessment, all mining-specific buildings and facilities that were not suitable for reuse due to radioactive contamination or their construction on contaminated ground or because of their design and their technical condition were dismantled and demolished.

The shipment of the radioactively contaminated materials was carried out on the basis of the specifications in the approved special operating plan “Landfill of radioactive scrap and other materials” by installation in the Dresden-Gittersee mining waste tip as described above.

Buildings and facilities that had been needed for administration and social care were demonstrably not contaminated, could be used until the completion of the rehabilitation of the company premises and were fully suitable for subsequent use.

Buildings of this category, which were no longer needed for the remediation process, could in some cases be handed over to commercial use quite promptly.

For the buildings and facilities that were intended for reuse for the preservation of historical monuments, the technical and legal requirements for handover to the subsequent user were completed (Wismut, 2010).

The total area used for uranium mining was about 29 ha, of which about 15 ha for areas used for facilities and buildings and about 14 ha for contact areas covered with mining waste tips.

The measurements of the local dose rate and soil sampling carried out as part of the Wismut environmental register showed very different radioactive contamination on the individual areas. It was shown that areas used by hard coal mining were partly contaminated with natural radionuclides. At the same time, an assessment of existing hydrocarbon contamination was carried out (Wismut, 2010).

Since there were ideas of the neighboring municipalities for the operating areas for reuse as industrial areas respectively green/park areas, the radiation principles of the Radiation Protection Commission formed the basis for necessary remediation measures. As a remediation measure, the removal of the contaminated soil layers up to a free/ clearance measurement limit was carried out. The excavated radioactive soil material was transferred to the Dresden-Gittersee mining waste tip. Thereafter, the application of arable soil was carried out in accordance with the guideline values recommended for the release of the areas and depending on the subsequent use. All rehabilitation measures were carried out according to approved projects of the competent authorities.

Table 4-8. *Scope of remediation of surface areas at Gittersee*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum 91/97
Removal of material	10^3 m^3	480	18	48	18	16	11	19	5	135
Filling of material	10^3 m^3	375	4	20	9	11	16	13	4	77
Profiling	10^3 m^3	95	---	22	7	---	1	5	3	38
Area rehabilitating	ha	74	---	1	1	1	---	1	---	4

Source: Chronicle Wismut 2010

In addition to the volumes given in **Table 4-8**, 36,000 m^3 of removal work and commissioned work of 4,500 m^3 were carried out in 1990. If transports of contaminated materials had to be carried out on public roads, tyre washing systems must generally be passed through when leaving the contaminated site.

4.2.2.6 Flooding of the mine workings

The flooding project of the Dresden-Coschütz/Gittersee mine workings had to take into account not only the resurgence of water in these pit cavities, but also the fact that mining had been carried out in the Döhlener Becken hard coal deposit since the 16th century and that extensive tunnel systems for water supply and discharge had been created. With the closure of mining on hard coal and the underwater setting of pit cavities, the flooding/partial flooding of entire mining fields in this deposit was completed many decades ago.

After the end of the uranium mining activities of SDAG Wismut in 1989, it was decided to flood the workings from the second half of the 20th century also. Rising flood waters had to drain over the former mining fields of the coal mines in the direction of Tiefer Elbstolln and to be fed to the Elbe River via this tunnel. A deep well to be built (production well #1) in the area of the Gittersee site was to serve as a fallback/ tailback variant in the event of insufficient water discharge in the direction of the Tiefer Elbstolln. The permit granted by the former Saxon State Ministry for the Environment and Regional Development for the handling of radioactive substances during flooding was made subject to the condition that the quality of the drinking water from deep well #4 is demonstrably not impaired by the flooding. Deep well #4 represents one of the deepest groundwater uses in Freital hard coal and uranium ore deposit. The requested flooding level was limited to a maximum of 130 m above mean sea level by the authorities. In May 1995, the final flooding of the pit was initiated. The rising flood water of the Gittersee pit had to pass over to the old Zauckerode hard coal pit field and flow via the Tiefer Elbstolln tunnel to the Elbe River receiving water. **Figure 4-14** show a safekeeping and backfilling of the “Schurfschacht 60” in 2002, which had been partly filled with hazardous chemicals in 1958 – not originating from SDAG Wismut.

Figure 4-14. *safekeeping of the “Schurfschacht 60” in 2002*

left: location view, right: view into the shaft with wooden casing

Source: environmental report Wismut 2002,
https://www.wismut.de/de/downloads/umweltbericht2002.pdf

In the flooding project of the Dresden-Coschütz/Gittersee mine, the connection to the problem “Schurfschacht 60”, in the Heidenschanze working panel, had to be established. In 1958, chemicals and other unspecified substances that had become unusable were dumped – in a disorderly manner – into this exploration shaft of the hard coal mine, which was intended for backfilling. In the former GDR, these materials were classified as Department 1 poisons (highly toxic) and were/are considered water pollutants. In the event of flooding of the “Schurfschacht 60”, it had to be assumed that the chemicals thrown-in there or metabolites resulting from them enter the flooding water stream according to their water solubility and will be discharged with the flooding water via the Tiefer Elbstolln into the Elbe River.

The flooding water depression in the Dresden-Coschütz/Gittersee respectively Bannewitz area, which had arisen since 1950, had replenished after the decommissioning of the water retention in 1995 after about two years, i.e., the predicted height mark of 130 m above mean sea level was reached. However, the beginning of the flooding water passing over from the flooding area Dresden-Coschütz/Gittersee respectively Bannewitz to the Tiefer Elbstolln clearly did not occur. In the event of non-existent or delayed water path or hydraulic routing from the Dresden-Coschütz/Gittersee pit to the Tiefer Elbstolln, a total of six fall back respectively recurrence variants were worked out.

Due to the expected development of the iron contents in the flooding waters, the commissioning of the water treatment plant (calcification and aeration) at production wells FB #1 and #3 (in the area of the Heidenschanze deposit) became necessary. Due to the installed alternative water retention via FB #1 and #3, the flooding process could be sufficiently controlled, documented, and controlled. The alternative water management had to be operated until the uninhibited discharge of the flooding water according to the direction of the flooding project. The flooding project of the underground mine workings of the Dresden-Coschütz/Gittersee pit was developed in such a way that the total flooding of the deposit is completed and no transfer of flood water into the upper aquifer can occur.

In **Figure 4-15** is shown the Wismut-Stolln, wich has been driven between 2007 and 2014, with a total length of 2,900 m, the tunnel system for the safe discharge of excess flooding water from the Dresden-Coschütz/Gittersee site.

Figure 4-15. *Wismut-Stolln (2016),*

Source: *https://www.wismut.de/de/pressefotos.php; 11.01.2016*

Since the existing Tiefer Elbstolln did not extend to the Dresden-Coschütz/Gittersee mine workings, a winze was put down in the immediate vicinity of the Tiefer Elbstolln, and from it a mine opening that was interconnected to the Elbstolln was excavated. In order to use the Tiefer Elbstolln as a drainage tunnel of the deposit, further measures had to be initiated and carried out. To ensure the long-term functionality of the Tiefer Elbstolln, extensive reconstruction work/mining security work had to be carried out on sections. On the length of the Elbstolln to the Dresden-Coschütz/Gittersee mine boundary – after having obtained official permits – the accumulated sludge had to be picked up, drained and disposed of. The flooding water leaving the Tiefer Elbstolln tunnel passed through a water treatment plant before being fed to the Elbe River receiving water (Wismut, 2010).

If, after expiry of the officially prescribed observation period, sufficient flooding water does not pass over into the Tiefer Elbstolln, for load relief purposes a new mine opening must be built in the direction of the Tiefer Elbstolln or Weißeritz river.

Table 4-9. *Annual flooding extent of the underground mine workings at Gittersee*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
Flooding of underground mine workings	10^3 m^3	13,000	---	9	216	225	535	866	1,221	3,072

Source: Chronicle Wismut, 2010

Flooding in stages: The flooding of the pit began in May 1995, and it was divided into two mine fields. The aim in this area was to restore the natural groundwater level in the Freital mining district. Characteristic of the flooding course was the gradual increase or maintenance of the water levels by means of two installed production wells in the underground mine workings. The aim of this measure was to avoid mining damage and other adverse effects that could be caused by the disused mine. With the achievement of a flooding level of about 180 mamsl, local water leaks occurred and it was assumed that partially unknown waterways of centuries-old coal mining played a decisive role. In order to gain more detailed knowledge, the re-impounding to a level of 165 mamsl was requested.

The drive of the Wismut Stolln: The flooding is accompanied by an extensive monitoring system in order to detect such outlets of flooding water on the surface in good time and, if necessary, to avert damage with appropriate measures. During the re-impoundment > 156 mamsl, the hydraulic connection between the Dresden-Coschütz/Gittersee/ Bannewitz and Heidenschanze working panels was confirmed. However, since further mining damage could not be ruled out at this flood level, a connecting section (Wismut Stolln) from the Dresden-Coschütz/GitterseeBannewitz working panels to the Tiefer Elbstolln was mined for the permanent, safe drainage of the flooding water from the underground mine workings to the right of the Weißeritz at a geotechnically uncritical level of 120 masl. Over this route, the flooding water flows from the working panels of the former hard coal and uranium ore mining districts to the Tiefer Elbstolln and over this into the Elbe river in a controlled manner. The flood water level is thus permanently maintained at 120 mamsl.

The Wismut Stolln, which was newly mined from April 2007 on, has a total length of around 2,900 m. The access to the tunnel is via a ramp and was then driven in the direction of Tiefer Elbstolln or in the direction of shaft #3. The minimum vertical distance of the drivage to the day's surface is about 40 m in the area of the Weißeritz river. After 1,910 m of drivage of the Wismut Stolln to the west, the breakthrough in the deep Elbe tunnel took place on 14th August 2012. With the approach of the weather borehole at shaft 3# on 11th June 2014, the excavation of the Wismut Stolln in Dresden-Freital was completed as planned.

This made possible to create a continuous connection from the Elbe river near Dresden via the Tiefer Elbstolln to the weather borehole not far from the former shaft #3 of the Dresden-Coschütz/Gittersee underground mine workings. The remaining work was completed in October 2014.

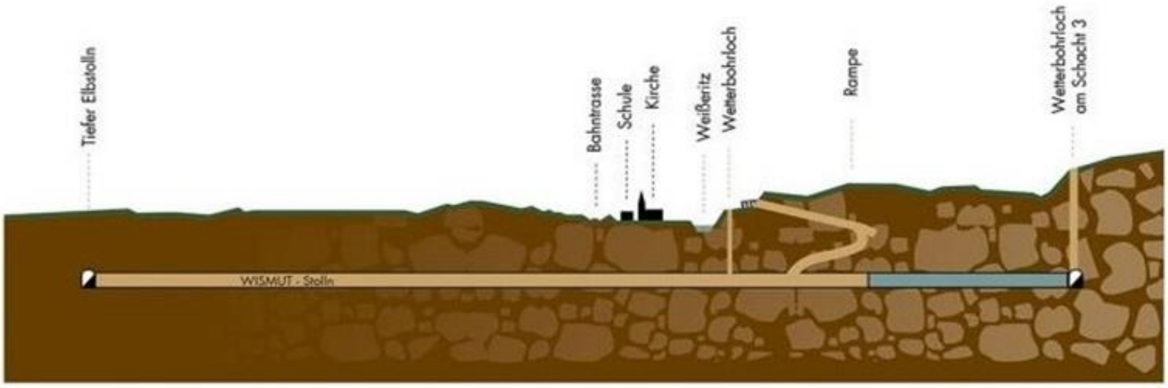


Figure 4-16. *Scheme of the driving of the Wismut Stolln in Dresden-Coschütz/ Gittersee 2007-2014, towards the Tiefer Elbstolln*

Source: https://www.wismut.de/de/nl-koenigstein_projekte.php?id=101&back=nl-koenigstein_ projekte. php%3Fyear%3D%26index%3D0

The hydraulic connection of the Wismut Stolln to the Gittersee underground mine workings was established by four boreholes with a diameter of 200 mm each from the end of the tunnel at weather borehole #3. After the drilling work was completed, the water sluices in the tunnel (gutters for water drainage) were completed and a water overlift was temporarily installed for the time of the dismantling work in the tunnel. Since 7th October 2014, the flooding water of the Dresden-Coschütz/Gittersee and Heidenschanze underground mine workings has been draining from in Dresden-Freital via the Wismut Stolln to the Tiefer Elbstolln successfully.

The previously practiced pumping down the flooding water via the production borehole, the water treatment and the discharge of the treated water into the Kaitzbach near Dresden-Gittersee were discontinued. With the demolition of the buildings and facilities and the removal of the contaminated soil on around 21 hectares, the work on the operating area was also completed. This completes all renovation measures at the Dresden-Coschütz/Gittersee site.

<u>Long-term tasks:</u> Treatment of mining water is no longer required at the Dresden-Coschütz/Gittersee site. The Dresden-Coschütz/Gittersee underground mine workings are drained into the Elbe River via the Wismut Stolln and further over the Tiefer Elbstolln. The monitoring of the water levels of recent years in the pit cavities has shown that at intervals of several years, the connecting boreholes between the pit and the Wismut Stolln must be cleared of incrustations in order to prevent accumulation of mine water in the flooded underground mine workings. For this purpose, the condition of the holes is regularly examined by means of camera inspections. The condition control and the cleaning of the connecting boreholes are long-term tasks, as well as the maintenance of the water drainage adits Wismut Stolln and Tiefer Elbstolln. The latter requires the clearing of sludge at intervals of several years.

4.2.3 Uranium mining waste sites Seelingstädt and Crossen

4.2.3.1 Remediation of the mining waste tips and settling basins - Seelingstädt

Due to the hydrometallurgical processing methods used, no dumps of processing residues were filled at this site. Adjacent exhausted open pit mines were used as settling plants respectively tailings facilities during the operation of the processing. The mining waste dumps deposited at the edge or within the opencast mines during the mining phase were partly used to build dams of the settling plants, respectively former mining waste dump areas were flooded by deposited tailings and thus acted as barrier dams.

The mining waste dump contact area is approx. 332 ha and the mining waste dump volume is approx. 80 million cubic meters. The majority of the individual dumps were recultivated during the mining period before 1990 and are forested. Their plateaus were mostly levelled. The influence of pollutants escaping from the mining waste and tailings on the environment was detected respectively demonstrated by sampling and measurements. This is relatively low, but locally different. From the investigations carried out (local dose rate measurements, drill core sampling), different levels of radionuclide were identified. The remediation of the inadmissibly highly contaminated mining waste or tailings dumps areas was provided for by excavating and transferring it to a settling basin, which was prepared for it (Wismut, 2010).

The rehabilitation of the mining waste and tailings dumps depends on the technological and temporal sequence of the remediation of the settling basins. Near the Trünzig settling plant, the dumps with a contact area of about 184 ha were cultivated before 1990 and their morphology was adapted to the former terrain relief, but these had to be improved. The plateaus are covered with grass, the embankments are forested.

4.2.3.2 Remediation of the mining waste and processing residues tip - Crossen

Crossen had only one mining waste and processing residues tip created during the operating period. The contact area was initially poured from residues of wet mechanical processing as a basin about 4 m thick and then completely covered with fine- to coarse-grained residues of radiometric processing about 40 m (Wismut, 2010).

The contact area was approx. 22 ha and the dump volume approx. 3.2 million cubic meters. The radioactively contaminated construction rubble resulting from the demolition of buildings as well as the radioactively contaminated soil excavation as part of the remediation of the farm area had been temporarily stored on special areas of the stockpile from 1993 onwards.

In the immediate vicinity of the mining waste and processing residues tip was the urban district Crossen of the city of Zwickau. Allotments were cultivated just a few meters from the foot of the pile, and the minimum distance to the nearest residential building was about 50 m.

According to the data obtained from the Wismut Environmental Cadastre, environmental risks emanated from the dump. As security measures, the dump was fenced in 1992/1993 and the leachate collection plant was completed and put into operation in 1993. The radioactively contaminated water was/is fed to the Helmsdorf settling basin.

Extensive geological, hydrological and geophysical investigations of the tailings pile were carried out. As a result of the technical and technological investigations, it was decided to relocate the whole mining waste and processing residues tip to the nearby Helmsdorf settling basin, to use it there as a building material for the intermediate cover and to make the contact area in Crossen usable again. The relocation of this mining waste and tailings pile was thus closely related to the safeguarding of the Helmsdorf settling basin. Further technological investigations regarding the transfer or relocation of the dump, in particular for the transport of the excavated dump masses to the transfer point in the area of the Helmsdorf settling plant (approx. 2 km), led to the conclusion that a pipe conveyor could best meet the requirements of environmental protection regulations.

Together with the equipment configuration for the excavation of the mining waste and tailings dump mass and for the continuous feeding of the pipe conveyor of approx. 2 km in length as well as the removal technology of the mining waste dump material from the bunker to the settling plant, the overall technology for the transfer of the whole dump was approved by the competent authorities in 1996 and then began the relocation of the mine waste dump masses.

The pipe conveyor – a system where the belt is curved by a special arrangement of the transport rollers to form a tube (see **Figure 4-17**) – was put into operation in 1997 for the environmentally friendly transport of the mining waste and processing residues masses, the demolition material of the company premises and the excavated soil from Crossen to Helmsdorf. The conveyor system was designed in such a way that there was no contamination of the environment with dust during transfer.

On its length of about 2 km, the 300 mm diameter pipe conveyor crossed the river Zwickauer Mulde, the former Bundesstraße 93/175 and the railway tracks of Deutsche Bahn AG. An altitude difference of approx. 102 m has been bridged.

Figure 4-17. *Transport of Crossen mining waste and processing residues to the industrial settling plant Helmsdorf with Pipe Conveyor*

Source: https://www.wismut.de/de/pipe_conveyor.php

As part of the rehabilitation of the Wismut site in Crossen, 3.25 million m^3 of radioactive material were transferred to the industrial settling plant Hermsdorf with the pipe conveyor by 16 February 2016. 130,000 journeys with large trucks with all the associated burdens on people and the environment could thus be avoided. The tailings pile material was transported dustproof, safe and environmentally friendly.

After 20 years of continuous use, the pipe conveyor with all ancillary systems now had to be demolished. This included several bridge structures, pipelines, and systems for operating the conveyor system. In the last construction phase, reforestation and planting were carried out until 2018. The affected properties were restored to their original state and returned to owners.

Figure 4-18. *Former area of the Crossen operative plant and reclamined contact area of the mining waste and processing residues tip behind.*

Source: https://www.wismut.de/ de/pressefotos.php, 07.06.2016

4.2.3.3 Dismantling of the processing facilities - Seelingstädt

The buildings and facilities were mainly built between 1958 and 1960. Some buildings and facilities (leaching plants, flotation, etc.) were built later, sometimes only a few years before decommissioning. As a result of the operation of the treatment plant, buildings and operating areas were heavily contaminated and led to radioactive contamination of the environment. Equipment, including steel structures, had often been contaminated on the surface with ore remnants. Certain steel parts that have come into contact with acidic uranium-containing solutions had stuck uranium contamination as a result of cementation. Measurements carried out showed that the degree of contamination as well as the homogeneity was different. The dismantling of equipment and installations as well as the demolition of buildings was designed from the beginning of 1991 in such a way that no new capacities had to be built for further remediation work (Wismut, 2010).

Exceptions were, for example the conversion of the voltage level in the electric power transformation substation Berga carried out in 1992/1993 by Ostthüringer Energieversorgung AG and thus the construction of a new customer plant as well as the replacement of transformers and drive motors; the construction of a new heat supply plant as a result of federal legislation restricting the remaining useful life of old plants with limit values exceeded for pollutant emissions until 30 June 1996; the conversion and expansion of existing technological facilities with small capacities for the disposal of radioactive residual and cleaning products resulting from the demolition of the buildings, containers and facilities, as well as the re-precipitation of the so-called Königsteiner intermediate product (result of the destruction of uranium solution, transferred from the Königstein site) into disposable ammonium diuranate, which was carried out by the end of 1996.

The re-precipitation, drying and filling of disposal products (ammonium diuranate) in barrels was completed. The uranium-containing materials produced during the extensive cleaning of technological containers, bunkers and pipelines were processed. On September 12, 1997, the last barrel filled with yellow cake was moved from the packaging of the final mine to the warehouse for natural uranium concentrate. This finally ended the yellow cake processing in the Seelingstädt operative plant, almost 25 years earlier than at Königstein.

The disposal of radioactively contaminated construction rubble had been examined several times technically, technologically, and economically. As a result of the investigations, it was demonstrated that the construction rubble had to be broken and, due to its favorable soil mechanical properties when installed in the intermediate cover of mining waste dumps or other kinds of landfills, led to an increase in the stability of the covering layers and to the material substitution of the required covering compounds for the settling plants. As a means of transport, the truck was designed as the most suitable option on company roads. Compared to hydraulic transport, this meant that certain systems could be decommissioned, dismantled and demolished much earlier.

The radioactive contamination of the scrap was mainly caused by incrustations. In the meantime, the dismantling scrap from the ore processing plants had been temporarily stored on the concrete surfaces of the former thickeners (4 x 2,800 m²). Non-uranium-contaminated scrap from the sulfuric acid factory and the industrial power plant could be recycled as raw materials. Investigations carried out on the transfer of the contaminated scrap showed that the storage of the scrap in the depression in the terrain of the north dam area of the Culmitzsch settling basin was the most appropriate because it did not hinder the final safeguarding of that basin. The technology for the installation of the contaminated scrap and other demolition materials was designed for technological reasons in so-called cassette construction, with the cavities to be filled. The block storage targeted as a cassette structure offers a high level of stability and is durable in its shape.

Table 4-10. *Dismantling of the operating facilities at the Seelingstädt location*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
Removal of material	10^3 m^3	12,295	105	22	20	---	17	77	410	651
Filling of material	10^3 m^3	450	11	1	---	---	---	15	3	30
Area rehabilitating	ha	143	---	---	---	---	---	---	---	0
Seepage or leachate water collection systems	10^3 m^3	320	---	---	5	23	32	16	18	94

Source: Chronicle Wismut 2010, https://www.wismut.de/de/veroeffentlichungen.php?id=614&back=veroeffentlichungen.php%3Fyear%3D0%26index%3D0

The existing laboratory was partially rebuilt and systematically used as a central laboratory for the entire Wismut GmbH. The changes led to higher utilization of cost-intensive equipment technology, to more accurate measurement accuracy and to a reduction in the outsourcing of analyses.

4.2.3.4 Dismantling of the processing facilities - Crossen

A radiation protection assessment carried out at the end of 1989 by the State Office for Nuclear Safety and Radiation Protection (SAAS) on the subsequent use of the processing plant showed, among other things, that it was not possible to reuse the old production buildings – several of the early pre-war period, when the plant operated as a paper mill – for dissimilar production.

On the basis of this finding and further investigations, in particular also on the structural condition of the buildings, work for dismantling and liquidation was determined. As a result of this determination, more than 70% of the former equipment of the production facilities of the uranium ore processing plant had already been dismantled and prepared for disposal at the end of 1990 (Wismut, 2010).

The dismantling of process equipment was essentially completed within the premises by the end of 1993. Excluded from this were equipment needed for further renovation work, such as electrical systems, pumping stations and others. The scrap produced during dismantling was separated according to grades and contamination and temporarily stored on concrete areas on the company premises. Uncontaminated scrap was sold.

Due to deposits of contaminated dust and discharges from tank and pipe systems (overflows, leaks), the interior walls of the production buildings were exposed to varying degrees of contamination with chemicals and radionuclide-containing substances. The use of mining waste and processing material as a building material – e.g., as aggregate for concrete – and the partial infiltration of radioactive and chemically contaminated solutions into the building fabric also led to high dose rate values of gamma radiation.

Planning documents were created for each building demolition, the relevant data were documented and archived. The demolition of larger and more complicated plants was carried out by tendering and awarding the service to external companies. The demolition work was essentially completed in 1996.

Table 4-11. *Scope of dismantling of buildings and operating facilities of Seelingstädt and Crossen plants, and uranium disposal*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum, 91/97
Dismantling and demolition of buildings and processing facilities										
Dismantling scrap	t	106,156	13,867	2,052	5,255	6,560	6,538	9,178	9,121	52,571
Demolition rubble	m^3	279,710	3,186	2,959	2,617	18,987	29,670	28,492	29,617	115,528
Disposal of uranium-containing materials										
“Königsteiner intermediate product”	t	471	---	162	189	16	51	53	---	471
Products of clean-up	t	14,095	---	---	5,164	6,641	1,000	1,290	---	14,095
Demolition rubble	t	29,588	---	---	---	---	4,880	24,708	---	29,588
Yellow Cake	t	1,140	---	73	280	393	260	134	---	1,140

Source: Chronicle Wismut 2010, https://www.wismut.de/de/veroeffentlichungen.php?id=614&back=veroeffentlichungen.php%3Fyear%3D0%26index%3D0

The radioactive materials resulting from dismantling and demolition work were later disposed of in accordance with official permits; crushed construction rubble was transported via the pipe conveyor from the mining waste dump to the Helmsdorf settling basin Contaminated scrap was placed in so-called cassette construction on fixed areas of the intermediately covered former flushing beach area of the settling plant. Wood and other contaminated demolition materials were also placed on selected areas and after specified compaction.

The asbestos cement panels were coated with foils in accordance with official requirements and disposed of with permission in the Schlema-Alberoda mine.

4.2.3.5 Remediation of operative plant areas - Seelingstädt

The area of the operative part (factory premises, connecting railway, pipe route, streets, and squares) was about 102 ha. The factory premises covered 83.3 ha, of which about 20% were built-up, the rest was free space with vegetation (lawns, shrubs, trees) or streets and squares. During the construction phase of the processing plant, the subsoil was relocated several times to compensate for morphological differences in the terrain and to deposit excavated masses from excavation pits. In addition to relocated materials from the subsoil, anthropogenic deposits in the form of processing residues (tailings), ore residues (mainly from the Ronneburg ore field) and large quantities of the relocated material from the Crossen mining waste and processing residues dump were also used for filling and as a construction aggregate. The thicknesses of this relocation and filling zone were sometimes several meters.

As part of the preparation of the Wismut environmental register, the entire operating area was examined; the data was documented and archived. The type and degree of contamination were found to be much differentiated, and they were significantly influenced by the respective process stage of the treatment (Wismut, 2010). The boundaries between the types of contamination were mostly blurred, as natural leaching processes between contaminants and rainwater caused changes in concentration. The soil tests carried out showed that the degree of contamination below 0.5 m was generally greatly reduced and that at about 1 m the contamination was on average below the exemption limit of 0.2 Bq/g according to VOAS.

Due to the contamination heterogeneity, each individual area was evaluated before the start of the remediation. Depending on the existing degree of contamination with radionuclides or other contaminants and in coordination with the municipalities and public interest bodies, the remediation of the operating areas was and still is carried out. So far, two remediation and custody options have been used:

- Application of a suitable cover on the sub-areas whose degree of contamination with radionuclides and the resulting hazards make this coverage necessary for the realization of the intended reuse.
- Excavation of surface areas heavily contaminated with radionuclides and subsequent transfer to basin A of the Culmitzsch settling plant. Subsequently, inert soil material was applied, which corresponds to the SSK recommendations for a succession landscape.

The transport technology was/is analogous to that of contaminated construction rubble. The loaded truck or dumper passed/passes through a tyre washing system when leaving the Seelingstädt premises and drove/drives along the service road to the settling plant. In the same way, radioactive contamination of areas, beds of former receiving streams or ditches and traffic routes outside the operating areas was/is excavated and disposed of in the settling plant.

4.2.3.6 Remediation of operative plant areas - Crossen

The area of the operative unit comprised several sub-areas (factory premises, connecting railway, pipe route, streets and squares) and amounts to approx. 30 ha, of which the factory premises approx. 21 ha, and it was intended to reuse it as a floodplain landscape in coordination with the Aue respectively Crossen municipality.

Extensive soil investigations had shown that areas on the factory premises contained anthropogenic deposits of different origins. These piles consisted of old deposits from the former paper production (ashes, slags, construction rubble) as well as material from the Crossen mining waste and tailings pile (Wismut, 2010).

The measurements and sampling of the soil for the preparation of the Wismut Environmental Cadastre showed that large parts of the area in the core area of the plant site were contaminated with radionuclides and arsenic. The reason for this was the use of Crossener mining waste and tailings dump material for the fastening of storage areas, as an underbed of roads and paths, as an aggregate for concrete and as filling material for terrain leveling. In addition, the soil was contaminated by uranium-containing ore residues, processing intermediates, solutions with various nuclide and other pollutants, as well as by overflows and leaks.

In order to further clarify the soil conditions and to develop remediation options for the plant areas, further technical and technological investigations and evaluations were carried out. As a result of the studies on the application of soil remediation methods, it was found that the remediation of the plant areas could largely only be carried out by mechanical soil excavation with subsequent re-deposition of inert soil substrates.

Studies have been carried out for possible safety measures with regard to the hydrological and hydrogeological insulation of certain areas. Further investigations into the quantity and pollutant balance of the water path have been undertaken in recent years.

The transport technology was analogous to that of contaminated construction rubble. In the same way, radioactive contamination of areas, beds of former receiving streams or ditches and traffic routes outside the operating areas were excavated and disposed.

4.2.3.7 Remediation of the industrial settling plants

The remediation of the industrial settling plants in southeastern Thuringia and western Saxony represented one of the greatest challenges in the rehabilitation of uranium ore mining remains. At the time of the cessation of uranium extraction in 1989, there were no technically, technologically and ecologically feasible ideas for the rehabilitation or safeguarding.

Wismut GmbH is responsible for the refurbishment of four industrial settling plants. These are the the Culmitzsch and Trünzig plants at the Seelingstädt site (Thuringia) and the Helmsdorf and Dänkritz 1 settling plants at the Crossen site near the city of Zwickau (Saxony). In these four plants, the fine-grained residues of uranium ore processing were flushed in via pipelines and stored. With the cessation of uranium ore extraction, the four plants covered an area of around 570 hectares.

Figure 4-19. *Remediation of industrial settling plant Trünzig.*

left: rinsing of fine sludges; right: settling plant Trünzig after the end of mining (1991)

Source: https://www.wismut.de/de/ nl-ronneburg_industrielle_absetzanlagen.php

The cessation of uranium ore processing in Seelingstädt and Crossen in 1989 had a negative impact, especially on the settling plants. Above all – due to gradually lowering the water level by evaporation and leakage – the flushing/ rinsing beach surfaces fell dry and thus increased wind erosion combined with contaminated dust drifts, as well as contaminated leachate flowed into receiving streams and aquifers.

<u>Immediate measures:</u> In the first years after the end of uranium extraction, immediate security measures had to be taken at all four locations. Exposed dried rinsing beaches were initially covered at short notice with mineral soil to reduce the blowing off of radioactive dust. To protect surface waters and aquifers, leachate catchments had been expanded and newly installed.

<u>Technology:</u> In parallel with these initial measures, various remediation options were investigated. The aim was the long-term safekeeping of the stored processing residues. These should guarantee a sufficient reduction in pollution, especially for the air and water path.

Neither nationally nor internationally had there been experience and investigations for settling plants of this size with the considerable potential of radium, uranium and arsenic as well as salts. Therefore, this difficult and at the same time complex task could only be tackled by uniting scientific-technical-technological investigations, carrying out experimental and pilot work, by sampling and constant measurements of contaminants and the degree of contamination, as well as effects on the environment (source Chronicle Wismut 2010).

From the outset, not only the competent authorities, but also national and international knowledge carriers were involved in order to solve this unique task in Europe. Three basic options for the possible safekeeping of the industrial settling plants were taken into account, extensively investigated and evaluated:

- Transfer of the tailings materials to another location to be prepared for final storage.
- Safeguarding of the tailings at the site without targeted technical measures to consolidate the tailings materials with the remaining residual lake, i.e. wet storage in situ, but with significant reinforcement of the lowest dam structures;
- On-site storage and safeguarding of the tailings using targeted measures to consolidate the tailings with the application of a final cover, i.e., dry storage in situ,

As a result of the investigations and based on the third option, the so-called dry in-situ safekeeping/storage was chosen as the most economical option.

The dry in-situ safekeeping/storage took place in several steps. In the first phase, the contaminated water covering the tailings, the so-called open water, was withdrawn and treated. The surface of the settling plant was then covered by a multi-layer system. Geotechnical aids such as geovlies, drainage grid mats and geogrids were placed on the exposed tailing areas.

In addition, so-called vertical drainage ducts, five-meter-long geotextile drainage wicks, were introduced. In the further course, an intermediate cover was applied to this load bearing working platform, which consisted mainly of tailings pile material. Due to the load on the tailings pile material, the effect of further dewatering was accelerated. The vertical drains created a waterway within the tailings. The pore water from the tailings was pressed out by the dead weight of the upper layers and applied covering materials and led to the surface via the vertical drains. Here the water collected and could be pumped out. The tailings were gradually drained and thus were more stable (Wismut, 2022).

The technique of drain drilling has been improved and adapted over the decades of application. In order to further advance the drainage even at greater depths and thus accelerate the setting of the tailings, up to 32 meters long deep drains were also introduced. This created the conditions for a comprehensive contouring of the IAA.

In the next work step, the final contour of the settling plant was created by foreset beds, by filling or removal of mineral materials in the dam and basin interior areas. In principle, this technology was and still is used at all four locations.

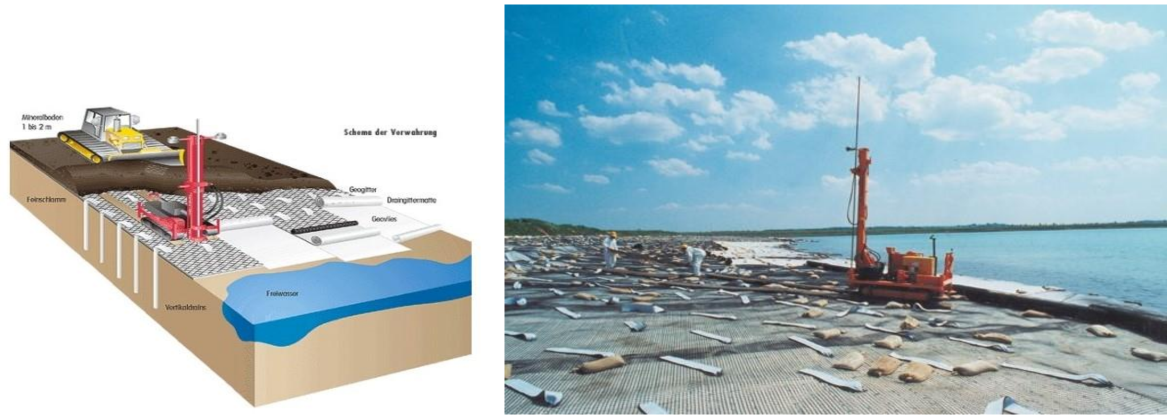


Figure 4-20. *Safekeeping of a settling plant.*

left: scheme, right: application of the intermediate cover.

Source: https://www.wismut.de/de/ nl-ronneburg_industrielle_absetzanlagen.php

At the IAA Helmsdorf and Culmitzsch settling plants, the rehabilitation technology of the intermediate cover was modified. Due to the difficult geotechnical conditions in the central areas of the basins, the very fine-grained sludges had to be stabilized before the water was withdrawn.

For this purpose, from a hopper barge floating on the free water surface free-flowing material (relocated mining waste and production residues material or gravel/sand) was applied in several thin layers onto the low-load-bearing bed of the water body or subground. This process was called subaquatic coverage and was performed from 2002 to 2003. A test cover had been successful at the IAA Helmsdorf in 1998. On basin A of the settling plant IAA Culmitzsch a group of boats was used since the spring of 2004 and this work was completed in the same year.

Contouring and completion of the remediation: Currently and in the coming years, the contour of the plants is being completed and provided with a final cover. In a further step, paths and water drains have to be built on the industrial settling plant surfaces. Finally, the resulting landscaping structures are greened and planted. The completion of the renovation is planned in Helmsdorf and Trünzig in the medium term and will take the longest in Culmitzsch. In order to secure the restructuring result, long-term tasks will be necessary.

With the increasing completion of areas, the need for care and maintenance on industrial settling plants increases. With the transition to the aftercare phase, they will become a major task. At the IAA Trünzig, care and maintenance expenses are already one of the current main tasks.

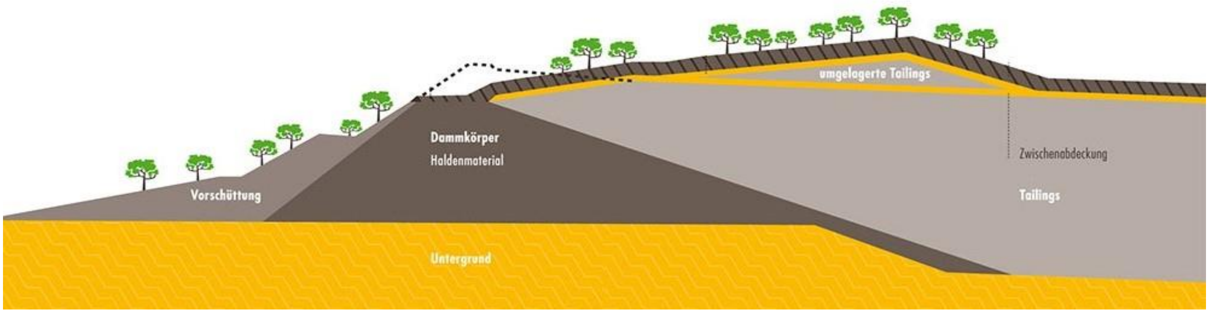


Figure 4-21. *Scheme of a completely remediated industrial settling plant*

Source: https://www.wismut.de/de/verwahrung_iaa.php

In 2020 and 2021, Wismut GmbH conducted an extensive study on the origin of the radionuclide lead (Pb)-210 in grass from the refurbished IAA Trünzig. So far, the areas have not been released for livestock farming, as a connection between the stored residues and the Pb-210 content in the grass was suspected. It has been demonstrated that this dose-relevant nuclide is subject to the same fluctuations at the IAA as in areas that have never been affected by uranium mining. This result confirms the high quality of the remediation. As a consequence of this study, the authority approved the unrestricted grazing of the area by farm animals, subject to subsequent sampling (Wismut, 2021).

4.2.4 Large Ecological Project SAXONIA Freiberg

The protection of the tailings is carried out by a cover, which has a different cover quality depending on the site. **Table 4-12** shows the differences of the cover groups.

The following requirements are placed on the cover materials:

- Cohesive soil materials
- Hydraulic conductivity ≤ 10-5 m/s
- Compacted in layer
- Stiff consistency (see DIN 18196)
- Installation limits depend on the background values and the contaminated site.
- The prohibition of deterioration and the improvement requirement apply (no new hazard potential).

Table 4-12. *Requirements - cover groups in the SAXONIA site project.*

cover group A	**modified cover group A** e.g. sludge dump Hammerberg	**cover group B/C** e.g. plateau of coarse tailings pile Davidschacht
	cover layer I (topsoil) 0.2 m	cover layer I (topsoil) 0.3 m
cover layer I (topsoil) 0.2 m	cover layer II (storage layer) 2-layer each 0.4 m	cover layer II (storage layer) 2-layer each 0.7 m
cover layer II (storage layer) 2-layer each 0.4 m	insulation layer (< 10^{-6} m/s) 2 x 0.50 m	drainage mat
		sealing layer (<10^{-8} m/s) here: Trisoplast ®(0.07 m)
leveling layer for profiling	leveling layer for profiling	leveling layer for profiling ≥ 0.2 m
dump material	dump material	dump material

Source: "Utilization of soil materials of the Freiberg area in the remediation of contaminated sites" presentation SAXONIA

For the filling of the layer of profiling and the cover layer, excavated soil of the same quality from the Freiberg area was used in the SAXONIA project. For the Freiberg area it is a question of four partial areas with the leading parameters arsenic, lead and cadmium. The concentrations are given in **Table 4-13.** The prohibition of deterioration is therefore fulfilled.

Table 4-13. *Background concentrations of arsenic and metals for the Freiberg region according to the soil planning area ordinance.*

concentration [mg/kg]	**subarea 1**	**subarea 2**	**subarea 3**	**subarea 4**
arsenic	< 57,5	≤ 265	≤ 790	> 790
cadmium	< 1,0	≤ 4,1	≤ 9,0	> 9,0
lead	< 175	≤ 765	≤ 1685	> 1685
concentrations	*slightly increased*	*increased*	*high*	*very high*

4.3 Remediation of mine-affected waters

4.3.1 Water Treatment Plants in Former Uranium Mining Areas of Wismut

The reference sites briefly presented in **Chapters 3.2.2** Dresden Coschütz/Gittersee, **Chapter 3.2.3** Königstein and **Chapter 3.2.4** Seelingstädt and Crossen already had plants for the treatment of water contaminated with pollutants during the operating period until 1989. These existing systems have been expanded by Wismut GmbH and constantly adapted to the new requirements.

The water treatment plants (WTP) in Dresden Coschütz/Gittersee were dismantled after completion of the rehabilitation work – the groundwater from the flooded pit cavities, which is only slightly polluted, flows into the Elbe in a controlled manner via the Wismut-Stolln and the Tiefer-Elbstolln. In Crossen, too, after the demolition of the operating facilities and the relocation of the mining waste and production residues pile material, no larger plant is necessary for the water flowing into the receiver Zwickauer Mulde.

Wismut GmbH currently operates six water treatment plants in Saxony and Thuringia, in which the relevant pollutants are removed by chemical/physical processes.

In the following text, the existing – and also active in future – plants Seelingstädt and Helmsdorf (the first for the reference site Seelingstädt and the second for the mining waste and production residues dump Dänkritz, where the contaminated material of the reference site Crossen is now stored), Ronneburg (for the mining district Ronneburg) and Königstein (for the reference site of the same name) are presented (Wismut, 2010).

Water treatment plants in Seelingstädt and Helmsdorf

Figure 4-22. *Water treatment plant WTP in Seelingstädt*

Source: https://www.wismut.de/de/ pressefotos.php, 05.04.2011

In the WTP Seelingstädt the water of the former industrial settling basins Culmitzsch and Trünzig is treated. These are still existing free surface water from the Culmitzsch site as well as escaping leachate that is collected in the vicinity of both settling plants. The waters to be treated have a slightly alkaline character. The main pollutants that need to be removed are uranium, radium and conditionally arsenic. The resulting residues are solidified with cement and stored at prepared points in the area of the Culmitzsch settling plant. The treated waters are finally discharged into the Culmitzsch rivulet. The WTP is designed for a throughput of up to 330 m³/h. Its operating life will be over 20 years.

The WTP Helmsdorf treats the water produced by the industrial settling plants at the site. These are temporarily available free surface water and the accumulating and collected leachate in the vicinity of the settling plants. The waters to be treated have a slightly alkaline character and are characterized by relatively high levels of arsenic and uranium. Radium is also specifically separated here. The residues of the water treatment are immobilized with ash and cement and stored at designated places in the area of the Helmsdorf settling plant. The treated waters are discharged directly into the Zwickauer Mulde river. The throughput of the WBA is approx. 200 m³/h. It is estimated that it will be necessary to treat water at the Helmsdorf site for several years to come.

The WTP Helmsdorf, which operated from 1995 to 2021, was replaced by a new facility in 2021. This had become necessary in order to be able to replace the applied "modified lime precipitation process" with the "ion exchange and adsorption" process. This entails a reduction in capacity from 200 m^3/h to 80 m^3/h. Here, water pollutants are removed by means of certain ion exchange resins and so-called adsorbers. The pollutant attached to the resin (especially uranium) can be chemically removed by it. The resin is regenerated and can therefore be used several times. This method was used by Wismut GmbH at the Königstein site to separate the uranium from the flooding water until 2021. In the newly built water treatment in Helmsdorf, this process is now also used to remove pollutants in a targeted and largely automated manner and to reduce the amount of residual material. The adsorber (Ferrosorp) is also used to separate arsenic and radium.

Due to the slow decline in pollutant concentrations in the collected waters, water treatment is a long-term task that must be carried out for many years to decades. The necessary expenses represent the predominant share of the costs for the aftercare of the remediated objects.

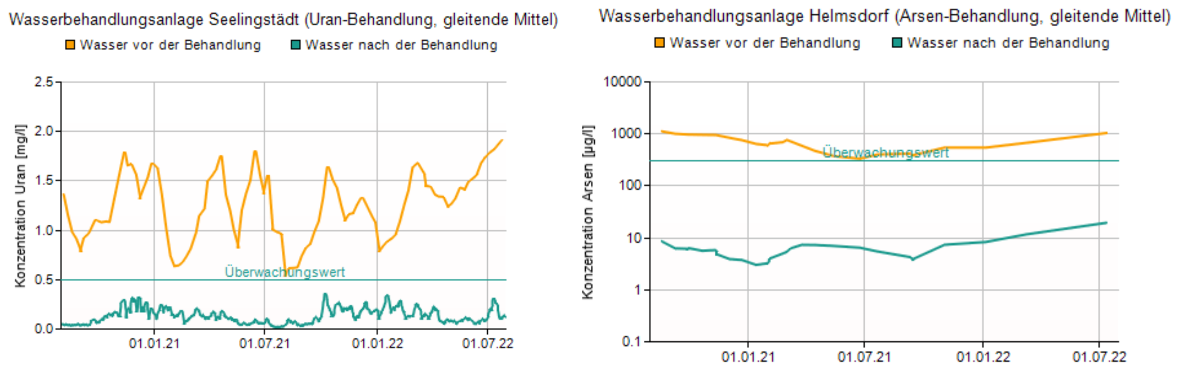


Figure 4-23. *Efficiency of the WTP Seelingstädt and Helmsdorf.*

Left: uranium content (mg/L) at Seelingstädt, right: arsenic content (µg/L) at Helmsdorf.

NOTE: Orange curves: water intake and green-blue curves: means after treatment; green horizontal line means allowed outlet limit value.

Sources:https://www.wismut.de/de/sanierung_messungenstandorte.php?station=seelingstaedt and https://www.wismut.de/de/sanierung_messungen-standorte.php?station=helmsdorf

WTP Seelingstädt: The concentration of the radioactive substance uranium in the water to be treated (orange curve in **Figure 4-23**) varies depending on the mixture proportions of basin/precipitation as well as collected leachate and pore water of the settling plant. In the process of water treatment, this is reduced by an average of about one order of magnitude (green-blue curve). The cleaning performance is geared towards the safe adherence to the officially defined monitoring limit value in the discharge water. In 2021, about 255 m³ of water per hour were treated and then released into the Culmitzsch rivulet. The necessity of water treatment will only be eliminated in the future if pore water no longer has to be pumped after completion of the remediation and the leaking leachate is insignificant in terms of quantity and concentration (Wismut, N.d. 1).

WTP Helmsdorf: The concentration of the substance arsenic known as toxic in the water to be treated varies depending on the mixture proportions of the collected leachate and surface waters from the subsoil and surroundings (orange curve in **Figure 4-23**). In the process of water treatment, this is reduced by about two orders of magnitude (green-blue curve). The cleaning performance is primarily geared towards compliance with the officially defined monitoring value in the discharge water. The cleaning performance is primarily geared towards compliance with the officially defined monitoring limit value in the discharge water. On average, about 21 m³ of water per hour were treated with the existing plant in 2021 and then discharged into the Zwickauer Mulde.

The need for water treatment in the WTP Helmsdorf will be eliminated in the future if, after completion of the remediation, the settling basins Helmsdorf and Dänkritz I are completely covered, or the leaking leachate is insignificant in terms of quantity and concentration.

Water Treatment Plant in Ronneburg

Figure 4-24. *Water treatment plant WTP in Ronneburg with the area for storage of immobilized pollutants behind.*

Source: https://www.wismut.de/de/pressefotos.php, 05.06.2015

The water treatment plant WTP Ronneburg hasn't been mentioned in the chapters before, but is included here to complete the survey, because it uses a different cleaning process and part of the immobilised residues of other WTP's are deposited here.

In the WTP Ronneburg, the water produced during the flooding of the underground mine workings is treated. This mine water is a typical mining water, which is characterized by a pH value in the acidic range and high heavy metal contents (especially iron, nickel, zinc). In contrast to the tasks of the other WTP's of Wismut GmbH, the radioactive components play a less important role. The flooding water is supplied to the WTP Ronneburg via a water catchment in the Gessental valley. The discharge of the treated water takes place via the Wipse trench into the Wipse. As determined in a forecast, in 2006 the water catchment/ intake in the Gessental was activated and the treatment plant was put into operation. The plant is currently capable of treating approximately 850 cubic meters of contaminated mine water per hour. An operating life of up to 25 years is expected.

Water treatment plant in Königstein

During the controlled flooding of the Königstein mine, the mine water contaminated with pollutants must be lifted and treated. Only then may these waters be discharged into the receiving water (Wismut, 2010).

From 2001 to 2021, the plant used an ion exchange-based process (see description of the WTP Helmsdorf) – mainly to separate and sell the uranium. In addition, lime precipitation with partial sludge recirculation / HDS process was used. The decreasing uranium contents made it possible - after prior testing - to convert the plant completely to lime precipitation with partial sludge recirculation / HDS process. The converted WTP went into regular operation in 2021. The complete cleaning of the flooding water now runs through the new system (Wismut, 2021).

Figure 4-25. *Water treatment plant WTP in Königstein with settling bassins prior to water discharge to the Elbe river*

Source: https://www.wismut.de/de/nl-koenigstein_wasserbehandlung.php

In the plant, uranium, radium and heavy metals are removed from the water by means of lime precipitation processes. After settling the solids in the thickener and clarifying the treated water in a special basin called “Klarwasserschönungsbecken” (clear water advanced treatment basin), it is discharged into the Elbe. The dewatered residues are deposited in the special storage area of the Schüsselgrund mining waste disposal facility in such a way that they cannot pose a risk to humans or the environment.

In order to maintain the flooding level in 2021, approximately 1.8 million m³ of flooding water had to be extracted. A very small part was plunged back into the pit untreated during the trial operation of the converted WTP for technological reasons. The throughput of the converted WTP in 2021 amounted to almost 2 million m³ of water. This includes the flood water and about 0.35 million m³ of surface water. The treated water flowed into the Elbe. The converted WTP requires significantly less energy than the old system. Above all, the rearrangement of the process stages, which avoid "uphill" conveying within the water treatment, improved energy efficiency. (Wismut, 2021)

Due to the current approval situation, the treatment of flooding water of the same order of magnitude as before will remain necessary for an indefinite period of time.

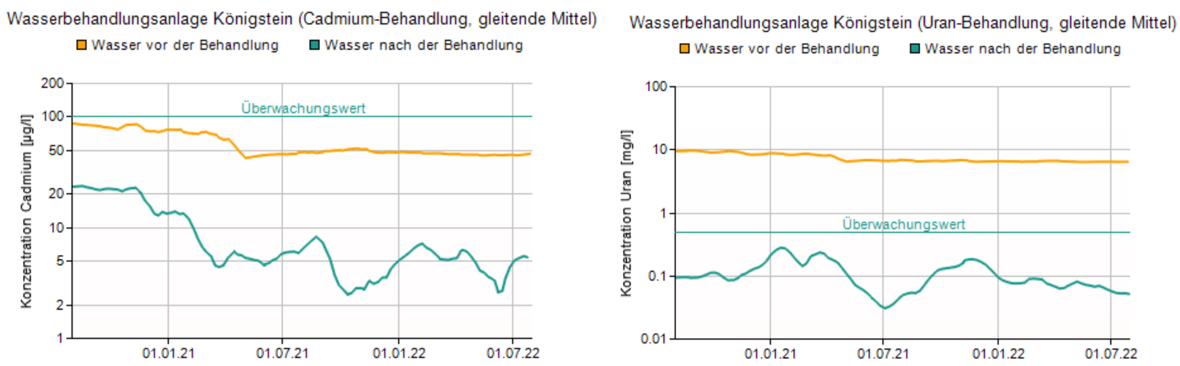


Figure 4-26. *WTP Königstein,*

left: cadmium content (µg/L), right: uranium content (mg/L).

NOTE: Orange curves: water intake and green-blue curves: means after treatment; green horizontal line means allowed outlet limit value.

Source: https://www.wismut.de/de/ sanierung_messungen-standorte.php?station=koenigstein

The concentration of the heavy metal cadmium in the flooding water (orange curve in **Figure 4-26**) varies depending on the flooding process. After initially very high inlet concentrations of more than 1,000 µg/L, the cadmium concentration has been 50-100 µg/L for several years due to leaching effects and thus below the permissible discharge value. The years 2020 and 2021 were marked by the implementation of the trial operation of the converted water treatment plant. Despite changed technology, the cadmium concentration could be reduced to about a quarter to a tenth and thus an additional positive effect on the pollutant load in the Elbe could be achieved (green-blue curve). In 2021, an average of about 214 m³ of water per hour was released into the Elbe. Further amounts of purified water were re-filtered into the pit. In the long term, the need for water treatment is eliminated if the flooded pit spaces do not pose an impermissible threat to surrounding protected goods.

The concentration of the radioactive substance uranium in the flood water (orange curve in **Figure 4-26**) varies depending on the flooding process. After initially very high inlet concentrations of more than 250 mg/L, the uranium concentration is currently around 7 mg/l due to leaching effects. The years 2020 and 2021 were marked by the implementation of the trial operation of the converted water treatment plant, in which no separate uranium separation takes place. Despite changed technology, the uranium concentration could be reduced by up to two orders of magnitude and thus the officially defined monitoring values could be reliably adhered to (green-blue curve).

Figure 4-27. *High-performance thickener at WTB Königstein.*

Source: https://www.wismut.de/de/nl-koenigstein_wasserbehandlung.php

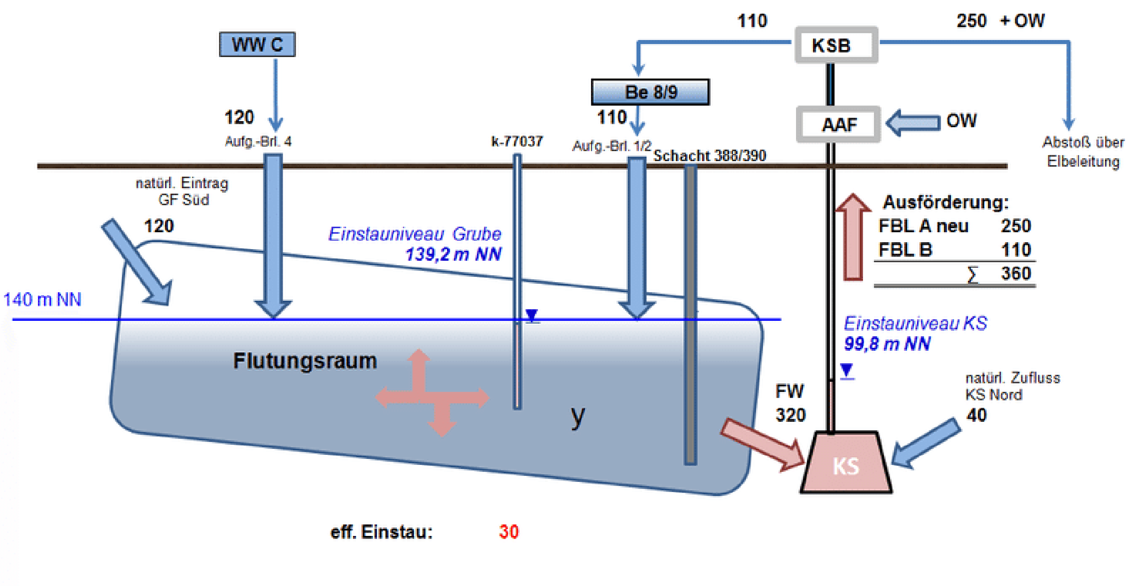


Figure 4-28. *Diagram of the current water management of the Königstein mine.*

Source: https://www.researchgate.net/figure/ Abb-2-Schema-des-aktuellen-Wassermanagements-der-Grube-Koenigstein-Im-Rahmen-der-Flutung_fig1_322024717/download

4.3.2 Leakage and Seepage Water Treatment plant at Bielatal tailing site

Water treatment tasks

Installation of a water treatment plant has been planned to reduce arsenic input to the Biela creek from leakage and seepage water of the Bielatal tailing area. A medium leakage water flux of 50 m³/h needs to be treated. The planning results have been confirmed by the authorities. Currently, the plant construction is preparing.

The mean *input leakage water quality* parameters for the plant design are:

- Arsenic 1.0 mg/L
- Iron (total) 2.5 mg/L
- Total dissolved solids TDS 160 mg/L
- pH 7.2

According to the statements of the water authorities, dissolved arsenic at the *output of the treatment plant* needs to be < 0.4 mg/L. Arsenic but also copper and zinc have to be controlled in the TDS fraction (<63 µm fraction), too. Considering background concentrations, TDS values have to comply with the following allowed limit values: Arsenic 123 mg/kg, Copper 197 mg/kg, and Zinc 800 mg/kg. An exclusive permission of the EU water authorities was needed for the safety of the downstream region. Sludge treatment requires a thickening in the sedimentation stage (up to of 0.9% of dry matter) and a maximum dry matter content of 8% for the sludge thickener.

Basic process engineering concept

The entire system is planned to treat leachate influenced by mining built. The leachate is collected in a leachate ditch and is supplied to the intake and distribution structure. During rainfall, the intake flux can exceed the treatment capacity. The excess water is then discharged via the overflow of a seepage ditch into the drainage channel. After the separation stage, the seepage water is treated chemically. This is carried out in two lanes with redundancy. The first basins of chemical cleaning serve for degassing (aeration) and mixing by bubbling in air. A flocculant is added in a second step to a reaction tank for flocculation. The iron-arsenic flakes are separated from the leachate by sedimentation. The leachate is then passed through a lamella separator and the cleaned water is put out to the drainage channel. The sludge from the sedimentation is first thickened and then stored. For sludge disposal a mobile dewatering system is available.

Object 1 - intake and distribution: It is designed as a monolithic reinforced concrete structure with external dimensions of L(ength) x W(idth) x H(eigth) = 9.7 m x 3.9 m x 1.5 m. If necessary, leachate streams A, B, and C can be separated at the basin chambers by a valve system. Low contaminated leachates can also bypass the plant via a Thomson weir. The intake areas are equipped with coarse screens.

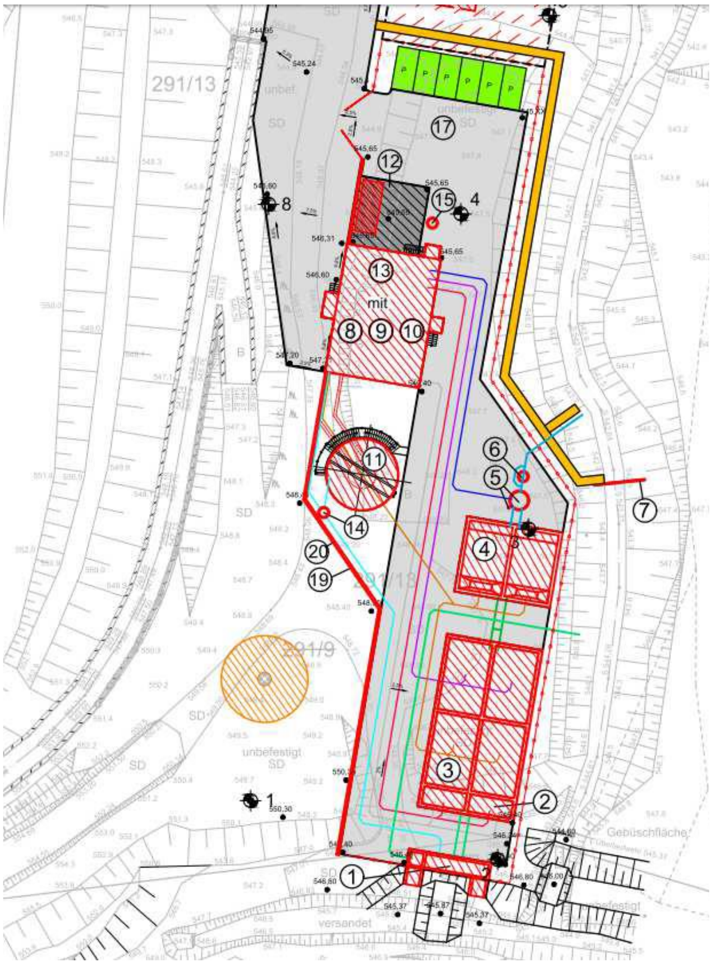
Object 2 - Chemical treatment: The chemical treatment consists of a compact structure, which is divided into an aeration and mixing tank (TO2.1) and a reaction tank (TO2.2).

Object 3 – Sedimentation: Separation of iron-arsenic flakes occurs in rectangular, horizontally-upward flow sedimentation tanks with inclined separators. The sedimentation basin is a monolithic reinforced concrete settling basin with a funnel and freeboard. The basin volume is V = 100 m³ (L x W x H = 8.0 x 3.5 x 3.5 m). The pre-thickened sediments are taken from the extraction funnel and iron hydroxide slurry is pumped to a sludge storage tank for thickening.

Settling and thickening properties can be improved by an optional sludge return. The cleaned water is drawn off to the Clear water drainage channel and to the seepage water ditch.

Objects 4 and 6 – flocculation plant and flocculant supply: The flocculant (Fe-III-chloride) is delivered to a PE storage silo (V = 25 m³). The flocculant supply (processing, dosing and conveyor technology) is located in the operation building. The flocculant solution is stored in a container (V = 1 m³). The stock solution is further mixed with process water in a static mixer and conveyed to the dosing point of the aeration and mixing basin.

Object 7 - Sludge treatment: It consists of a Sludge Thickening and Storage (TO7.1) and a Sludge Dewatering and Conditioning section (TO7.2). The volume of sedimentation sludge containing arsenic is further reduced by a thickener (closed sludge storage tank as a concrete construction with PE-HD multi-wall sheets). The inner diameter of the tank is t 7.5 m. Filtrate is removed via an automatic water extraction and returned to processing. The sludge can circulate there to improve the thickening. The storage time is designed for four months and the necessary storage volume is of 250 m³. Visual inspection and measuring can be performed in the operation building for leaks and all process streams. The sludge dewatering and conditioning is carried out by a mobile system. A sealed area is planned for this. The drainage channel is connected to the lowest tip of this area by means of a PE-HD pipeline.



1. Intake and distribution
2. Aeration and mixing
3. Reaction tank
4. Sedimentation basin
5. Process water storage
6. Flux measurement slot
7. Thomson Weir
11. Sludge storage and thickening tank
13. Operation building with chemical storage and flocculation plant.

Figure 4-29. *Water and sludge treatment plant for Bielatal tailing arsenic leakage.*

Source: LMBV mbH and PROWA GmbH (see appendix 1)

4.3.3 Passive Mine Water Treatment in Force Crag (United Kingdom)

Force Crag Mine is an abandoned underground mine located in the Lake District National Park, Cumbria (United Kingdom). For years it was considered as a major source of metal pollution to local waterways. The mineralogy of the deposit is dominated by barite ($BaSO_4$), galena (PbS) and sphalerite (ZnS); from 1835 to 1991 the single mine was mined using 9 interconnected levels which were numbered in sequence according to their elevation, with level 0 being the lowest (Mayes et al., 2021). Currently, the drainage from this mine flows through “Level 1 (Level One)” to a treatment system. According to the research of Jarvis et al. (2015), Gandy et al. (2021) and Mayes et al. (2021), this effluent has low concentrations of the major ions, however it has a high concentration of zinc, in the range of 1253 to 4600 µg/L; in 2014, a passive treatment system was implemented with the objective of removing zinc, which reached an overall efficiency between 70 and 99%.

The **passive treatment system at Force Crag** consists in a combination of two technologies, as a first stage two downwards flow compost bioreactor, or **Vertical Flow Pond (VFP)** which operate in parallel and afterwards one **wetland** (**Figure 4-30**, **Table 4-14**). The design takes up minimal space due to terrain limitations, which is very common in mountainous regions with steep topography (Wilson et al., 2010). In addition, waste from other industries and compost are used in construction as a substrate for VFP, this compost provides a carbon source and anoxic conditions for the development of bacterial sulfate reduction which immobilize the main polluting metals such as zinc, lead and cadmium (Gandy et al., 2021).

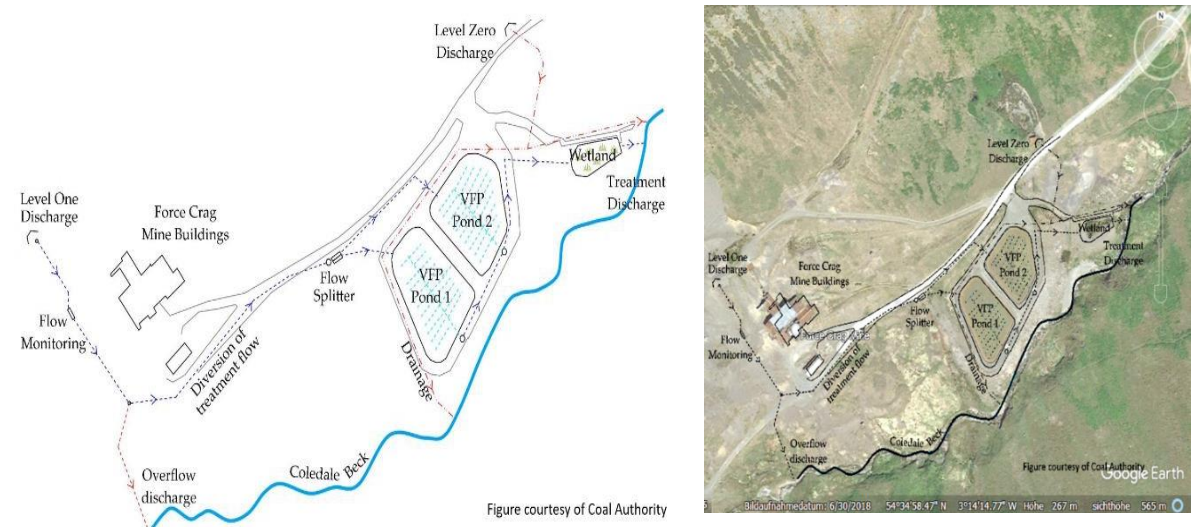


Figure 4-30. *Layout and spatial distribution of the Force Crag treatment system.*

Source: Jarvis (2015)

As shown in **Figure 4-31**, each VFP is lined with High-density polyethylene (HDPE) to prevent leakage and has at its base 4 perforated pipe networks, which are covered by a 200 mm layer of limestone and a 500 mm layer of compost substrate. The pipes pass into a manhole, in which a 350 mm water cover must be ensure (Jarvis et al., 2015)

Table 4-14. *Features of the Force Crag Mine water treatment system*

	VFP Pond 1	VFP Pond 2	Wetland
Flow rate	3 L/s	3 L/s	6 L/s
Area	760 m^2	760 m^2	
Volume	400 m^3	400 m^3	6 L/s
Internal slope	1:2,5	1:2,5	-
Hydraulic residence	15 -20 h	15 -20 h	-
Substrate	840 m^3. Mix of 45% wood chip, 45% municipal waste compost and 10% digested sewage sludge.		
Overall System Efficiency	97,8 % zinc; from a mean of 3,660 µg/L to a mean of 80 µg/L		
	90,6% cadmium; from a mean of 15.1 µg/L to a mean of 1.25 µg/L		
	91% lead; from a mean of 38,3 µg/L to a mean of 3,67 µg/L		

Source: Adapted from Bailey et al (2016), Gandy et al. (2021) and Mayes et al. (2021)

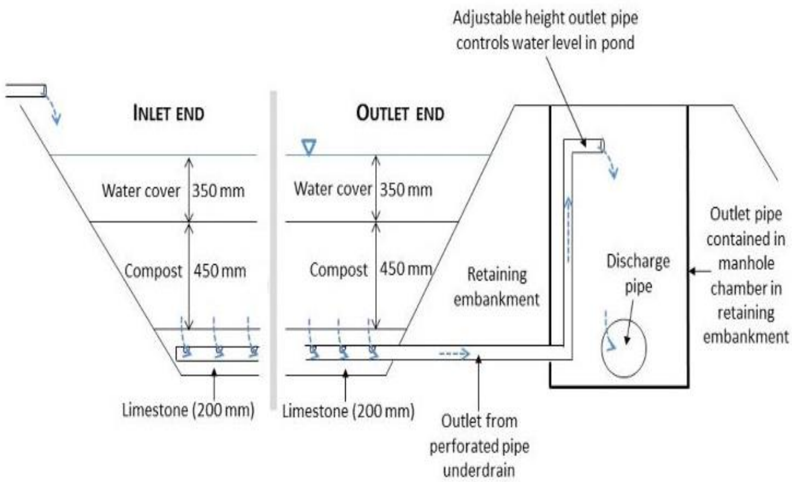


Figure 4-31. *Design of the Vertical Flow Pond (VFP) implemented in Force Crag*

Source: Jarvis (2016), https://bc-mlard.ca/files/presentations/2016-21-JARVIS-WATSON-operations-maintenance-downward-flow-compost.pdf

As reported by Mayes et al. (2021), during the operation of the passive treatment system a progressive decrease in the efficiency and a synchronous increase of the water level in the ponds was observed, also a dense formation of algae was noticed, these conditions indicated a possible reduction in the permeability of the medium, which prevented the water from flowing through the medium properly generated anoxic zones, as a response a routine cleaning of the algae was performed after which the water level decreased. In addition, after a period of cessation of treatment, the overall efficiency was reduced to 70% on day 1596 (4 years and 4 months approximately) of operation, therefore the substrate composed of a mixture of compost and wood chips was completely renewed, the latter improved the permeability of the substrate. After this improvement, the efficiency of the whole passive treatment system gradually recovered to 99%.

4.3.4 Pre-selection of suitable methods to apply in peruvian conditions

In order to preselect treatment methods suitable for their application in peruvian conditions, a quantitative comparison between methods must be done. Criteria for selection of methods previously discussed in section 2.4 was assessed and relevant criteria for their applicability in Peru were selected. The selected criteria were the following:

Criteria from site characteristics:

- **Spectrum of pollutants:** The capacity of each treatment method to act on a certain spectrum of pollutants is relevant to determine. According to the report presented by the Peruvian National Water Authority (ANA, 2015), based on the continuous water quality monitoring of 98 basins, concentrations of certain elements were detected to be exceeding environmental quality standards. From these pollutants, those related to mining activity are: **aluminum, arsenic, cadmium, copper, iron, manganese, lead, zinc** and **sulfate**.

Criteria from treatment feature:

- **Volume flow capacity:** Different treatment methods are more or less sensitive to variations in input flow rate. Higher or lower flow rates can determine the proper treatment method. During extreme events of rainfall, the design capacity of a water treatment system may be exceeded. In these cases, agreements can be made with authorities and stakeholders to by-pass the treatment in order to preserve the treatment facilities. High flow rates from these events may cause dilution of pollutants, decreasing concentrations. Treatment plants are not designed with capacities for extreme events since this would increase costs considerably. Although it is an important criterion for selecting a proper water treatment method, it is very dependent on the specific characteristics of each case, and a general evaluation of this criteria is not suitable. Therefore, it will not be included in the quantitative evaluation, but it must be considered as an important criterion.

- **Financing:** Investment required for the implementation and operation of the water treatment project. Expenses can be divided into:

    - **Capital expenses (CAPEX):** Materials, equipment, etc.
    - **Operating costs (OPEX):** Energy, staff, monitoring, maintenance.

  Each division of costs is considered separately for the quantitative evaluation of treatment methods. Capital expenses are considered to have a bigger weight on scoring, while operating costs have a lower weight. This is due to the fact that labor cost is lower in Peru, compared to Germany. Minimum weight in Peru by 2022 is approximately USD 280 (Supreme Decree Nº 003-2022-TR), considering 48 hours workload.

Each criterion is assigned with a weight value, as follows:

- Spectrum of pollutants: 40%
- CAPEX: 40%
- OPEX: 20%

Table 4-15 shows the assigned scores for each criterion, while the quantitative evaluation of water treatment methods presented in section 2.4.2 is presented in **Table 4-16**. Each criterion was given a score, and then weighted to obtain a total score. **Higher scores represent more appropriate methods for their application**.

Table 4-15. *Evaluation criteria and corresponding scores.*

Score	Spectrum of pollutants	CAPEX	OPEX
1	1 pollutant with limitations (pre-treatment required)	High / Undefined (only pilot plant available)	High
2	1 pollutant	High - medium	High - medium
3	2 pollutants	Medium	Medium
4	3 pollutants	Medium - low	Medium - low
5	All range	Low	Low

Table 4-16. *Scoring methods according to the criteria applicable in Peru.*

N°	Methods	Spectrum of pollutants (40%)	CAPEX (40%)	OPEX (20%)	Total (100%)
1	**Autotrophic sulphate reduction**	4	2	2	2.8
2	**Heterotrophic sulphate reduction**	4	2	3	3.0
3	**In-situ reactive barriers**	4	2	3	3.0
4	**Aerobically constructed wetlands**	3	3	5	3.4
5	**Anaerobic constructed wetlands**	3	3	5	3.4
6	**Schwertmannite process**	3	2	3	2.6
7	**Membrane process (nanofiltration)**	2	1	3	1.8
8	**Reaction carpets for surface waters inflow treatment**	3	3	3	3.0
9	**Oxidative mine water treatment**	4	2	4	3.2
10	**Membrane electrolysis**	3	1	3	2.2
11	**In-Lake Reactors for reductive sulphate separation**	4	1	3	2.6
12	**In-Lake process for water neutralization**	2	2	3	2.2
13	**Lake Conditioning**	2	1	2	1.6

Based on the results from the quantitative comparison, the three highest scoring methods were pre-selected for their applicability in Peru: aerobic constructed wetlands, anaerobic constructed wetlands, and oxidative mine water treatment.

4.3.4.1 Aerobic constructed wetlands

Aerobic constructed wetlands are ecosystems made to resemble natural wetlands. They consist of a barrier to prevent seepage (impermeable sediments or synthetic liner), flow control structures, and soil for roots support. Aerobic wetlands can be divided in two types (GTK, 2022, **Figure 4-32**):

1) Free water surface flow wetlands, and
2) Subsurface flow wetlands, which can be subdivided into:
    a. Horizontal flow
    b. Vertical flow

Pollutants are immobilized in a controlled environment by exploiting processes of natural wetlands. Iron, aluminum, and manganese oxidation by atmospheric oxygen is the main process, with subsequent precipitation of (oxy)hydroxides (DGFZ, 2018).

Iron oxidation is (micro-)biologically catalyzed through biological surfaces and biofilms. Microbial iron oxidation and further induced reactions immobilize various pollutants from the water phase into solid phase (DGFZ, 2018 and references therein). Reactions include:

- Microbially catalyzed **oxidation** of iron-II. Manganese-II reduction is also achieved when dissolved iron concentrations are below 5 mg/L,
- **Filtration** of colloidal pollutants through plant and soil filtration,
- **Sorption** (e.g., surface complexation) of other metal(-oid)s on the resulting iron/manganese (oxi)hydroxides,

Suitable planting with macrophytes is particularly important, since they will increase oxygen transport into the root zone, ensure filtration of the precipitated iron phases and control the flow rate and prevent hydraulic discontinuities (DGFZ, 2018).

Co-precipitation of ionic species as arsenic and molybdenum is also enhanced. Aerobic wetlands are effective for iron-rich mine waters treatment, however with limited capacity for acidic neutralization (GTK, 2022 and references therein).

Removal rates range between 10 to 20 g/d/m² for iron, and 0.5 to 1 g/d/m² for manganese (Hedin et al. 1994, Watzlaf et al. 2004, Younger et al. 2004). In addition, reduction of biological oxygen demand, coliform bacteria and cyanide oxidation can also be achieved (Wolkersdorfer 2008, Gusek & Figueroa 2009).

Aerobic wetlands consist of shallow ponds, these can be constructed or natural and are filled with gravel, soil and organic substrate for plant growth. Maximum water depth is commonly 30 cm. Water level is maintained by pipes and hydraulic controls, allowing aeration. In case aeration needs to be enhanced, this can be achieved by cascades, riffles, or falls between consecutive cells. As a general rule, higher iron contents require higher aeration steps (GTK, 2022).

This method is not adequate as a single stage treatment method for mine waters. Waters to be treated must be iron-rich, net alkaline and pH should be above 5.5 (DGFZ, 2018). Wetlands are most effective when constructed as a hybrid wetland system, incorporating surface flow wetlands with vertical and horizontal flow wetlands combined, complementing the advantages and disadvantages of each method (GTK, 2022 and references therein). Pre-aeration and sedimentation stages can also be implemented prior to wetlands (DGFZ, 2018).

Wetlands are cost-effective and long-term, compared to other passive water treatment methods. Pumping costs are low to non-existent and sludge removal is only necessary every

10-20 years, thus having low maintenance costs (DGFZ, 2018). Large storage volumes allow to easily control flow rates. In addition to water treatment, wetlands serve as a method of wildlife and landscape remediation (GTK, 2022). Disadvantages of this method are clogging of pipelines by iron precipitation, inability of sulfate immobilization, requirement of large areas for construction, and sensibility to weather conditions (e.g., freezing or lower efficiency during winter conditions).

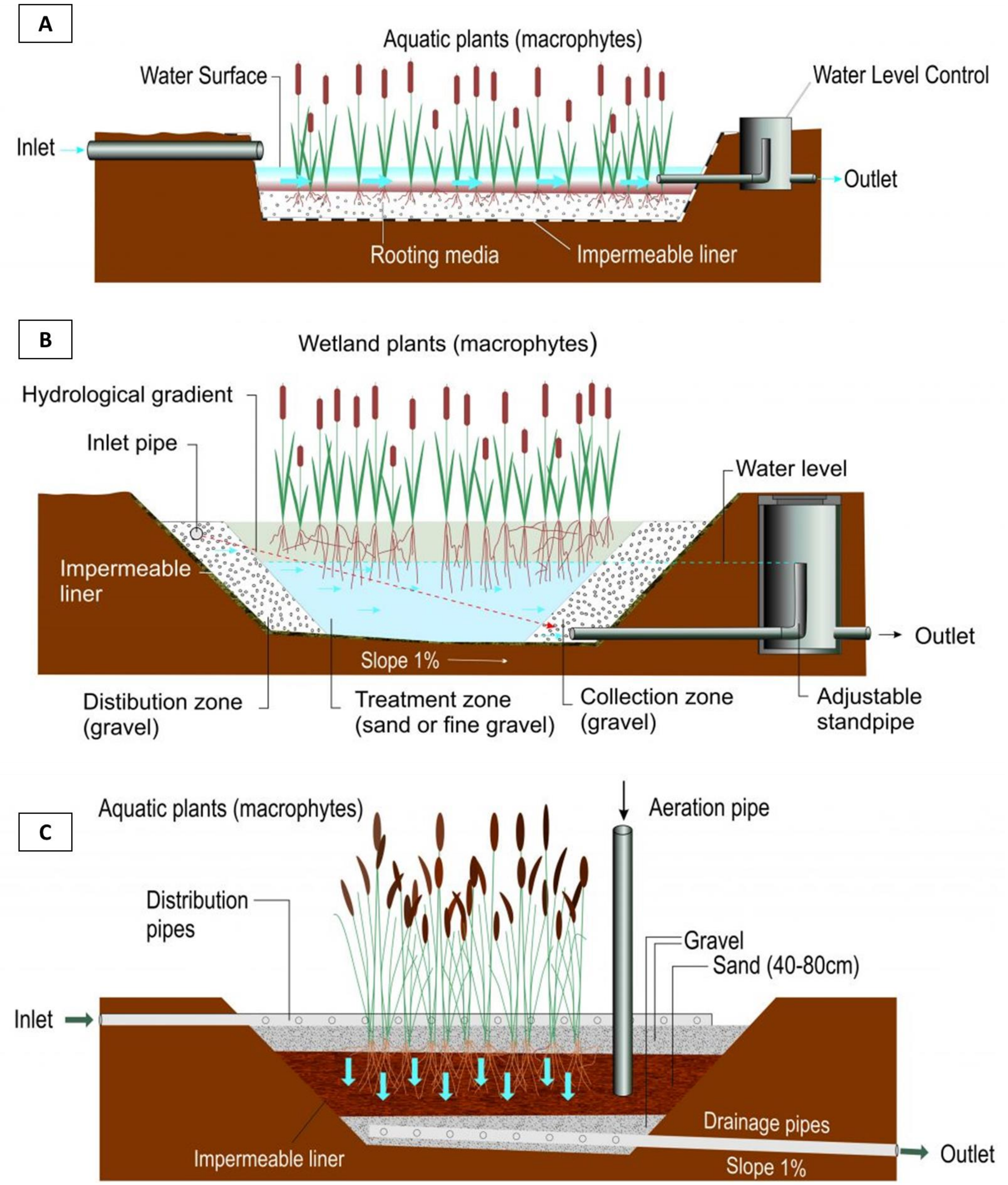


Figure 4-32. *Schematic diagram of common types of constructed wetlands.*

A: Free water surface flow. B: Horizontal flow. C: Vertical flow.

Source: GTK (2022)

4.3.4.2 Anaerobic constructed wetlands

Anaerobic constructed wetlands are similar to aerobically constructed wetlands, but with the main difference that an anaerobic environment is created for water treatment. Mine water flow is directed through the soil layer (substrate), where sulfate reduction takes place. Substrate acts as a carbon source and oxygen influx to the organic layer must be avoided for the reductive process to take place. Aerobic zones are always found in the upper zone of anaerobic wetlands due to the contact with the atmosphere (DGFZ, 2018). Typical substrates include (DGFZ, 2018 and references therein): mushroom culture substrate, sawdust, straw, hay, horse manure, or municipal waste.

Anaerobically constructed wetlands have thicker layer of organic substrate (0.3 – 0.6 m) and thinner layer of free-standing water (0-8 cm) than aerobic wetlands (GTK, 2022 and references therein; see **Figure 4-33**). Wetlands are not always planted, although the presence of macrophytes offers advantages, as detailed in aerobic constructed wetlands (DGFZ, 2018). Lime is often added to the substrate, in order to increase alkalinity.

The main process involved in anaerobic constructed wetlands is the microbial induced sulfate and iron reduction by the organic substrate, with subsequent precipitation of metal sulfides (e.g., iron, cadmium, lead, and zinc), co-precipitation of arsenic in iron sulfides. In addition, the same processes as in aerobically constructed wetlands occur in the upper layer in which oxygen may be present and aerobic zone can always be found (DGFZ, 2018). A complex community of microorganisms is developed. Degradation of organic matter to short-chain carbon sources usable for sulfate reduction is also relevant (DGFZ, 2018).

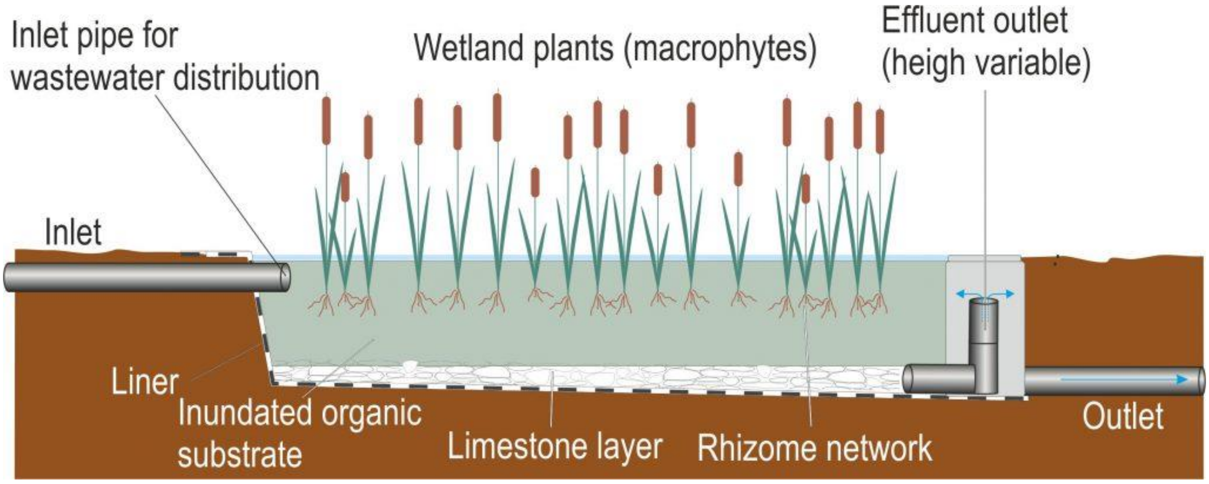


Figure 4-33. *Schematic diagram of anaerobic constructed wetlands.*

Source: GTK (2020)

Typical removal rates are 10 g/d/m² for iron and 3.5 g/d/m² for acidity. Also, sulfate reduction is often < 20% (DGFZ, 2018). The optimal pH range for anaerobic wetlands is 6 – 9 and show better results when used to treat low flows of waters with moderate water quality and higher net alkalinity than acidity. Water depth is an important factor for anaerobic wetlands process: if water depth is too deep, exchange between water and substrate will be reduced, causing a decrease in efficiency. Also, if substrate's permeability is low (K: 0.01 – 1 m/d), water flow will be mainly above the substrate layer, and microbially catalyzed reducing reactions won't take place, thus decreasing the efficiency of treatment (GTK, 2022).

Anaerobic wetlands operational costs are low and can also be used as wildlife and landscape remediation measures. If performance decreases, organic matter may need to be added.

Otherwise, operation and maintenance costs are fairly low. Boundary conditions affecting effectiveness include (DGFZ, 2018): maintenance of anaerobic conditions during operation, provision of continuously available carbon source, and high residence times

Unlike aerobic wetlands, anaerobic wetlands are less sensitive to cold weather conditions, and can operate in winter (GTK, 2022).

4.3.4.3 Oxidative mine water treatment

Oxidative mine water treatment is a common active water treatment method for mine waters. Metal removal and neutralization of waters is achieved by an increase in pH and oxidative conditions. This technique is used for metals with low solubility that form oxides/hydroxides in a controlled pH/Eh spectrum. Of particular relevance to mining are iron, aluminum and manganese. Copper, nickel, and zinc form hydroxides at higher pH values, and tend to be deposited by sorption processes onto the hydroxide slurries of other metals (DGFZ, 2012).

Neutralization agent is usually added as water slurry for increasing pH to a value at which solubility of target pollutants have low solubility (DGFZ, 2012). Oxidation is done by aeration in the reaction tank. Reduced metals (e.g., iron and manganese) oxidize and form precipitates (flocs). Flocculants are added to accelerate the settling of flocs (Wolkersdorfer, 2013). The resulting sludge from this method needs to be dried in order to be deposited.

Hydroxide precipitation is a prerequisite for coagulation and flocculation and thus for solids separation. The solids formed have a catalytic effect on the oxidation of further metal ions and their co-precipitation by sorption. In this process, high pH values increase the sorption capacity of the hydroxide solids. Finally, the solids are separated from the solution mostly by sedimentation, more rarely by filtration (DGFZ, 2012).

This is a well-proven technology for the remediation of AMD. Several full-scale plants are operated by LMBV (e.g., Rainitza), VEM (e.g., Tzschelln) and MIBRAG (e.g., Vereinigtes Schleenhain). The process is stable and easily controllable, while it is adaptable to changes in water flow and quality (GTK, 2022). Disadvantages of this method is the inability to eliminate sulfate, the non-selective nature of the process and the possibility of failure due to blockages (DGFZ, 2012; GTK, 2022).

In general, an oxidative mine water treatment plant consists of a reaction pond, in which neutralization and oxidation are carried out, and a sedimentation pond, in which the solids formed are settled and separated (**Figure 4-34**). In the simplest version, the solids precipitated in the neutralized water are deposited in an earthen dam pond, which is dredged discontinuously (DGFZ, 2012).

Oxygen is introduced passively via the water surface, which results in a surface area requirement adapted to the iron load, or via aeration cascade. Higher iron (II) concentrations are thus difficult to oxidize, especially since large settling pond areas increase the susceptibility to wind (stirring up of already settled iron hydroxide sludge) (DGFZ, 2012).

The classic method includes the following steps:

1) Neutralization of mine water in a reaction tank by controlled pH-dependent addition of hydrated lime with simultaneous aeration,
2) Addition of flocculants, and
3) Sedimentation of the sludge in a sedimentation pond.

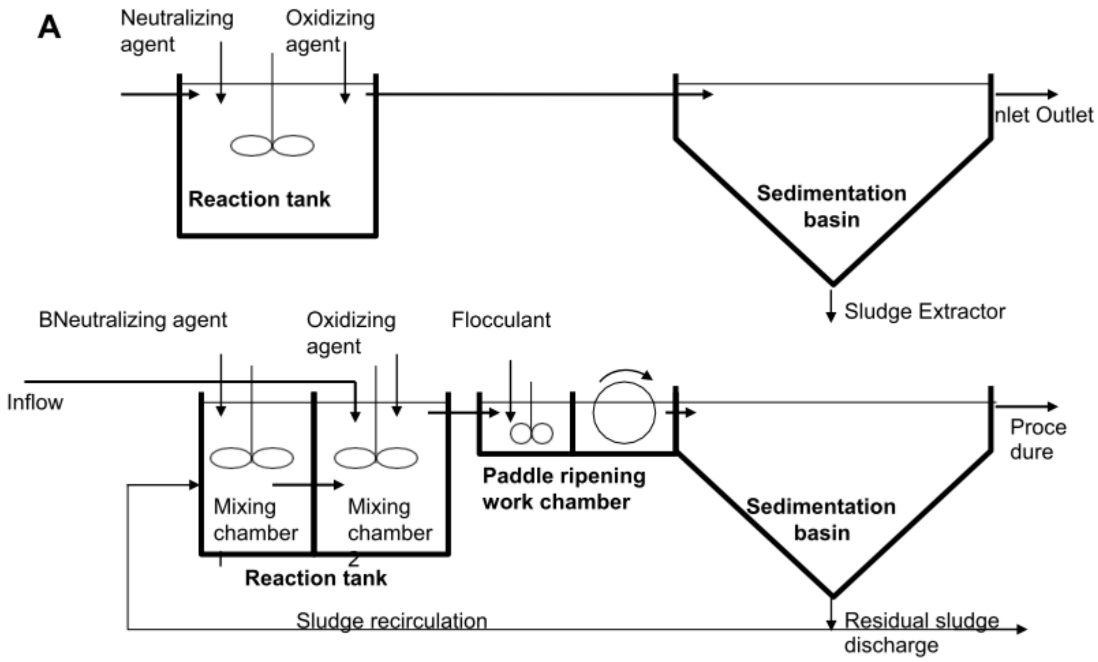


Figure 4-34. *Schematic diagram of an oxidative mine water treatment method.*

Source: DGFZ (2012)

The High-Density Sludge (HDS) process represents a further process optimization, which consists of the following 4 sub-steps:

- Introduction of the neutralization agent into the recycled sludge in an upstream mixing tank/basin. These forces contact between the solids, which promotes coagulation of the lime particles with the re-cycled precipitates.
- Neutralization of the mine water in the actual reaction tank by controlled pH-dependent lime-milk/sludge addition with simultaneous oxygen addition. Due to the addition of the neutralized slurry, the oxidation and precipitation reactions take place increasingly on the surface of already existing particles, thus forcing their growth.
- Precipitant addition in a flocculation tank.
- Sedimentation with increased effectiveness (higher flow rates, shorter residence times). Part of the sludge removed from the sedimentation tank is returned to the mixing tank.

Advantages of this improved process are the good process control, the producible sludges with up to 20 % dry mass and the thus lower expenses for sludge treatment (thickening, dewatering, and landfilling). The HDS technology is currently not used in Saxony, since the Lusatia-specific possibility exists to discharge the resulting iron hydroxides sludges into the opencast lakes (DGFZ, 2012). This means that the sludge volume no longer represents a decisive cost factor.

4.4 Protection or Containment Measures

Protective and containment measures are to be used when decontamination and safeguarding procedures are not feasible or are disproportionate. Optionally, they can also be useful supplements to decontamination and safeguarding procedures. In contrast to remediation measures, which act directly on the source of the pollution or the emissions emanating from it, protective and containment measures relate directly to the protected assets. Depending on how they are affected, they are directed at the direct use of the contaminated area or its surroundings. For example, restrictions on use can be imposed within the framework of permissible use under planning law. All measures to secure the access of humans and animals to the contaminated site fall into this category (LfULG, 2020).

Examples of protection and restriction measures are:

- Temporary simple covering of tailings piles with e.g., tarpaulins, foils, etc. to prevent drifting or the entry of precipitation water,
- Temporary sealing of openings in structures or waste disposal lines to temporarily reduce the discharge of pollutants,
- Restrictions on the use of traffic routes crossing a contaminated site or buildings located on a Contaminated site located buildings,
- Closing off parts or the entire contaminated site to prevent access by unauthorized persons, etc. (LfULG, 2000).

4.5 Monitoring the Effects of Site and Local Watershed Remediation

A monitoring strategy is proposed for Los Rosales, based on results from the oriented investigation carried in 2021 by the DGFZ team. Monitoring strategies from saxon reference sites are presented in this chapter.

4.5.1 Monitoring in Los Rosales

4.5.1.1 Overview on Current Monitoring in Los Rosales

Water monitoring is currently performed on five locations. All of them correspond to surface water. Three are located in the mining properties area and two are located in the Vilque River: upstream and downstream of Los Rosales, for monitoring possible effects of the project in the river water quality. Soil monitoring is performed in two locations inside the project properties. One location near the processing plant and the other location is in the planned tailings. Monitoring locations are detailed on **Table 4-17** and shown on **Figure 4-35.**

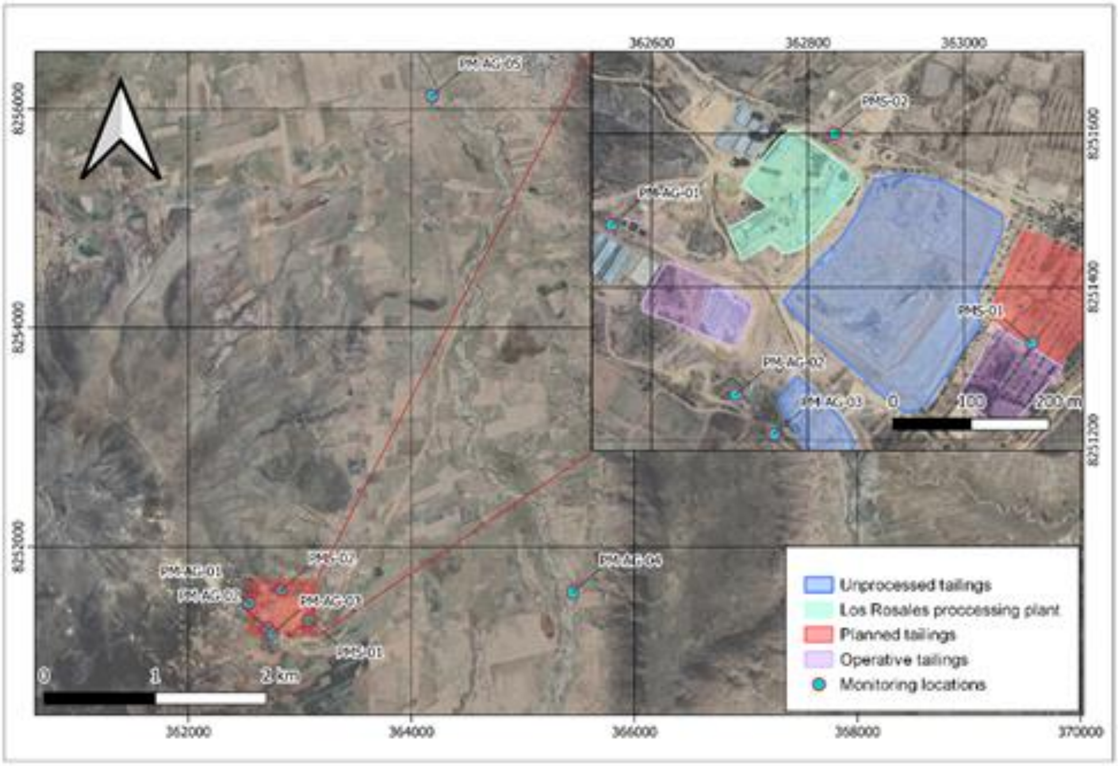


Figure 4-35. *Current monitoring locations at Los Rosales site.*

Source: Quantum MVA SAC (2020) and Sesam-Peru (2021)

Table 4-17. *Los Rosales monitoring locations.*

Location ID	Description	Type
PM-AG-01	Candelaria mine water outflow	Mine water
PM-AG-02	Ojo de Agua spring	Spring
PM-AG-03	Tuntani spring	Spring
PM-AG-04	Vilque River upstream	Surface water
PM-AG-05	Vilque River downstream	Surface water
PMS-01	Planned tailings area	Soil
PMS-02	Processing plant area	Soil

Source: Golden Growing (2020) and SMRL Los Rosales (2021)

Monitoring has been performed in Los Rosales on a yearly basis. Sampling campaigns have been carried out in March, at the end of the rainy season. In 2020, only four sites were sampled for water, from PM-AG-01 to PM-AG-04. No sample from Vilque River downstream is available from 2020. All five locations were sampled in March 2021. Monitored parameters and analytical methods used in current monitoring are shown in **Table 4-18.**

Table 4-18. *Monitored parameters and analytical methods at Los Rosales.*

Parameter	Method
Total metals	ICP-AES / ICP-MS
Anions	Ion Chromatography
WAD Cyanide	Weak Acid Dissociable Cyanide
Fecal coliforms	Standard Total Coliform Fermentation Technique
Total coliforms	Standard Total Coliform Fermentation Technique
Biochemical oxygen demand	5 – Day BOD Test
Chemical oxygen demand	Closed Reflux. Colorimetric Method
Phenols	Chloroform Extraction Method

Source: Golden Growing (2020) and SMRL Los Rosales (2021)

Laboratory analyses were not performed on all samples in every campaign. The March 2020 campaign did perform ICP-AES analysis on all collected samples, excluding the PM-AG-05 location which was not sampled. Anions were not analyzed during the 2020 monitoring campaign (Quantum MVA SAC, 2020). The March 2021 campaign only has laboratory analysis data for Vilque River samples (PM-AG-04 and PM-AG-05) for all parameters shown in **Table 4-18** (Sesam-Peru, 2021).

4.5.1.2 Recommendations for the Improvement of Monitoring Program in Los Rosales

Based on the assessment on the existing monitoring program, results from field activities in Los Rosales, regulations, and the methodology on management of contaminated sites presented in **Chapter 2**, recommendations are presented in order to improve the monitoring program in Los Rosales.

In general, monitoring in Los Rosales should be oriented, in addition to compliance with regulatory obligations, to improve the understanding of the different components of the water cycle in Los Rosales. A better understanding of the surface and groundwater behavior will allow for better and more efficient monitoring.

Based on the results from the oriented investigation presented in **Chapter 3**, it is possible to confirm the presence of substances exceeding the environmental quality standards in the groundwater, thus including groundwater as a pathway for contamination in Los Rosales. Therefore, it is necessary to include the groundwater component to the existing monitoring in Los Rosales. Specifically, the groundwater monitoring will allow for the determination of spatial distribution of pollutants in groundwater, temporal behavior of concentrations and groundwater levels, and flow direction and groundwater velocity

In addition, results from mine water and treated water in Los Rosales show that treatment increases pH and thus decreases concentrations of metals, nevertheless, some elements (iron and copper) still exceed permitted values for water discharges. Monitoring of water discharge from mining sites is required by Peruvian authorities.

Groundwater: Groundwater monitoring sites should be located upstream and downstream of the contaminated site. Installed monitoring wells are located downstream of Los Rosales. There are no monitoring wells installed upstream of Los Rosales. Installation of monitoring wells upstream of Los Rosales is recommended in order to gain information on spatial extent of groundwater pollution. In addition, a second row of monitoring wells downstream of the 3 wells installed in November 2021 should be considered to be installed, in order to obtain information on hydraulic parameters as groundwater velocity. Also, relevant geological data can be obtained, in order to develop a local geological and hydrogeological model.

Table 4-19. *Recommended groundwater monitoring locations Los Rosales*

Groundwater monitoring site	Description
Downstream Los Rosales	Existing monitoring wells, installed in 2021 Second row of monitoring wells (installation recommended)
Upstream Los Rosales	Installation recommended

***Mine Water and Treated Water*:** Treated water must be included in the monitoring program. Peruvian regulations require constant monitoring of water discharges from mining sites. Previous monitoring from 2020 and 2021 do not include treated water on their sampling sites. Monitoring on mine water and treated water must include chemical analyses and flow rate measurements in order to obtain information on contaminant loads. A stream gauge station is recommended to be installed in the Candelaria mine water monitoring site.

Table 4-20. *Recommended mine and surface water monitoring locations at Los Rosales*

Monitoring site	Description
Candelaria Mine	Mine water
Water treatment outflow	Water discharge from Los Rosales
Monitoring wells downstream	Groundwater downstream of Los Rosales, additional row downstream of existing monitoring wells
Monitoring wells upstream*	Groundwater upstream of Los Rosales
Tuntani spring	Spring water. Baseline condition
Ojo de Agua spring	Spring water. Baseline condition
Vilque River upstream	Receptor
Vilque River downstream	Receptor

**: observation point ist not constructed; recommendation to install and include in monitoring.*

***Surface Water*:** *Tuntani* and *Ojo de Agua* springs should be continued to be monitored. Results from previous monitoring in 2020 and 2021 indicate low concentrations of metals and sulfates, opposed to the results from mine water samples. Results from monitoring these springs can be used for baseline conditions determination on water quality.

Vilque River sampling sites are consistent with requirements from Peruvian authorities. Rivers should be monitored upstream and downstream of the discharge site. In this case, Vilque River is monitored upstream and downstream of Los Rosales collecting channel discharge into the river.

In general, existing monitoring sites shall be maintained, and treated water along with groundwater monitoring sites are recommended to be included in the monitoring program. Additional groundwater monitoring sites are recommended to be installed upstream and downstream of Los Rosales tailings. Flow rate monitoring on mine water and treated water should be included, and the installation of a stream gauge in Candelaria mine water is also recommended. **Table 4-20** summarizes the recommended sites for the proposed water monitoring in Los Rosales.

Monitoring Frequency: Peru's National Water Authority water monitoring protocol (ANA, 2011) recommends a monitoring frequency determined by the natural changes occurring in the area. This shall be based on:

- Monitoring program objectives,
- Available budget,
- Basin seasonality, and
- Extraordinary events' occurrence.

Based on precipitation data presented in **Chapter 3**, two distinct seasons were identified in Los Rosales. Monitoring frequency is therefore recommended to be twice per year, in order to assess seasonal variability in water quality.

Groundwater levels monitoring shall be performed in a higher frequency (i.e., weekly) in order to determine groundwater levels seasonal behavior.

***Parameters*:** Monitored parameters must be in compliance with Peruvian regulations. For mine water and treated water, monitored parameters are determined by the maximum allowed limits from the Peruvian General Environmental Law. For groundwater, springs and Vilque River sites, monitored parameters are determined by environmental quality standards in Peruvian General Environmental Law. **Table 4-21** shows the different parameters to be monitored.

Table 4-21. *Parameters to be monitored for different locations in Los Rosales.*

Monitoring sites	Classification	Frequency	Parameters to be monitored
Mine water Treated water	Maximum allowable limits	Twice a year	pH, TDS, oils and fats, cyanide, As, Cd, Cr, Cu, Fe, Pb, Hg, Zn, flow rate, conductivity, temperature, turbidity
Groundwater Vilque River Water springs	Environmental quality standards	Twice a year	pH, temperature, conductivity, dissolved oxygen, coliforms, worm eggs, BOD, COD, oils and fats, Cl, HCO3, Nitrates, SO_4, S2, Ca, CO3, Na, Al, As, Ba, B, Cd, cyanide, Co, Cu, Cr, Fe, Li, Mg, Mn, Hg, Ni, Ag, Pb, Se, Zn.

4.5.2 Gittersee site environmental monitoring

During the underground stabilization and clean-up work, neutralized mine water was pumped above ground and fed into a settling basin with other water accumulating on the premises for mechanical cleaning. Operationally, a monthly sampling was ordered for the Kaitzbach and Elbstolln discharge points. Groundwater dynamics were/are controlled via observation wells of water levels and quality.

As part of the exposure pathway analysis, dynamic core probing, drilling and soil sampling were also carried out and examined with regard to radionuclides, hydrocarbons, acids, bases, heavy metals. The stability and subsidence behavior of the ground surface was monitored at regular intervals. At 52 measuring points, the air path was/ is monitored with regard to pollutants and pollutant concentration. In addition, two of the measuring points have been specially equipped for the determination of dust precipitation and a measuring point for the suspended dust concentration measurements.

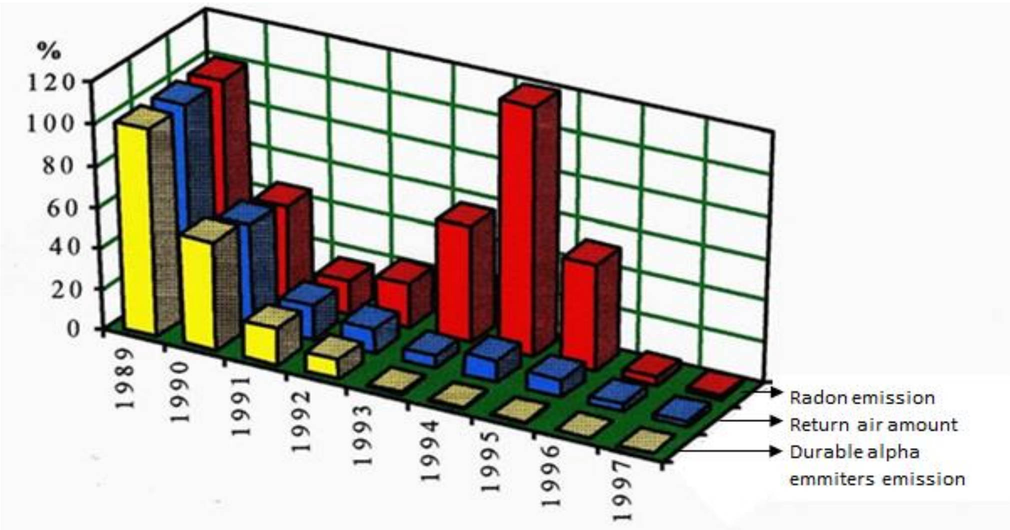


Figure 4-36. *Percentage of total radionuclide emissions at the Gittersee site.*

Source: Chronicle Wismut 2010, https://www.wismut.de/de/veroeffentlichungen.php?id=614&back=veroeffentlichungen.php%3Fyear%3D0%26index%3D0

Today the monitoring of the water path at the Dresden Coschütz/Gittersee site is limited to the water discharged into the Elbe, to the monitoring of the Kaitzbach creek at the foot of the Gittersee mining waste tip and to the groundwater in the mine fields as well as in the vicinity of the tip and the former operating area. The statements of recent years continue to apply, according to which there is still a slight mining influence in groundwater (max. observed uranium concentration = 141 µg/l). The water discharged to the Elbe river via the mine drainage tunnels contains uranium of 62 to 65 µg/l. In the Kaitzbach creek, an annual average of 17 µg/l has been measured downstream of the Gittersee area. The creek water flux is low. Even an occasional human use of the water would be radiologically harmless.

The monitoring of the air path was still focused on the measurement of radon concentrations outdoors at the mouth of the Tiefer Elbstolln, at shaft 3 and in the vicinity of the mining waste tip. In the order of enumeration, the annual average was 23 Bq/m³, 28 Bq/m³ and at the tip a value range of 17 to 44 Bq/m³. Radiologically significant burdens on the population can be excluded on the basis of the values and taking into account the location of the measuring locations.

Table 4-22. *Scopes for initial exposure monitoring for the remediation of Gittersee site.*

Task	Unit	Total extent	1991	1992	1993	1994	1995	1996	1997	sum 91/97
Work of the exposure path analysis										
bore hole	piece	677	5	124	193	177	10	46	7	562
bore hole	m	1,590	8	220	343	549	72	142	26	1,360
sampling	piece	13,000	108	242	1,438	1,103	1,223	960	573	5,647
Work for monitoring										
GWBM new bore hole	piece	178	3	7	24	10	20	20	17	101
GWBM new bore hole	m	23,815	750	1,487	1,801	1,343	2,566	3,440	1,827	13,214
GWM remediation	piece	134	---	---	11	12	7	5	8	43
GWM liquidation	piece	88	---	---	7	7	3	6	10	33
GWM liquidation	m	10,323	---	---	846	928	183	985	1,361	4,303
GWM clean-up	piece	127	---	---	---	---	---	---	---	---
GWM- clean up	m	26,110	---	---	---	---	---	---	---	---
air-to-ground pathway samples	piece	8,250	226	226	191	465	614	571	585	2,878
surface water samples	piece	15,330	536	536	520	609	609	546	523	3,879
groundwater samples	piece	23,870	569	569	810	824	947	1,698	2,685	8,102
subsidence measurements	piece	33	2	2	1	2	1	2	2	12

NOTE: GWBM = groundwater quality measuring point, GWM = groundwater measuring point

Source: Chronicle Wismut 2010, https://www.wismut.de/de/veroeffentlichungen.php?id=614&back=veroeffentlichungen.php%3Fyear%3D0%26index%3D0

The rehabilitated former operating area and mining waste tip at Dresden Coschütz/Gittersee, which has been transformed into a secondary biotope since the end of the remediation, is a very interesting area for observing rare animal and plant species due to its location on the outskirts of the city and the protective fence. As part of a project of the Nature Conservation Union Germany (NABU) and the City of Dresden with the aim of creating a breeding bird atlas for the city, for example, a bird count was carried out in the area with an ornithologist at the beginning of May 2020.

Rehabilitation monitoring of the water pathways

Until 2019, the water level measurements in groundwater and heap measuring points took place monthly. 7 years after the end of the active construction measures, the measurement frequency was reduced to once per quarter. Short-term changes in groundwater conditions are no longer to be expected. Due to the constantly increasing mineralization, the water level in the more distant outflow is also measured quarterly. It is no longer necessary to record the amount of seepage water from the heaps. The continued operation of the measuring devices will be retained for the time being. However, reinvestment is not planned.

The inflow in the Quaternary is evaluated as part of the Wismut GmbH environmental monitoring. A sampling interval of 2 years is sufficient for the inflow measuring points in the Karbon and Rotliegend. Due to the increase in mineralization, the annual survey of the Cretaceous Aquifer will be maintained. In the immediate vicinity of the heaps, the chalk aquifer will continue to be examined annually for heap-related changes in the chemistry of the groundwater. Due to the increasing mineralization in the more distant outflow, the annual sampling in the Rotliegend is carried out every two years in the Cretaceous.

In the case of increases in radionuclide or heavy metal concentrations or increasing mineralization in the leachate of the tailing pile outflow, the measuring points in the dams and deposits of the tailing pile must be included in the monitoring. In the current state, no periodic measurements are required. Surveys every 2 to 5 years are recommended to monitor conditions in the unpatched area of the tailing deposits. In order to assess the function of the cover of heap B, a quarterly check of the water levels in the body of the heap with on-site parameters, radionuclides U-238, Ra-226 and heavy metals are recommended. As long as no damage to the covers of the heaps with exposure of the emplacement masses or leakage of leachate is observed, there is no reason for regular sampling and examination of the surface water from the heaps' intakes.

The main receiving creek for the site is the Kaitzbach. With the end of the flooding water discharge by Wismut GmbH after 2014, there was a significant decrease in mineralization, pollutant concentrations and loads. In order to monitor the influence of the heap location, it is recommended that the annual inspection of the inflow and outflow measuring points be retained and the measured values from the environmental monitoring of the Wismut be included.

Table 4-23. *Long-term post mining water monitoring tasks at Gittersee site (after 10 y)*

Object of monitoring	# Monitoring element	Available / maintained	Currently active
Tailings + dams	Approx. 40	12	3
Groundwater	Approx. 35	22	7
Filtration water	6	3	2
Surface water	15	12	-
Creeks	7	5	4

Rehabilitation monitoring of the air pathways

Due to the stored masses, landfill gas (methane) is only formed in heap A. As long as the size and number of release points does not increase, periodic monitoring at almost every 5-10 years should be sufficient to assess methane formation. Together with the emission of landfill gas, radon formed in the deposits can also be discharged. At heap A, the radon concentration in the atmosphere close to the ground is influenced by the formation of landfill gas, especially in the plateau area. The inspection intervals of 5 years should be retained, both for reasons of aging of the cover of the heaps and of the landfill gases at heap A.

As the deformations of the heap surfaces subside further, the measurement intervals/time stretching of deformation measurements can be extended to intervals of 3-5 years.

Previous measurements of the radiation dose rates on the heaps about 5 or 10 years after the surface was covered did not show any significant changes. The radiation protection authority therefore does not consider any further periodic measurements to be necessary.

Perspective of post rehabilitation monitoring

Controls, inspections, and periodic inspections of the site are carried out to ensure order and safety, to document the condition and any adverse effects that may occur on construction elements of the tailing facilities. For example, 14-day visual inspections are carried out in parts of the heaps with regard to surface water and seepage water catchment facilities at Kaitzbach creek, intake and outlet areas of the Kaitzbach tunnel, vegetation, and buildings.

The aftercare also includes an annual inspection of the structures, cover, vegetation, measuring points, water intakes and discharges and receiving waters by technically qualified personnel. The inspections serve to identify problems and damage in good time that could jeopardize permanent final storage. The environmental agency of the state capital of Dresden is informed about critical problems, damage, and suggestions for remedying them in the form of inspection logs. According to the radiation protection permits, reporting must be carried out at least once a year for the entire aftercare period (25 years).

As part of the aftercare, care measures must continue to be guaranteed for the elements of the end-of-life heaps: cover and vegetation, paths, water intake and drainage, buildings, and construction site facilities.

4.5.3 Königstein mine water treatment

With the cessation of chemical uranium extraction in the Königstein deposit, the facilities for environmental monitoring were further expanded and technically qualified. The annual environmental monitoring focused on the year-round emission and immission monitoring of the water, air and soil pollution paths as well as the metrological monitoring of approved remediation measures in accordance with the official requirements for approval. The continuation of the exposure pathway analysis in accordance with the annual state of preparation for flooding was the focus of environmental monitoring in the first decade.

Figure 4-37. *Environmental monitoring in 2016 near Thürmsdorf respectively several kilometers northward of the Königstein site.*

Source: https://www.wismut.de/de/pressefotos.php; 08.06.2016

In order to monitor the water path, a comprehensive control system was built up and set up, taking into account the requirements of water management usage permits, which includes surface, seepage and groundwater. In addition to the operational sampling points, the hydrographic network was/is monitored. Groundwater monitoring was carried out by more than 100 groundwater measuring points (GWM) and quality measuring points (GWQM), which record data at different times. All discharge points into the Elbe River and the smaller receivers Pehna and Cunnersdorfer Bach floodplains were/are monitored in accordance with the conditions of the water management use permit and the permit for liquid ejections. Further water sampling was carried out by the water supervisory authority.

All operationally used and adjacent areas were examined with regard to their radioactive and chemical contamination and documented in the Wismut environmental register. As part of the exposure pathway analysis, these data have been/are constantly being improved. For this purpose, dynamic window sampling, drilling and soil sampling were carried out and examined with regard to the contaminants and the degree of contamination. In order to evaluate the subsidence and imbalances influenced by mining, measurement programs were carried out in an area of about 10 km^2 and on about 100 rocks in the area (see **Section 4.5.2**).

To monitor the air path, an environmental monitoring network of the immission control for the pollutant concentration in the air was set up on an area of about 50 km^2 from 52 radon measuring points. The radon concentration determined in the measuring points by means of long-term detectors was/is evaluated by the Federal Office for Radiation Protection and the Karlsruhe Nuclear Research Centre.

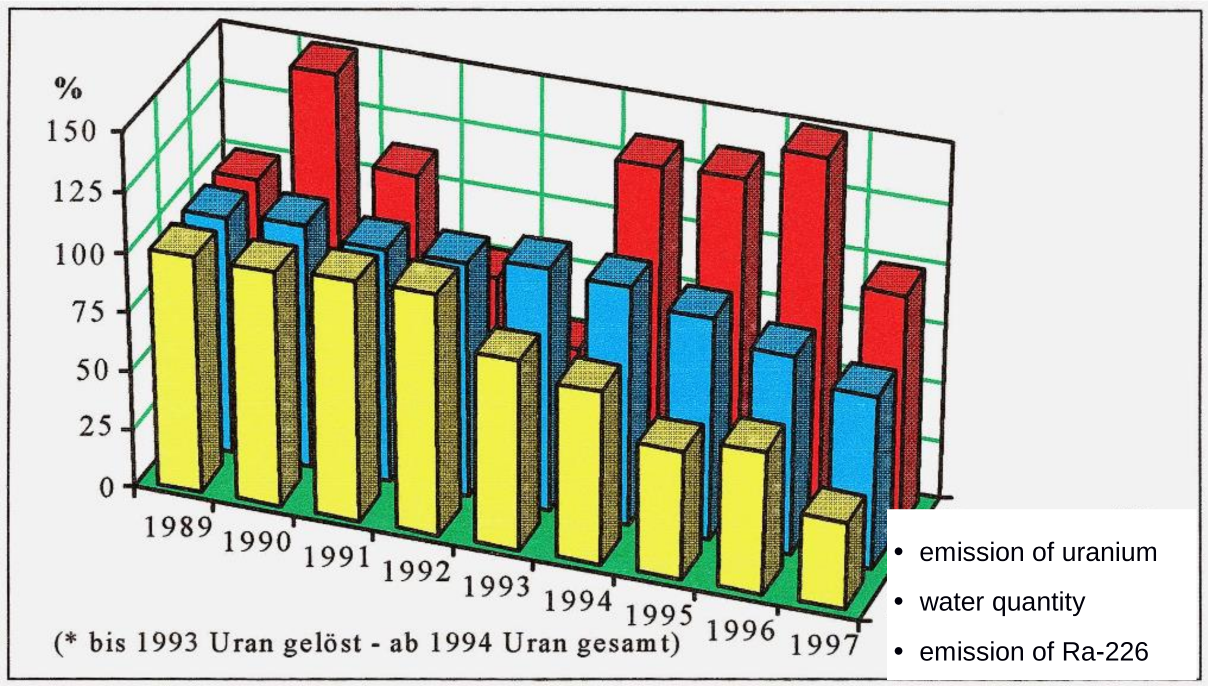


Figure 4-38. *Relative wastewater volume and dissolved radionuclide emission at Königstein site in the initial remediation processes.*

Source: Chronicle Wismut 2010, https://www.wismut.de/de/veroeffentlichungen.php?id=614&back=veroeffentlichungen.php%3Fyear%3D0%26index%3D0

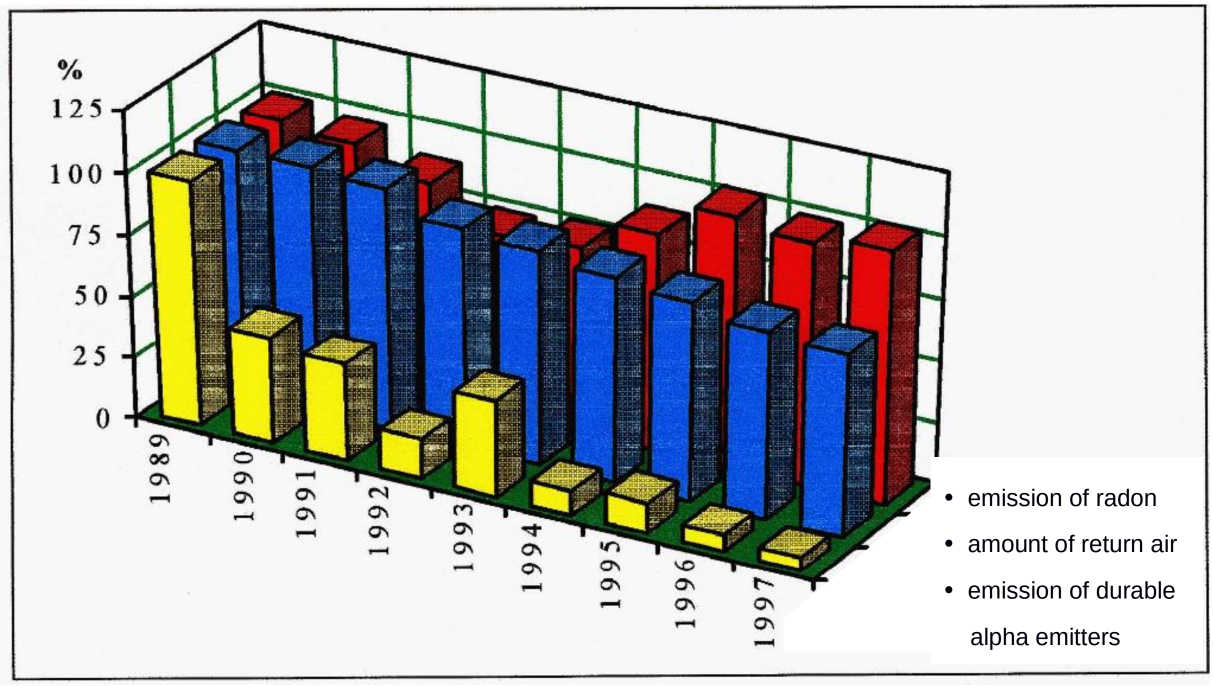


Figure 4-39. *Relative total air and radionuclide emissions at the Königstein site in the inicial remediation processes.*

Source: chronicle Wismut Chronicle Wismut 2010, https://www.wismut.de/de/veroeffentlichungen.php?id=614&back=veroeffentlichungen.php%3Fyear%3D0%26 index%3D0).

The monitoring accompanying the rehabilitation was and is carried out by the use of mobile measuring devices, with which the primarily labor and municipal hygiene concerns in connection with the effects of the immediate remediation activity were/are monitored (see example in **Figure 4-37**).

Land remediation and demolition work took place at the Königstein site in several major phases - first in the early 1990ies demolishing a lot of buildings not useful for the long-term remediation process, second when the headgears and shaft buildings were no longer needed for preparing the underground workings for the flooding process around 2015 and third in the recent past up to present – after extracting of uranium from the treated groundwater has ended in 2021 and the facilities have to be demolished or removed. Therefore, radioactively contaminated material in relatively large quantities has to be handled even today. During its rearrangement, dust develops, which can also contain radionuclides and leads to the release of the radioactive gas radon. Dust generation can be counteracted with technical measures, e.g., irrigation.

Figure 4-40. *Rehabilitated area of the shaft complex 388/390 at Königstein site in 2015.*

Source: https://www.wismut.de/de/ pressefotos.php, 22.07.2015

The nearby Schüsselgrund mining waste tip was/is used for depositing the construction materials which cannot be decontaminated and recycled. Therefore, the waste tip and mainly the special storage area within it is in turn a permanent facility that remains in place with its radioactive inventory for generations to come. The impact on groundwater from seepage and the effects on the atmosphere from radon release must be permanently monitored. The measurement tasks at the Königstein site result from the activities of remediation, flood control with water treatment and monitoring of permanent environmental impacts. The measures contained therein are listed in the following compilation:

1. control of uranium/Ra-226 discharges with the treated flooding water into the Elbe River,
2. monitoring the influence of the pit on the 3rd and 4th aquifer,
3. analysis of samples from the potential transfer points in the 3rd aquifer to be protected,
4. monitoring of the influence of the release of pollutants from the Schüsselgrund waste tip,
5. control of the influence of radon release from the waste tip, from the mining complex, which is now an industrial development area, and from the recently rebuilt water treatment plant (see **Chapter 4.3.1**) as well as from other areas around,
6. monitoring of the release of dust and long-lasting alpha emitters during the ongoing demolition work and surface rehabilitation.

More information about the up-to-date situation can be obtained from **Chapter 4.3.1** “Water treatment plants in former uranium mining areas of Wismut”.

5. Social conflicts at post-mining sites in Peru

This chapters presents the social aspects related to water problems in post-mining areas. First, the Espinar case is presented, a conflict in Cusco involving different mining projects and mainly indigenous communities due to water quality problems related to mining activity. Then, a local women and indigenous inhabitant engagement section is presented. During the second trip to Peru in June-July 2022, several interviews were done to local actors from the different study sites and related NGOs. Here is reflected the concern to ensure water access for domestic and occupational activities, as well as participation in water resources protection measures. Finally, the case of Mrs. Brigida Huachani Lasarte is presented. In cooperation with the local NGO Descosur, Mrs. Brigida conducted a local project of water management in the Natural Reserve Salinas y Aguada Blanca.

Details on the trip to Peru in 2022 can be found in **Annex 2.**

5.1 Introduction to local mining conflicts: The case of Espinar

Espinar is one of the thirteen provinces of Cusco region. It has eight districts and 79 rural communities. The town of Yauri, the capital of Espinar, is the most important among the other district capitals, and it has the largest number of inhabitants (Cusco Regional Government, 2019).

Hydrographically, Espinar belongs to the Atlantic slope, in the upper part of the Apurimac River basin, it has 8 major rivers, 245 rivers and streams, and 1082 springs inventoried. The area of the two watersheds covers approximately 7000 ha.

- The Cañipia River has a catchment area of 400 km², a length of 52 km and an average annual flow of 4,2 m³/s. Its main tributaries are the Allahualla and Choco rivers. The Cañipía watershed is home to the Alto Huarca, Cala Cala, Huisa, Huarca, Huisa Ccollana, Anta Ccollana and Suero farming communities, among others. There are also two independent farmers' associations in Huinipampa (Levit, 2014).
- The Salado River has a lagoon system in the Quinilla pampas. There are 14 communities in the basin: Huano Huano, Pacopata, Guini, Coroccohuayco, Alto Huancané, Bajo Huancané, Antacollana, Tintaya Marquiri, Ccama, Chellque, Suero y Cama, Mollocahua, Kanamarca, and Mamanocca (OCMAL, 2022; MINAM, 2019).

5.1.1 Mining Activity

Mining concessions cover 94,6 % of the total area of Espinar. There are three mining projects in this area: Tintaya, Antapaccay , and the project Integración Coroccohuayco.

In 1981, state activity was withdrawn, and private foreign investment was promoted. The company Minero Peru contributed 25 % of the capital, and private investors, preferably foreign, contributed the remaining 75 %. In 1985, Magma Copper Company began production; 10 years later (1996), Magma was acquired by BHP Billiton. In 2006 Glencore Xtrata PLC bought the Tintaya mine from BHP Billiton, and renamed it Xtrata Tintaya S.A. (Levit, 2014). In 2008, Glencore started the Antapaccay project, as the expansion of Tintaya. The Antapaccay - Tintaya Expansion Project has an operational horizon until 2034 (Levit, 2014).

Antapaccay is located on the left bank of the Cañipia River, where open pits and waste rock dumps have been built. The north pit (135 ha), and the south pit (252 ha). The Huinipampa tailings deposit (184 ha) is located on the right bank of the Cañipía River. Downstream of the dam is the Ccoloyo River, whose waters drain into the Cañipía River (Levit, 2014). Tintaya was developed on the left bank of the Salado River. In 2012, Tintaya projects starts is closure phase; however, Tintaya pit is currently used as a tailings deposit for the Antapaccay mine (Levit, 2014). The copper project Integracion Coroccohuayco, which is in the exploration stage, is located on the left bank of the Salado River, in the Ccamacmayo river micro-basin.

5.1.2 Communities involved in the Conflict

The main actors in the conflict are the indigenous populations organized in autonomous communities, with their historically established boundaries (Ombudsman's Office, 2018, Preciado & Alvarez Gutierrez, 2016). Peasant communities, villages and hamlets have similar characteristics. These actors are in rural areas, most of them with high rates of poverty, illiteracy and malnutrition. In many cases, they do not have public drinking water service, so they are supplied directly from nearby water sources, and it is used for consumption, livestock and agricultural activities, which are for self-consumption, and in some cases, serve as an element of cultural transcendence and spiritual importance (Andean cosmovision) (Ombudsman's Office, 2018).

In Espinar the mobilization of people is constant and progressive, under a preferential orientation from the rural side to cities; this is due to structural causes, such as the lack of productive organization, deficient distribution of wealth, and development policies that are not applicable to reality. The most frequent destinations of rural migration are Yauri, Arequipa and Cusco (Cusco Regional Government, 2019).

There are approximately 50,000 people in 13 communities inside the zone of direct influence (ZID) of the Antapaccay mining operation in the province of Espinar (Preciado & Alvarez Gutierrez, 2016). The communities of Espinar have socioeconomic indicators below the national average with very low human development indexes (HDI) (Ombudsman's Office, 2018). In this case, social vulnerability converges with environmental vulnerability, giving rise to emerging forms of social inequality (Preciado & Alvarez Gutierrez, 2016).

The K'ana nation, an ancestral ethnic group, is represented in part by the 13 indigenous communities mentioned above. Their territories are suffering soil degradation and contamination of water resources. The main impacts are lack of access to sources of natural resources for economic sustain, lack of respect for their cultural identity, especially the conservation of the territory they inhabit, which they use for practical (obtaining resources) and symbolic (ritual significance) reasons, lack of comprehensive health care due to having ingested water containing heavy metals (Ombudsman's Office, 2018; OCMAL, 2022).

The main activities in the province of Espinar are tourism, commerce, folklore, agriculture, livestock, administration, and agroindustry. Agricultural production is purely subsistence; there is no government support for agricultural development in rural areas (Cusco Regional Government, 2019). The lower agricultural productivity is associated with the loss of the quality of environmental factors (water, air, soil, etc.) in the mining area, especially water due to the contamination of aquifers, which has led to a loss of possibilities to continue productive activities. There are evidence of lower crop yields due to loss of water, air and soil quality and less productive workers. In the case of livestock, the number of head of cattle has also decreased, since they do not have access to water from natural sources with minimum quality, and the grazing areas have been reduced by white dust from the mining operation (Orihuela et. al., 2019).

5.1.3 Evolution of the Conflict

Environmental contamination of the province of Espinar related to mining activities dates back many years (1980s). In 1981, the state-owned company Etaminsa, with public and private capital, expropriated 2,368 hectares from the community of Anta Cama and began extractive operations in the Tintaya project (OCMAL, 2022).

On May 21, 2003, the Unified Federation of Farmers of Espinar (FUCAE) and Sole Front for the Defense of Espinar's Interests (FUDIE) began to mobilize at the mine's facilities. The main demand was to sign a framework agreement that includes the hiring of local labor, reparations for environmental damages, land claims and respect for human rights. (Preciado & Alvarez Gutierrez, 2016). On May 23, 2005, there was a takeover of the mine. Demands included the reformulation of the Framework Agreement and increase of the company's contribution to community. They also demanded: the waterproofing of the dam of the new tailings dam at Huinipampa, the installation of a joint Environmental Surveillance Committee, the construction of a hospital in the town of Yauri and the asphalting of the road leading to the city of Arequipa.

The Framework Agreement for the development of the province of Espinar, between the communities and BHP Billiton, was signed in September 2003; it included 21 clauses. This document specifies the establishment of a Community Environmental Oversight Committee with periodic environmental monitoring and a contribution of up to a maximum of 3% of the company's pre-tax profits for the people of Espinar (OCMAL, 2022).

During the month of May 2012, a 7-day strike began (with marches, road blockades, protests, and violent confrontations). The Government declared a state of emergency for 30 days in the area. Among the main demands were the initiation of the process to reformulate the Framework Agreement, economic oversight and accountability of the commitments and activities undertaken by Xstrata Tintaya under the Framework Agreement, and permanent environmental monitoring. As a response the Government commissioned several authorities (ANA, INGEMMET, OEFA, GERESA) to carry out studies covering different disciplines (environmental assessment, hydrogeology, health, etc.) to determine the environmental situation of the area and the health of the people affected with heavy metals.

The Environmental Evaluation and Control Agency (OEFA) was commissioned to contract specialized stable isotope and radiotracer isotope studies to obtain relevant data on the causality of the contamination in the area. (MINAM, 2013B) This agency contracted two studies with the Peruvian Institute of Nuclear Energy (IPEN):

- The first one on water characterization, by means of stable isotope analysis (18O and 2H), of the surroundings of the Ccamacmayo and Huinipampa tailings dams, in the mining area of Antapaccay, Tintaya Expansion (IPEN, 2013).
- The second report included the monitoring of the injection of Radiotracers (^{3}H), to determine the presence of leaching and infiltrations in the Ccamacmayo tailings dam and in the Huinipampa tailings dam, or filtrations of runoff (IPEN, 2017).

On this year, Ministerial Resolution No. 164-2012-PCM formalized the creation of the Dialogue Table for *"promoting a dialogue process between the various public and private sector actors regarding the socio-environmental problems in the province of Espinar and analyzing viable alternative solutions"*.

As urgent actions, two were determined:

a) Alternative supply of drinking water to the communities with 200 tanks of 660 L, the calculated need was 1000 tanks of 660 L, this would be temporary on a weekly basis with 5000 Gal trucks; it was also requested the preparation of profiles of drinking water supply projects for the communities of Espinar (MINAM, 2013A; MINAM, 2013B).

b) OEFA should conduct an evaluation to detect physical and ecosystem changes around the Huinipampa and Camacmayo tailings dams.

In April 2013, the Ministry of Environment (MINAM), released the summary results of its MSAP that was commissioned by the State in 2012 (MINAM, 2013C). The report indicated that there is contamination in Espinar Province that appears to be related to mining activities, along with pollution that appears to be caused by natural sources (geogenic origin). These instances of pollution include metal contamination in surface level waters, as well as sediments in the Ccamacmayo, Tintaya and Collpamayo water bodies. More than half of all monitored sites had at least one sample exceeding regulatory standards, and high metal concentrations (mercury, arsenic, cadmium, and lead) was found at 64 sites involving water used for human consumption. In addition, it was demonstrated that the people living near the mining activities were exposed to heavy metals such as arsenic, thallium and lead MINAM, 2013C).

The Action Plan became a long list of investment projects, including several water damming projects (Prado Esperanza) and projects in the Cañipia and Salado River basins (Sahuamayu, Huayllumayo, Tacomayo); projects for the installation of irrigation systems, reforestation projects at the provincial level; construction of canals; construction of a hospital; soil recovery projects with MINAG's Agrorural; electrification investment plan with the Peru Ministry of Energy and Mining (MINEM) and with the Peru Ministry of Transport and Communications (MTC) for the construction of roads in the province (MINAM, 2013A)

In response to the continuous and persistent complaints from the 13 communities in the area of influence of the Antapaccay mining operation, the Government issued the Ministerial Resolution No. 174-2020-PCM, dated July 22, 2020, where the working group called *"Multisectoral Commission in charge of evaluating possible damages in the area of the native communities of Huano Huano, Huini Coroccohuayco, Pacopata, Alto Huancane, Huancane Baja, Tintaya Marquiri, Alto Huarca, Cala Cala, Huarca, Suero y Cama, Huisa Ccollana, Huisa and Anta Ccollana in the province of Espinar, department of Cusco, and the corresponding repair plan if necessary".* This commission began operating in the middle of 2021.

The coordination of the commission's activities was in charge of MINAM, and the representatives of the communities participated with the advice of NGOs. Among the actions carried out was the review of the documents prepared on this issue by state institutions (INGEMMET, DIGESA, etc.) and agencies (ANA, OEFA, etc.). After several virtual meetings, MINAM, evaluated a preliminary report, which showed major methodological and conceptual shortcomings. In May 2021, a forum "Conflicts and dialogue spaces in Espinar: Balances and challenges" was organized.

IPEN's reports were not understood by OEFA, which led that the first report (December 2013) was observed. There was a second deliverable (March 2016), including Annex 2, with the results of the analysis of laboratory tests. In 2017, a second report was submitted with 5 deliverables, and the fifth was not approved by OEFA. This brought the case to court, a process that lasted more than four years. This information was only available in November 2021. These reports have been reviewed by experts, demonstrating that there is scientific evidence of tailings seepage into the subsoil. (IPEN, 2013; IPEN, 2017).

In the current year 2022, a campaign called "Espinar cannot wait" has been generated, with the participation of the communities affected by the contamination and the support of NGOs (DHSF, OXFAM, Cooperation, etc.).

5.2 Citizen Engagement

During the second visit to Peru in June – July 2022 by the DGFZ team, in company of SMEKUL representatives, interviews with local actors in different sites were performed. The objective was to receive feedback about the BLP Saxony Peru methodology and learn about the local concerns about water problems in different areas. Interviewed people correspond to local actors, with different participation levels at study sites and NGOs in Peru. More information on the results from the June – July 2022 visit can be found in Annex 3. Questions are divided in two sections:

- **Questions related to water problems in personal life:**
    - *How is your access to drinking water?*
    - *How is the access to drinking water in the communities that live in the areas of the projects you have worked in?*
    - *What is the main use you give to water in your family group and in the communities that live in the areas of the projects you have worked on?*
    - *What is the main water quality and/or quantity problems in the areas of the projects you have worked on? If so, what do you think is the cause of the problem?*
    - *How sensitive are the communities to a deterioration in the quality and/or quantity of water?*
    - *Is there information within the communities about water regulations and institutions in your city?*
    - *What connection do you see between water quality/quantity and development (health, infrastructure, education)?*
    - *In your experience, do water problems affect women as well as men, and indigenous communities as well as urban areas?*
- **Questions related to the BLP project:** The following paragraph was mentioned to the interviewed person:

  > *The BLP-SN-Peru project* ***seeks to generate an exchange of experiences between Peru and Germany (Saxony) regarding water management in post-mining areas****. The methodology consisted of visiting study sites in Peru with a history of water-related problems that could be linked to mining activities. Subsequently, practical activities were carried out to gather information (measurement of parameters, sampling of drinking water, installation of shallow sampling wells) that will be transmitted to local stakeholders. The aim is also to carry out small on-site training sessions that can help local stakeholders to monitor water quality.*

  Then, the following questions were asked:

    - *Do you think the project's initiative is innovative?*
    - *Do you think the study methodology and project management is adequate, and what suggestions would you propose to achieve the objectives?*
    - *If there were the possibility of carrying out a second stage of the project in relation to water management, what do you think should be the objectives of this?*

The results of the interviews are now presented. First, the interviewed person is individualized, and then the answers are shown. At the end of the chapter, a general outcome from the interviews is given.

Name: Ayde Huanqui Sisa (**Figure 5-1**)

Gender: Female

Age: 30 years old

Company - position: Municipal Manager, Madrigal Municipality

Ethnic group (if applicable): Quechua

Figure 5-1. *Mrs. Ayde Huanqui Sisa, Municipal Manager at Madrigal Town.*

<u>Questions related to water problems in personal life:</u>

Question (Q): How is your access to drinking water?
Answer (A): The access I must drinking water is through the drinking water network that we have in town.

Q: How is the access to drinking water in the communities that live in the areas of the projects you have worked in?
A: Access is the same because more than 90% already have access to the water network.

Q: What is the main use you give to water in your family group and in the communities that live in the areas of the projects you have worked on?
A: Human consumption and in the community is to irrigate their crops, their gardens, also for construction sites, it is being misused.

Q: What are the main water quality and/or quantity problems in the areas of the projects you have worked on? If so, what do you think is the cause of the problem?
A: In terms of quantity, water is being misused and this is harming the entire population because it is not being supplied. We need to regulate; we need an ordinance from the municipality so that we can sanction those people who are misusing water, and the amount of water is insufficient and drinking water should not be used for construction.

Q: How sensitive are the communities to a deterioration in the quality and/or quantity of water?
A: The population reacts strongly because we have become accustomed to having all our water networks in every home; for example, when we clean the reservoirs, we have to cut off the water to the population and well, they are already affected, they are sensitive.

Q: Is there information within the communities about water regulations and institutions in your city?

A: Recently, due to the mining issue we have here. We are able to know about the water qualities, all the samplings that are taken through the environment, more or less 4 or 5 years ago.

Q: What connection do you see between water quality/quantity and development (health, infrastructure, education)?
A: The quality of water is going to influence a lot, especially in education due to the issue of anemia in children; therefore, it is necessary to provide quality water. In terms of quantity as well, because the basic drainage services and all of this are already connected to it.

Q: In your experience, do water problems affect women as well as men, and indigenous communities as well as urban areas?
A: Women used to be affected by the water issue, if there was not a good quality of water for food preparation, but now that it is used for construction, men are also affected.

Questions related to the BLP project:

Q: Do you think the project's initiative is innovative?
A: Yes, because it is important to carry out this type of analysis, especially to see what quality of water we are consuming in the district and to be able, based on this, to determine solutions or propose solutions, to see how we can solve this conflict that exists.

Q: Do you think the study methodology and project management is adequate, and what suggestions would you propose to achieve the objectives?
A: It is good, because many do desk studies and doing it on site is different and more effective.

Q: If there were the possibility of carrying out a second stage of the project in relation to water management, what do you think should be the objectives of this?
A: As you have visited the area, there are 25 hectares of farmland that we do not currently use, so it is important that we recover this land so that we can improve our economy.

Q: Do you have any other message?
A: I feel very grateful for the participation, the collaboration that you have given us in the district of Madrigal, as you can see, it is the last district on the right bank of the Colca and we almost do not have much support due to the accessibility and all that; but with the support that you are giving us we are going to be able to be clear on many points and above all it was necessary to carry out this analysis because we have mining that they want to exploit in the upper part of the Palca River. So, we can demonstrate with this that now (the quality) is good and once it starts suddenly it will be possible, so it is a very important point for us to have now.

Name: Deysi Lisseth Callo Apaza (**Figure 5-2**)

Gender: Female

Age: 25

Company - position: SMRL Los Rosales, laboratory assistant

Ethnic group (if applicable): Quechua

Figure 5-2. *Mrs. Deysi Lisseth Callo Apaza, SMRL Los Rosales.*

Questions related to water problems in personal life:

Q: How is your access to drinking water?
A: In the place where I live there is access to drinking water, for human consumption, for the people who live in that place.

Q: How is the access to drinking water in the communities that live in the areas of the projects you have worked in?
A: (Access) is by normal pipeline.

Q: How is the access to drinking water in Los Rosales?
A: They bring in big bottles from Vilque. What would be missing (to improve) would be to implement more, to make a drinking water reservoir so that we also consume water.

Q: What is the main use of water in your family group and in the communities that live in the areas of the projects you have worked on?
A: In that aspect, we consume water for human consumption and also to wash our clothes; but for cultivation it is another water, which usually comes from the streams and that comes from the ponds or lagoons.
In Los Rosales, the water in general is treated because we see that they have several chemical components that are toxic, you could say, which needs treatment. The rest of the water in the area is used for irrigation of crops generally. I believe that the animals do not drink this water because there is a river beyond, and I believe that is where the water is captured for animal consumption.

Q: What are the main water quality and/or quantity problems in the project areas you have worked in? If so, what do you think is the cause of the problem?
A: The water problem here in Los Rosales is pollution due to the simple fact that here in the plant we use reagents and to make a water treatment it has to take more time, so when the water is all poured, for a good consumption it takes a long time.

Q: Would you associate the cause of this water problem to the mine in particular?
A: Generally, yes.

Q: How sensitive are the communities to a deterioration of water quality and/or quantity?
A: They are affected because contaminated water going to their crops or to the farm as they say is not feasible because they would simply be killing all the plants or their crops.

Q: Is there information within the communities about water regulations and institutions in your city?
A: There is little access to information because mostly the people who know about water contamination are more involved. There are people who do not know and simply do not take interest.

Q: What connection do you see between water quality/quantity and development (health, infrastructure, education)?
A: Well, in other parts yes, because every time, let's say, that we treat water for human consumption, at the same time it goes hand in hand with the infrastructure that can be supported here in the community; because yes, they also have the right to receive economic support, or something industrialized so that they can also be benefited.

Q: What has been the role or experiences of your company (municipality or NGO) where you work in water management?
A: Yes, I have seen during my time here that the company is also concerned about water treatment. Because even the company would not be concerned that the water is contaminated, we also must see as a company, as workers, to take care of the environment and try to take care of the water; to make a good water treatment so that everything flows well and there is no inconvenience for the worker or the population, for the community.

Q: What connection do you see between sustainable water management and women's independence?
A: No, mostly I am talking about the women here, we are doing well, in solidarity or simply working (as) a good team and at the same time we are sharing well with each other. And we are also doing well with respect to each other.

Q: In your experience, do water problems affect women as well as men, and indigenous communities as well as urban areas?
A: It does affect both men and women equally.

Q: And also equally to indigenous communities than urban areas?
A: Yes, it also affects equally.

Q: How feasible do you think it is to find a solution to the water problems, in what time horizon? What is needed? Who should act?
A: Yes, it is possible to have a solution, it is simply a matter of managing it or a follow-up for water treatments because each type of water has different treatments, but it could be controlled.
For these solutions we, the people, must act, and also if the company is involved in this, the company must also be involved to reach a good treatment, so that there is no contamination of the water.

<u>Questions related to the BLP project:</u>

Q: Do you think the project initiative is innovative?
A: Yes, it is very good. Thanks to you, to the experiences and the things that you bring for the Los Rosales company will be very useful for us, I also saw yesterday's initiative, how you handled or simply guided us on how to do or how we should sample the water, and everything with care. This is going to be very useful for us here for the Los Rosales company, especially the handling of the environment.

Q: Do you think the study methodology and the project management is adequate, and what suggestions would you propose to achieve the objectives?
A: Yes, it is really something new for us and little by little we will know how to cope, and we will be learning, and we will continue to apply it.

Q: If there is the possibility of carrying out a second stage of the project in relation to water management, what do you think the objectives should be?
Q: When we start working at the Candelaria mine we could make some good improvements later on, if you bring us the technology. Also, when we see you, how you work, we learn from all of this, so that we can continue to manage all of this (according to) what you do or carry out.

Name: Fiorela Enma Choquehuanca Medina (**Figure 5-3**)

Gender: Female

Age: 23

Company - position: SMRL Los Rosales, on-call chief

Ethnic group (if applicable): Aymara

Figure 5-3. *Mrs. Fiorela Enma Choquehuanca Medina, SMRL Los Rosales.*

<u>Questions related to water problems in personal life:</u>

Q: How is your access to drinking water?
A: Where I live the water is normal because I live in the city.

Q: How is the access to drinking water in the communities that live in the areas of the projects you have worked in? If answer is negative, what do you think is needed to improve access to drinking water?
A: There are rivers, there is a plant and I think that is where they are doing the treatment and that is where they distribute it.

Q: Do you know what the water source is for the people who work on this farm?
A: Through the river.

Q: They don't have sewage and drinking water?
A: No, there are water springs from which they rotate through various places from which they pump water.

Q: What is the main use of water in your family group and in the communities that live in the areas of the projects you have worked on?
A: For food, for cooking, only for housing. On the land it is for the harvest, for the crops and for the animals.
(In Los Rosales), in the plant what we do is to reuse, to recirculate our tailings, what we do is that it sediments, the solution comes out and we recover it. We try not to use this acid water or water that comes out of the mine, so it is a closed circuit.

Q: What are the main water quality and/or quantity problems in the areas of the projects you have worked on? If so, what do you think is the cause of the problem?
A: Well, sometimes, in our fresh water or water for consumption, in the dry season it decreases a little bit; then, we have to limit ourselves, we have to take care of it.
Of course, sometimes the treatment is the most careful thing, sometimes it goes away, you forget for a little while and then the pH rises and all that, but it is controlled, it is controllable.

Q: In relation not only to Los Rosales but also to the area, for example, with artisanal mining, does that generate a problem in the water?
A: Of course, I have not seen it now, but before they did release acidic water, upstream, but they have already had an agreement and have been talking. I believe we have agreed that it is going to be treated or we are going to treat it.

Q: How sensitive are the communities to a deterioration in the quality and/or quantity of water?
A: We know very well that water is life, yes, they are sensitive because this is part of the livestock, the harvest, the whole livelihood; so it is very important that we deal with it and that we support the community. So far there have been some problems, but it has been because sometimes the flow of the mine increases and that is when the people from above, or the artisanal miners, release the water. The flow increases and then it gets a little out of control, but it is always manageable, it is always treatable.

Q: Is there information within the communities about water regulations and institutions in your city?
A: Yes, there were workshops with the main people, the board of directors, where it was made known that it was going to be dealt with, and also some meetings where it was made known that it was going to be dealt with. There are agreements with the community itself.

Q: What connection do you see between water quality/quantity and development (health, infrastructure, education)?
A: Of course, because as long as our water quality is better, our health will be much more comfortable for each one of us; but if our water is a little contaminated, our health itself plays a role.

Q: What has been the role or experiences of your company where you work in water management?
A: With water management I have learned many things, there are many issues to investigate, many projects to implement, to test and at the moment we are dealing with the pH or with the tests we have; however, we are also looking for more ways to solve or to provide better treatment. Our goal is to improve and optimize.

Q: What connection do you see between sustainable water management and women's independence?
A: Yes, more than anything women are related to Pachamama. Pachamama is the earth, she is the main character of our culture. If they develop it with empowerment, well the environment itself inspires them, I trust in a woman, in a lady and that gives you more security, more self-confidence. Before, in old times, in general, ladies or women used to manage, maybe not so much in the mining world, but more clerical, you could say. Now we are going out to the field, we experiment, we talk with our colleagues or go to the communities, and we try to be more sociable and open, more empathetic with others.

Q: In your experience, do water problems affect women and men in the same way, and indigenous communities and urban areas in the same way?

A: The communities are always going to be more exposed, as I told you, it is from that riverbed or river that they get their sustenance, whether it be for their farms, for livestock, even for consumption; however, in an urban area, in a town, there are treatments and there is no problem.

Q: How feasible do you think it is to find a solution to the water problems, in what time horizon? What is needed? Who should act?
A: We should act. The acidic water that comes from the mine, we did not cause it, it comes from the interior; what we propose or have as an objective is to treat it and improve it, as I was saying, to optimize it so that it can be used for drinking water or something like that. We need a lot of testing and experimenting as well.

Questions related to the BLP project:

Q: Do you think the project initiative is innovative?
A: Of course it is, it is very innovative, it will help us a lot to improve our quality of life, both in the plant and in the communities, and it will help us a lot to help others as well.

Q: Do you think the study methodology and the project management is adequate, what suggestions would you propose to achieve the objectives?
A: Yes, because the first step is a little difficult to take, and then, at the moment of having an initiative you get inspired and generate confidence and you go to everything always thinking about the goal and the objective. I suggest to be more constant in the trainings and talks.

Q: If there is the possibility of carrying out a second stage of the project in relation to water management, what do you think should be its objectives?
A: This could be the mine closure, it is another of the problems, and they are large studies.

Name: Kenny Carol Caballero Marchan (**Figure 5-4**)

Gender: Female

Age: 43

Company - position: DESCOSUR - Project manager and natural resources management specialist

Ethnic group (if applicable): Mestizo

Figure 5-4. *Mrs. Kenny Caballero, Descosur.*

<u>Questions related to water problems in personal life:</u>

Q: What is your access to drinking water like?
A: In the Salinas y Aguada Blanca National Reserve (RNSAB) area, the main population centers have access to spring water, which is purified for domestic use.
At the ranch level, water comes from natural sources (springs) and is not purified.

Q: How is the access to drinking water in the communities living in the areas of the projects you have worked in?
A: The communities have access to water through natural sources (springs).

Q: What is the main use of water in your household and in the communities living in the project areas you have worked in?
A: In my family group we use it directly for food preparation, personal hygiene and other daily domestic activities.
In the communities the use is for food preparation, family hygiene, as well as for improving their natural pastures and raising domestic livestock (alpacas, llamas and sheep).

Q: What are the main water quality and/or quantity problems in the project areas you have worked in?
A: Regarding quantity, the main problem is related to climatic variations, referred to a decrease in rainfall, with a marked wet season (rains) and dry season, the presence of water in the area depends directly on rainfall, so measures must be taken to adapt and ensure the availability of water. Regarding quality, the main problem is the loss of vegetation cover due to bad practices by the peasant communities, such as overgrazing and inadequate water use.

Q: What do you think is the cause of the problem?
A: Climate change, bad livestock practices

Q: How sensitive are the communities to a deterioration in water quality and/or quantity?
A: They are quite sensitive, because they depend directly on water for subsistence and to raise their livestock, which is their main economic activity.

Q: Does information exist within the communities about water regulations and institutions in your city?
A: No, it does not exist, because the legislation on water resources is recent, and it has not been adequately socialized with the populations of the highlands.

Q: What connection do you see between water quality/quantity and development (health, infrastructure, education)?
A: It is a direct and strong connection, because if the quality and quantity of water are assured, adequate development of the populations will be achieved, which includes an improvement in the quality of life.

Q: What has been the role or experiences of your company (municipality or NGO) where you work in water management?
A: DESCOSUR is a pioneer in actions related to planting and harvesting water, activities that have been replicated by the population due to their effectiveness and efficiency. We have played a role as promoters of good practices for the management of natural resources, which have been implemented with some populations in the highlands.

Q: What connection do you see between sustainable water management and women's independence?
A: The connection is direct, because it is women who are in charge, most of the time, of managing the ranch, assuming not only a reproductive role, but also a productive one. They are the "heads" of the family who for a long time have been invisibilized.

Q: In your experience, do water problems affect women and men in the same way, and indigenous communities and urban areas in the same way?
A: Water problems affect men and women in the same way, since the use given to it is the same, the purpose of properly managing water is to ensure water for the family's subsistence and for raising domestic livestock, so there is no difference in its use or affectation.
Where there is a difference is between rural communities and urban areas, because the accessibility and availability of water is different.

Q: How feasible do you think it is to find a solution to water problems, in what time horizon? What is needed? Who should act?
A: A solution can be found, but in the long term, with an adequate management of water resources, which not only contemplates actions to ensure its quantity and quality, but also strengthens grassroots organizations so that local populations can replicate good practices and make appropriate decisions for its management. Water management must be comprehensive, in which all stakeholders converge, in a real and participatory manner.

Questions related to the BLP project:

Q: Do you think the project initiative is innovative?
A: Yes, it is an innovative idea to make monitoring participatory.

Q: Does the study methodology and project management seem adequate to you? What suggestions would you propose to achieve the objectives?
A: Yes, I think the methodology is adequate. All factors that may influence water quality (sewage and/or gray water discharge, old mining concessions, thermal waters and nearby springs, etc.) should be taken into account and monitoring points that can be comparable (other watercourses) should be taken into account. It is important to take into account the historical climatic and geological basis.

Q: If there is the possibility of carrying out a second stage of the project in relation to water management, what do you think should be its objectives?
A: Measures/actions for the restoration of water quality that are accessible to the population, i.e., that the population can implement them.

Name: Delmy Poma Bonifaz (**Figure 5-5**)

Gender: Female

Age: 45

Company - position: DESCOSUR - President

Ethnic group (if applicable): N/A

Figure 5-5*. Mrs. Delmy Polma Bonifaz, DESCOSUR.*

<u>Questions related to water problems in personal life:</u>

Q: What is your access to drinking water like?
A: The families of the RNSAB maintain a dispersed housing pattern with the so-called ESTANCIAS, which are family dwellings with distant levels of neighborhood (3 to 4 Kms. distance between each estancia). The water supply in the estancias is only from springs and irrigation ditches. There is no access to potable water on these ranches. The public network for access to drinking water is located in the towns, localities and district capitals where education, health, justice, commerce, etc. are also concentrated.

Q: How is the access to drinking water in the communities living in the areas of the projects you have worked in?
A: There is an urgent need to improve access to drinking water in these territories.

Q: What is the main use of water in your household and in the communities living in the project areas you have worked in?
A: The use of water is mainly for human consumption, hygiene, but also for the management of the productive base of South American camelids, since it is the only productive activity in the area.

Q: How sensitive are the communities to a deterioration in water quality and/or quantity?
A: There is no full awareness of the deterioration of quality and/or quantity, but rather the sensitivity is due to the need for access in the cabins or ESTANCIAS.

Q: Does information exist within the communities about water regulations and institutions in your city?
A: In the populated centers where there is potable water service, which is provided by the Municipalities or in some others by the Administrative Boards of Sanitation Services (JASS), the population has limited knowledge about the regulations and obligations as well (there is little culture of care and payment of the tariff), and it is normally subsidized.

Q: What connection do you see between water quality/quantity and development (health, infrastructure, education)?
A: The problem of not having access to quality and quantity of water in the high Andean zones adds to the historical gaps suffered by these populations, such as the quality of health services, communication routes, internet access, education, among others. These territories remain in poverty or extreme poverty.

Q: What has been the role or experiences of your company (municipality or NGO) where you work in water management?
A: Local governments are concerned about providing these services, particularly in district capitals or towns and localities with high population concentration, whose investment costs have an equitable relationship with the number of beneficiaries.

Q: What connection do you see between sustainable water management and women's independence?
A: Women and girls are the most related to water, since they are mostly in charge of household responsibilities and for several months they are also in charge of productive activities, in which water is the fundamental element for these activities, the lack of access, as well as the dedication to water management to improve their pastures and therefore the feeding of their animals is directly related to water management and their independence.

Q: In your experience, do water problems affect women and men in the same way, and indigenous communities and urban areas in the same way?
A: The problem of water does not affect equally, in rural areas there is no access to drinking water, in some cases you have to walk several meters or even kilometers to access a "water source" to collect it in the ranches or cabins, in the case of populated centers due to little knowledge or even irresponsibility of both municipalities and JASS water is not chlorinated or treated, that is, the population has water in their homes but this is only piped.

Q: How feasible do you think it is to find a solution to water problems, in what time horizon? What is needed? Who should act?
A: Access to drinking water in dispersed population centers is a challenge for the country, because it requires validation through research and testing to find the model that will serve so that families settled in "ESTANCIAS or CABAÑAS" can have a water system that gives them access, the piped system that is implemented in the population centers is not feasible in these dispersed areas because it implies abysmal budgets that are impossible to be covered.

<u>Questions related to the BLP project:</u>

Q: Do you think the project initiative is innovative?
A: Yes, the project is innovative, especially when mining management and its impact on water quality is questioned in Peru.

Q: Does the study methodology and project management seem adequate to you? What suggestions would you propose to achieve the objectives?
A: The training of local stakeholders should be more of a training program that can later be replicated by some public or private entity and that is articulated with the municipality or with

the JASS, if the latter is the one that exists, it would be the members who participate in the training program.

Q: If there is the possibility of carrying out a second stage of the project in relation to water management, what do you think should be its objectives?
A: Generate research on water sources to design water supply models for dispersed rural populations. To investigate the quality of groundwater resulting from the infiltration of the "Sowing and harvesting of water".

General findings from the interviews

From the five interviews collected from local stakeholders in the study area, there is a general perception that there is access to fresh water from natural sources such as rivers and springs, which are used for human consumption, agriculture: and livestock or small-scale domestic animal farming. They also indicate that the main water problems are related to the lack of potable water treatment, lack of infrastructure, and limited availability of fresh water during the dry season. These problems seem to be related with health issues; it is worth mentioning the situation of some group living in “estancias”[1] in the Andean territories where the population does not have access to drinking water or other basic services, being the indigenous population the most sensitive. On the other hand, in the area of Los Rosales, the stakeholders perceive an influence of mining on water problems, linked for example to the presence of artisanal mining. Also, it is observed that the regulations related to water management are not known by the entire population.

It is important to highlight the perception of gender equality regarding water problems; currently; women and girls have assumed a productive role within the families and find solutions to these problems by working as a team within their community. For their part, the institutions represented are involved in different ways in water management, for example SMRL Los Rosales performs acid water treatment and DESCOSUR has actions related to the plant and water harvesting.

The solutions proposed by the stakeholders include improvements in water management, which should be integrated and participatory, better monitoring of water quality, improvements in treatment and access to drinking water for the population centers scattered in the Andean areas.

Finally, there has been positive feedback from the present project. It is hoped that training programs for local stakeholders can be reinforced and that studies for the remediation of possibly contaminated sites and evaluation of water sources can be deepened.

[1] "The estancias or hatus occupy the peripheral spaces surrounding the administrative centers or towns of the localities. Although the human settlement is dispersed, there are in some small groupings of ranch houses (hatus wasikuna), around a free space and with corrals or roosts (kanchakuna) in the periphery." (Palomino, 2012)

5.3 Local water management solutions in the Salinas y Aguada Blanca National Reserve

The Salinas y Aguada Blanca National Reserve is located in the provinces of Arequipa (RNSAB), Caylloma and General Sánchez, in southern Peru (**Figure 5-6**). Descosur, an NGO, has been working there since 2007 through a Partial Administration Contract signed with the Ministry of Environment in 2006. In 2012, an extension of the contract was approved until 2027.

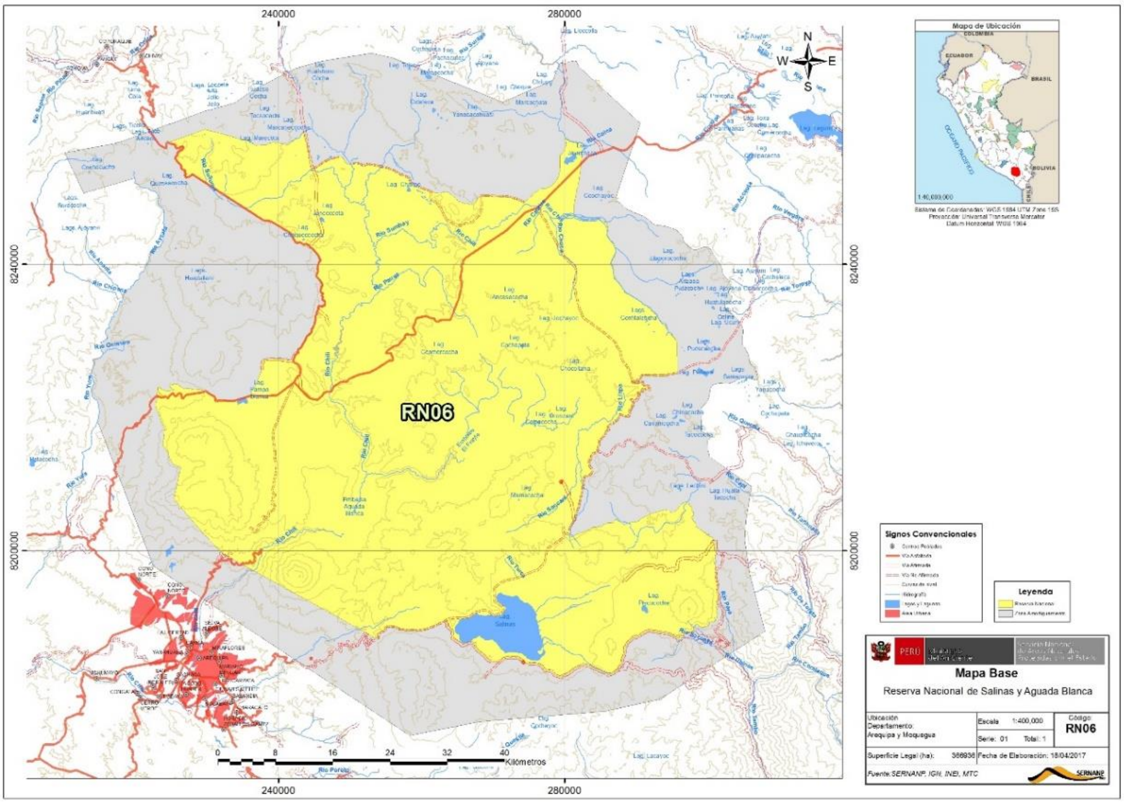


Figure 5-6. *Location of Natural Reserve Salinas y Aguada Blanca.*

Source: SERNANP

Descosur works in RNSAB together with local communities on projects focused on resource management. During the 2022 trip, Descosur invited the DGFZ team to visit RNSAB to see the results obtained to date, where they saw the projects of Mrs. Brigida Huachani Lasarte **(Figure 5-7),** who with Descosur's support has developed two local water management projects, within the concept of planting and harvesting water.

Brigida's economic activity, like most of the local communities in RNSAB, is the breeding of Alpacas, for the subsequent sale of wool or meat. Mrs. Brigida built a small water reservoir in 2020, located near her home and the place where she raises the Alpacas. This reservoir allows her, among other things, to have drinking water for her home, for irrigating her land and for drinking water for her alpacas. Before this project, the source of drinking water was a canal on the side of the road, which was constantly contaminated with garbage thrown from cars, and there was no control of water storage and protection. Along with improving water storage for her, other improvements included improving the soil where her alpacas graze. She planted local grasses from nearby areas, and the reservoir allows her to optimally irrigate her crops through irrigation canals (**Figure 5-8**), for the alpacas' food. These areas have been historically deteriorated and the soil quality was not good enough for alpaca raising, and through Mrs. Brigida's project they have been able to recover the soil quality by improving water management, thus allowing for an improvement in their economic livelihood (**Figure 5-8 and Figure 5-9).**

Figure 5-7. *Mrs. Brigida Huanachi Lasarte, in National Reserve Salinas y Aguada Blanca.*

Figure 5-8. *Local water storage and distribution management at RNSAB*

left: small reservoir. right: irrigation channels built by Mrs. Brigida Huachani

Figure 5-9. *Different areas improved by Mrs. Brigida's project.*

Another project visited was the micro-dam built by Mrs. Brigida in 2021. This micro-dam was built within the other properties of Mrs. Brigida, responding to the problem of rainwater storage that has been affected by climate change. As in the previous project, this micro-dam improves local water management, increasing storage capacity for soil improvement, planting pastures and drinking water for animals **(Figure 5-10).** Mrs. Brigida indicated that in late years, rains are coming in fewer months, having more intense rains but in shorter time periods, therefore having the problem of properly storing the water for later use in dry periods. This project comes as a solution for that problem.

According to Descosur, this type of local solutions can also help on a bigger scale. By improving storage capacity upstream of watersheds, retention time is increased. This results in a greater capacity for infiltration at upstream areas, reducing stream run off, causing less problems by high flow rates (e.g., floods) in the downstream areas, where the city of Arequipa is located.

Data shared by Descosur on results from Mrs. Brigida's projects indicates a total of 13.5 ha of improved area, a total capacity of 5000 m³ of water for the microdam, and a storage of 800 m³ of water on 2020 and 360 m³ on 2021 for the small reservoir **(Table 5-1).**

Table 5-1. *Summary of results from Mrs. Brigida*

		2020		2021	
Project	**Unit**	**Small reservoir**	**Microdam**	**Small reservoir**	**Microdam**
Capacity	**m³**	800	N/A	360	5000
Improved area	**ha**	3	N/A	1.5	9

Figure 5-10. *Micro-dam project within the properties of Mrs. Brigida*

Up: Microdam wall. Middle: Collected water. Down: Channel and improved lands.

6. Summary and Challenges

The project "Water protection in the mining rehabilitation in Peru" was part of the German Government and Federal States Programme (German: Bund-Länder-Programm, BLP), which was coordinated by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH on behalf of the Federal Ministry for Economic Cooperation and Development (BMZ).

A review on the existing experiences on water management in post-mining sites from Saxony was done in the context of the BLP project Saxony-Peru, in order to strengthen the capacities of selected subnational administrations in Peru to implement international standards of water protection in post-mining rehabilitation.

The BLP project "Water protection in mining rehabilitation in Peru" focuses on the effects of mining on water and the necessary water protection. Water is of paramount importance for many areas of life. Water itself is a habitat and at the same time fulfills essential functions for other habitats of plants and animals. It is a necessary and indispensable resource for the drinking and service water supply, for food production and for ensuring a wide range of economic activities.

Recognizing the climate change regional effects and the need to achieve a structural change in energy use, Saxony will have to deal more intensively with questions of sustainable rehabilitation and management of water bodies, especially in mining areas but also in other landscapes. The main task of water management in Saxony will therefore be to organize sustainable use of water as a limited resource. To this end, SMEKUL has drawn up the "Principal Concept for Water Supply 2030", which is published in 2022. But it is not only the renovation that plays a role here, the social consequences must also be dealt with. Saxony has therefore set itself the goal of creating new jobs in post mining regions by establishing new, primarily innovative branches of industry in order to be able to offer alternatives to the local population.

6.1 Summary of project results

Water protection related regulations from Peru were reviewed to understand the legal framework in Peru for water management in mining affected areas. In addition, water protection regulations from the EU and Germany, together with regulations related to the management of contaminated sites from Saxony were reviewed to compare the legal instrumentation in Germany with Peru (**Chapter 2**). The German and Saxon legal framework resulted to be more detailed on contaminated sites. Furthermore, differences on environmental quality standards were identified between both countries. Peruvian environmental quality standards are based on the end-use of water bodies, while German are based on the nature of each water body, having a more complex classification (23 types of surface water bodies). In addition, no specific groundwater EQS were found in Peruvian regulations, as opposed to German EQS from *GrwV.*

The Saxon methodology for contaminated sites management SALM was presented, describing the subsequent steps contained (**Chapter 2.3**). Historical investigations were conducted on study sites from Peru with the available information prior to any field activity (**Chapter 3.1**). Afterwards, oriented investigations on selected sites were planned, in order to obtain more detailed information on identified pathways of pollutants (**Chapter 4.1**).

A state of the art on water treatment techniques was done based on the VODAMIN and VITAMIN projects of the Saxon State Office for Environment, Agriculture, and Geology LfULG (**Chapter 2.4**). Main processes involved in water treatment were explained, different classifications were presented and finally the criteria for selection of proper techniques were presented. Best recommended water treatment methods and the selection criteria to apply for the local peruvian conditions have been summarized in **Chapter 4.3.4**. Metal contaminant retention by wetland technologies and classical oxidative mine water treatment were identified to gain the highest scores of local applicability.

Three reference sites in Southern Peru have been finally studied in this BLP project:

- the Los Rosales secondary mining site located in contact to the Vilque River Basin in the Puno region;
- the community of El Madrigal in the Colca River Basin with deposits of former copper and gold mining on their territory and;
- the National Reserve Salinas y Aguada Blanca as the formation zone of the Chili River Basin and the main water storage and supply region for the city of Arequipa.

Investigations on mining implications to the water catchments were performed at the Los Rosales and Madrigal sites, and are included in **Chapter 4** of this guide (see Annex 1 for the detailed information of both sites).

Results in Los Rosales allowed to identify both surface and groundwater as pathways for contaminants. High concentrations of metals and sulfate are consistent with the presence of AMD, in surface water and groundwater. Three shallow monitoring wells were installed in Los Rosales, allowing the monitoring of groundwater in the site for the first time. An enhanced environmental water monitoring concept has been proposed and has been started to implement in cooperation with Saxon partners during trainings in June 2022. A mobile testing lab and instrumentation for sampling have been provided to the environmental department of Los Rosales. The monitoring concept adds groundwater filtrates, spring waters, treated mine water with stream sampling (collecting channels), and the Vilque river to the existing programme. Furthermore, an advanced oxidization installation in the processing water ponds of tailing secondary leaching has been recommended for effective water circulation and reuse. Also, black waters of the mine village should be monitored and treated.

Results in Madrigal allowed to identify high concentrations of some metals and sulfate in rivers near the Madrigal Mine area. No specific source of these contaminants could be identified. Also, results on Madrigal drinking water comply with drinking water regulations. An in-situ short training on water sampling and field analysis was given to the local committee of water control. The importance of a quality control of spring waters and the protection from pollution risks of the up-hill spring area have been addressed. Possibilities for a technical improvement of the filtration ponds of the local drinking water plant have been recommended. Care should be taken with the use for irrigation of filtrate drainage affected creek waters in a (closed) mine tailing affected sub-valley of the location of Madrigal.

At the National Reserve Salinas y Aguada Blanca, an example of typical conflicts in rural regions is presented: local water retention and nature protection, informal mining, and water supply for urban areas and industry (see **Chapter 5.3**). Enhancement of performance of micro reservoirs, and control of water storage (including losses) and quality in sensitive sub-regions of the RNSAB have been discussed as a step for strengthening the cooperation between the local population and down-stream main users of the water resource. Nature and environment protection is needed to be integrated given by RNSAB regulations.

Saxon references sites were selected considering their experience on water management at post-mining sites (**Chapter 3.2**). The focus was on the Ecological Remediation Main Projects in Saxony of Dresden Coschuetz-Gittersee and SAXONIA Freiberg with the Davidschacht. Moreover, additional information of the German federal mining rehabilitation entities Wismut and LMBV have been integrated with their remediation sites of Koenigstein, Seelingstaedt, and Bielatal in Saxony. Based on these experiences different measures applied in the reference sites were presented in **Chapter 4**. Preventive measures such as flooding, water treatment, and containment as well as monitoring experiences are detailed.

Finally, social conflicts at post-mining sites are discussed (**Chapter 5**). Local women and indigenous inhabitant engagement is presented in the form of interviews to local actors from different study sites. These interviews were done during the visit to Peru in 2022. Here is reflected the concern to ensure water access for domestic and occupational activities, as well as participation in water resources protection measures. The case of Mrs. Brigida Huachani Lasarte in the Reserve Salinas y Aguada Blanca is presented as an example of positive experience on local water management. With the support from Descosur, she is developing a project in order to improve the local water supply, and this way improve land use for her main economic activity, llama breeding.

6.2 Statements of representatives of the State of Saxony

Burkhard Huth, project coordinator of SMEKUL:

With the direction of the German Society for International Cooperation (GIZ) and with co-financing from the Free State of Saxony, proposals for two mining sites in the provinces of Arequipa and Puno in southern Peru were drawn up, which offer possible solutions adapted to the local conditions for the use of environmentally friendly technologies for a sustainable water protection in post-mining areas and the management of limited water resources. In a discussion process with members of national and sub-national authorities as well as local actors, including members of indigenous population groups, possibilities for citizen participation were tested. Taking into account the experiences of saxon sites, which were visited by a peruvian delegation, and the legal regulations applicable to Peru and Germany, a technical guide was created that will support the competencies of Peruvian authorities in the implementation of applicable laws on water protection in post-mining operations. The project contributes to the realization of SDG goal 6 "Clean water and sanitation".

Dr. Christin Jahns, SMEKUL:

The aspects of climate protection, energy transition, raw materials boom, and mining and environmental protection are closely interrelated. Water protection and water management are not only affected here, they are also an essential basis for the successful implementation of the respective goals. We are facing complex challenges that can only be overcome through joint efforts. Cooperation at state government level, as in the BLP project “Water protection in mining rehabilitation in Peru”, can only be an initial. In our understanding, such projects can and should provide impetus for intensified cooperation in the scientific and economic sectors between the partner countries. I would like to promote this on behalf of the Saxon Ministry for Energy, Climate Protection, Environment and Agriculture SMEKUL and the Saxony Trade &

Invest Corporation WFS. It should understand as an essential guiding principle that knowledge transfer is not one-way. We are also open to impulses and ideas from Peru.

During the visit to the water treatment plant of the municipality of Madrigal, it became clear that there are opportunities for cooperation in questions of safe water supply. I would like to thank the implementation partners in the BLP for being open to the questions of the Madrigal community and providing them with technical support in addition to the main BLP tasks. During the German delegation's trip, I also got to know the protected area "Salinas y Aguada Blanca" near Arequipa. I would like to thank the DESCOSUR institution for the presentation and excursion to this region of impressive images and hard living conditions. It was shown, what role sustainable land and water management can play on water supply safety and the support of the population in rural areas.

Of further interest on the part of SMEKUL is the secondary mining, i.e., the reprocessing of old mining dumps for the production of secondary raw materials. Ideally, there should be found a combination of remediation of old mining sites and residues with the extraction of valuable materials. This is already being implemented by the mining company SMRL Acumulacion in Los Rosales. I would like to thank their representatives for the interesting excursion. I was impressed by the technological developments still planned to improve the process flows and to diminish the impact to soil and water. We hope that the recommendations of the BLP can provide important impetus. I was also pleased that BGR was involved in the development as part of the BMZ-GIZ project MINSUS. In my opinion, the cooperation with the National University of the Altiplano in Puno, in particular with the Faculty of Mining Engineering, is also of high importance. Because today's students will be tomorrow's engineers.

6.3 Statements of representatives of Peruvian project partners

Ing. Ronal Fernandez Bravo, ANA Arequipa:

The BLP project and the final visit to Saxony have been extremely beneficial for my activities in the National Water Authority, especially in the areas of monitoring and control of water quality in sources affected by mining activity. There were two aspects that are useful for my work: a) the treatment that is carried out for the closure of mines, considering the environmental impacts that they produce; b) a useful topic has been the research on filtering systems in water treatment, because in southern Peru natural waters have high arsenic and boron contents and require efficient but low-cost systems. I would like to continue the cooperation in technologies of water treatment systems for purification, mainly in filters and the use of flocculants or coagulants for heavy metals to precipitate.

Geog. Oliver Huamán Soto, SMRL Acumulación Los Rosales:

The project was of great importance for the development of the company based on caring for the environment through the implementation of groundwater and acid mine water monitoring. The project support helped us to get information on the quality of groundwater to avoid any alteration due to the Los Rosales mining project.

Particularly, the study trip to Saxony has been enriching, knowing how can be approached the problem of mining in the closure or sanitation in the field of water, energy, among others. The importance that is given to research, technology, and the academy, is what I can highlight the most. A perspective aspect for our company is the alternative use that can be given to the land after the closure of mines. That caught my attention, perhaps I need to complement more practical cases in this field.

Biol. Delmy Poma Bonifaz, Descosur Arequipa:

The project allowed me to identify possibilities so that the demand of good practice in water management can be met and the roles that can play the population and civil society for this. What was new was the involvement of various actors to carry out the studies that allow for the different perspectives and perceptions.

An important aspect of the visit to Saxony was the opening for alliances for academic exchange that would serve to strengthen local capacities for a good management of water resources. With the Basin Council and the head of the Salinas and Aguada Blanca Reserve, a good governance platform is in discussion for the implementation of measures with the Retribution Mechanism of SEDAPAR Ecosystem Services. We are insisting on the importance of investigation in monitoring. I would like to implement a training program on management of water resources related to mining and high mountain ecosystems directed to young professionals in the region. This could be semi face-to-face to make it more possible.

Furthermore, I would like to promote a collective critical understanding of the effects of environmental degradation and climate change, as well as the damages of the linear economy, in the territory and families of the inter-Andean valley and high mountains of the western cordillera of dry Puna. It could be created a community of practice to study and advocate based on evidence on the installation of a territorial laboratory related to natural resources in climate change for sustainable development. The Chila mountain range suffered the disappearance of about 99% of its snow-covered surface caused by global warming. The mountain range provides water to the Valley of the Volcanoes, as well as being part of the headwaters where the construction of a new dam with a capacity of 1,100 million m³ is planned as part of an irrigation system for Arequipa.

Ing. José Luís Valverde Ortiz, Arequipa:

Madrigal is a town that is very close to a closed mine that used the waters of the nearby rivers and that are the same ones that currently serve as a source for drinking water supply to the community, as well as to irrigate their cultivated land. Since long ago, the authorities and community have been very concerned about not knowing with certainty if the waters were or were not contaminated by the closed mine. The project has served to evaluate the water quality with specialized experts and with properly calibrated equipment. The responsible for the local medical station must control the quality of the drinking water. The training has served to replicate good practice in planning and monitoring of controls they have to carry out routinely.

Participation in the DGFZ team gave me the vision to contribute to water management at mining sites, but especially, to suggest and develop the rules of governance that make the sustainable management of resources in mining areas. I would like to implement an effective local water education plan as a sustainable work that guarantees results that can be replicated across the country. Trained in standards and encouraged the good use and control of water, everyone should have access to safe water and sanitation.

7. References

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8. Annexes

Annex 1. BLP Travel Report October-November 2021

Annex 2. BLP Travel Report June-July 2022

Annex 3. BLP Study tour in Saxony 2022

Annex 4. German Federal Soil Protection Ordinance 2021

Annex 5. Presentations and recommendations in Peru