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Management of passive biological water treatment systems for mine effluents

Short title: **Management of biological mine effluent treatment systems**

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Abstract

This contribution describes the approach of WISUTEC, a subsidiary of the mine remediation company WISMUT, to passive biological water treatment as a long-term solution to water contamination problems at former Uranium mining and milling sites.

The paper starts with an introduction into the WISMUT project, with special emphasis on water management and treatment in the closure and remediation process of decommissioned mining and milling sites, and illuminates the variety of water-related problems within this framework. One of the peculiarities of mining and milling operations in Germany and Europe in general is the relatively high population density in the affected mining areas and the scarcity of land, compared to other typical mining regions worldwide. This also leads to strict requirement with respect to the technical solutions applied in mine closure and, in particular, to restrictions on the land surface available for semi-natural and constructed wetlands. The regulatory expectations with respect to compliance with discharge standards and long-term stability are high, and command highly effective solutions on a small area.

Apart from rather general aspects, the paper also highlights the practical experience from design, construction and the first years of operation of the Pöhla wetland as a well-suited example.

In particular, the present paper shows the pitfalls and potential problems including some realistic cost estimates which are often hidden behind the general, over-optimistic statement of "maintenance-free, zero-cost" passive water treatment systems.

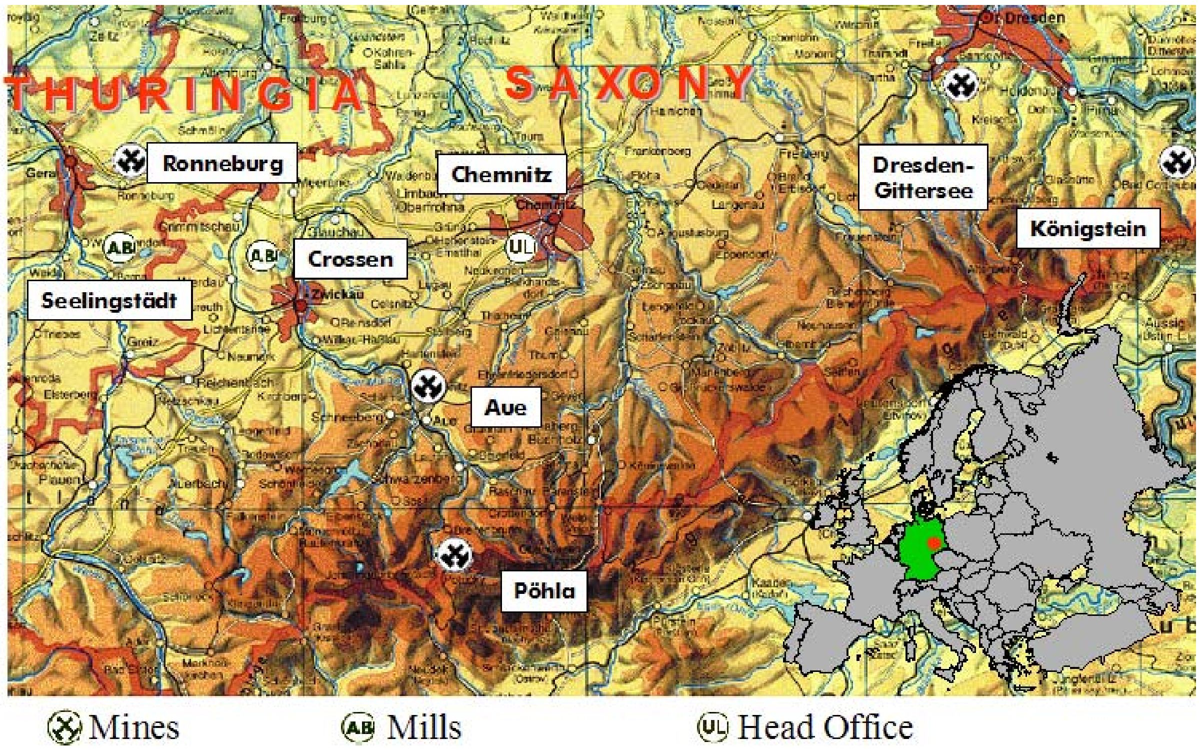
Keywords: constructed wetlands, passive biological water treatment, adsorbents, uranium, radium, arsenic, iron, manganese

1 Introduction

In the period of the cold war, the Soviet, later Soviet-German company WISMUT had become the 3rd-largest producer of natural Uranium in the world, supplying the Soviet nuclear program with approximately 230,000 tons of Uranium. Upon the fall of the Berlin wall in 1989, the operations which had become less and less viable, came to a sudden standstill, and WISMUT was transformed into a company commissioned with the cleanup and remediation of the mining and milling sites, and is owned by the German Ministry of Economy (Mager 1996).

The German government devoted a total budget of around 6.5 billion € to what has become known as the WISMUT Project. These funds do not only cover technical tasks, however, but are also used to bolster the socio-economic consequences of the abrupt end of mining in the East-German *Länder* (federal states) of Saxony and Thuringia which struggle with serious economic challenges after German re-unification. The presence of radioactive contamination on large areas may have contributed to the attention the WISMUT Project has attracted over time since the early 1990's. Since then, WISMUT has become a key reference and benchmark for mine closure, rehabilitation and regional redevelopment on an international scale.

Figure 1 WISMUT mine and mill sites (Inset in the lower left corner shows the location of the WISMUT Project in Europe)



The following data may convey an impression of the environmental legacy tackled by the WISMUT Project:[1]

- 3700 hectares of mining liabilities
- 2 large ore processing plants (Seelingstädt, Crossen)
- 311 million m³ waste rock dumps, partly radioactive
- 600 hectares of tailings management areas (10 tailings ponds)
- 4 underground mines (Pöhla, Schlema, Königstein, Gittersee) and an open pit mine connected to underground operations (Ronneburg)
- 31 million m³ per year mine water discharge

The main tasks of the WISMUT Project are

[1] This list contains only liabilities of WISMUT as of 1990.

1. flooding and geotechnical stabilisation of underground mines, particularly those which came close to the surface and may lead to subsidences
2. closure and long-term stabilisation of tailings ponds
3. in-situ remediation (including covering) or relocation of waste rock piles
4. demolition of production plants, cleanup and redevelopment of the affected property

Flow rates and contaminant concentrations in the effluents of WISMUT sites lie roughly in the following ranges:

- Flow rates:
  - Seepage: 1...10 m³ per hour, partly strong fluctuations up to 100 m³ per hour
  - Mine effluent: 10...1,200 m³ per hour, depending on catchment area of mine
  - Free water removal from tailings ponds: approx. 200 m³ per hour
- Contaminant concentrations:
  - Uranium, Arsenic: a few mg/L
  - Radium: a few Bq/L
  - Sulphate: some 100 to 1000 mg/L
  - Nitrate: some 10 mg/L
  - Iron, Manganese: some 10 mg/L

Water treatment is one of the largest single cost items of the entire project, being invoked in at least the first 3 tasks of the above list. The importance of water treatment derives mainly from the long period of time over which water treatment at the various sites is required, the high flow rates at some sites and, partially, from the complex chemism of the effluents for which off-the-shelf solutions did not exist (Kießig and Kunze 1996). Apart from the consumables, the high costs result mainly from the expensive labour of staff in the water treatment plants.

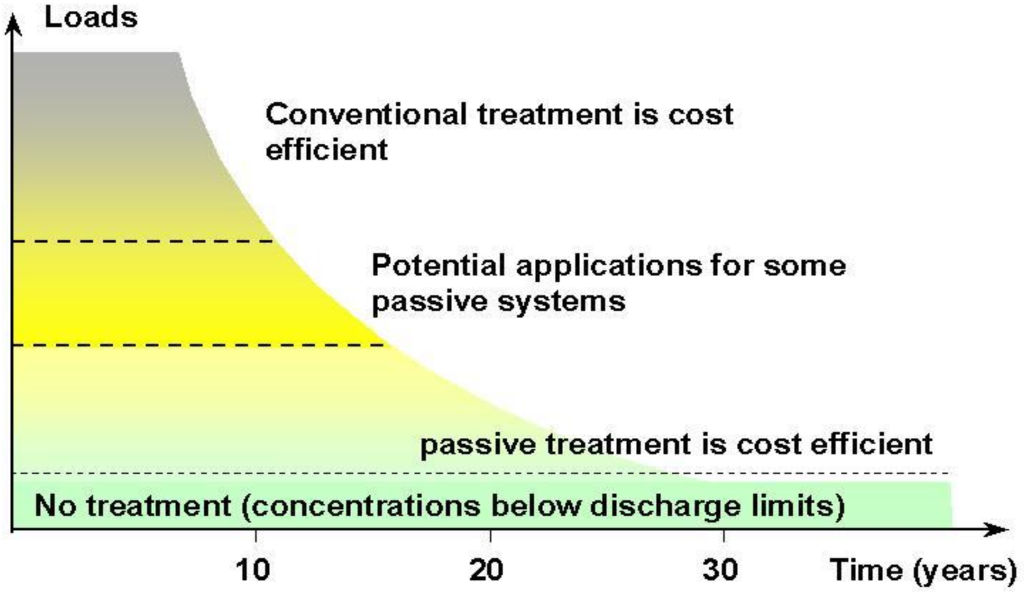
The effluents in the closure of mining and milling sites can be grouped into three classes with respect to their temporal evolution:

- Effluents of flooded mines: these waters are characterised by a more or less constant flow rate but a characteristic decrease of the contaminant load over time, resulting from an initial flush at the time of flooding and a long-term tail due to the dilution of the mine water body by infiltration water inflow (which is partly overlain by dissolution, adsorption and precipitation processes within the mine)
- Seepage from waste dumps and tailings ponds: the flow rate is determined by the cover system and, during consolidation, by the hydraulic processes within the tailings body. Likewise, the contaminant concentration depends on the chemical reactions within the waste rock and/or the pore water quality of the tailings. In waste rock seepage, both flow rate and chemical characterstics can be rapidly vary over time, especially after strong precipitation events.
- Free water removed from tailings ponds: WISMUT has adopted the dry remediation approach for tailings ponds, which requires the removal of the free water lakes in the ponds, and the treatment of the free water before it can be discharged into the environment. These waters can be roughly characterised

as having high concentrations of the typical contaminants, but with a rapidly decreasing tendency, as the ever-smaller lake is continuously diluted by precipitation. Whereas one is interested in a quick removal of the free-water lake so that the interim cover can be placed on top of the tailings pond, which requires a water treatment plant of sufficient design capacity, the treatment technology must be flexible enough to cope with the changing chemism of the free water, and over the long-term, with the dam seepage, if the latter has also to be treated.

In a very simplified fashion it can be stated that conventional water treatment in mine closure projects becomes less and less efficient because ever decreasing loads are removed by a technology the cost structure of which contains a high proportion of fixed costs (staff, energy), while variable costs decrease only weakly over time.

Figure 2 Crossover from conventional to passive water treatment vs. time



The water treatment strategy over the long-term must take into account this evolution of both water quantity and quality over time. A strong motivation for passive water treatment systems, given the high overall costs of water treatment in the closure and post-closure phase, is the reduction of long-term costs by the introduction of low-cost, self-sustained systems requiring only a minimum of staff and consumables.

The remainder of this paper is structured as follows:

- Section 2 is devoted to the mine water treatment at the Pöhla mine site. Whereas Subsection 2.1 describes the mine water characteristics and the conventional water treatment plant which had been built in the mid-1990's, Subsections 2.2 and 2.4 show the two-step approach of WISMUT (and later WISUTEC) to replace the conventional plant with a passive, or at least semi-passive system for the long-term.
- Subsection 2.3 is devoted to the macrophytic algae which are successfully used in the pilot and full-scale wetlands for the removal of Radium.

- In Section 3, some aspects of management and operation are highlighted. In Particular, Subsection 3.1 contains a realistic cost structure which shows where the main risks and advantages of passive water treatment systems lie.
- Subsections 3.2 and 3.3 are devoted to other practical aspects such as waste disposal, sampling and maintenance which may well affect the cost structure of a constructed wetland and hence its viability compared to conventional water treatment installations.
- Section 4 then summarizes the lessons learned in the design and operation of constructed wetlands under the site-specific conditions of WISMUT and, where possible, draws some conclusions and generalizations.

It must always be borne in mind that the present paper describes the experience from a particular site in Germany, with its own peculiarities and regulatory framework. The approach shown in the following and the conclusions drawn may not be applicable in other countries with different conditions. Another issue which must not be forgotten is the fact that the mine effluent is radioactively contaminated which leads to increased public attention and, thus, possibly stricter requirements to the performance than in the case of conventionally contaminated effluents.

2 Conventional and passive-biological water treatment at the Pöhla mine site

2.1 Conventional water treatment plant

The Pöhla mine has been the first to be flooded within the WISMUT Project, so that in 1995 a water treatment plant was erected and put into operation.

The neutral mine effluent, rich in bicarbonate (approx. 1000 mg/l) with an average flow rate of 17 m³/h has undergone a marked evolution over time since flooding of the mine was complete:

Table 1 Main components of the mine effluent

Component	Unit	Limit for discharge	1995	1997	1998	2003	2005
Fe	mg/L	2	5	4	4	4	4
Mn	mg/L	2	3.7	1.6	1.1	0.5	0.4
As	mg/L	0.1	0.5	2.0	2.2	2.2	2.9
U	mg/L	0.2	1.8	0.2	0.2	<0.1	<0.1
Ra-226	Bq/L	0.3	1.1	3.9	4.5	4.3	4.3

The treatment technology was based on a selective precipitation/flocculation process which was specifically developed by WISMUT in collaboration with leading German research institutions:

- Uranium was adsorbed to GOPUR, a reactive polymeric flocculant
- Radium was co-precipitated as Radium/Barium Sulphate by adding Barium Chloride,
- and Arsenic was removed using $FeCl_3$,

- Iron and Manganese were oxidised by aeration.
- The resulting residues were dewatered, filled into drums and disposed of in dry parts of the Pöhla mine.

The unit cost of this technology including disposal was approximately 4 € per m³. It is estimated that the need for treatment will continue until at least 2020. This has prompted the search for alternative, less expensive techniques which take the changes of the mine water chemistry into account, as well as the overall decreasing load of contaminants over time.

Soon after commissioning the conventional treatment plant described above, it became clear that a passive or semi-passive, biological treatment system would be needed for the long-term. Therefore, WISMUT adopted a two-step approach:

- in the first step, a pilot wetland would have to be designed and operated over a couple of years in order to obtain experience with biological systems under the given climatic conditions, to optimize the system and to create a basis of trust with the community and the regulatory bodies that a passive system would be a secure alternative to the proven techniques of conventional water treatment.
- in the second step, the full-scale constructed wetland would be built, the design and operating parameters of which being based on the results of the pilot wetland.

Another argument which led to the installation of the pilot wetland was the perspective of having an experimental basis for passive treatment systems which could be used at other sites within the WISMUT Project.

These two steps will be described in the following sections.

2.2 The Pöhla pilot wetland

The pilot and experimentation plant at the Pöhla mine site was built in a concrete pond (part of the former mine operation), with a footprint of 475 m² and a total volume of 830 m³. After the installations were built in, the usable volume was 415 m³.

The installations divided the concrete pond into seven treatment basins (cells) which served different purposes:

- a small pond to trap coarse matter
- sedimentation pond
- gravel-filled pond for aerobic-anaerobic conditions
- gravel-filled pond for anaerobic-aerobic conditions which can also be vegetated with plants
- polishing/oxidation pond with plants
- two small ponds which can be filled with reactive material (adsorbents)

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Before reaching the wetland itself, however, the mine water was led through an aeration cascade (see Figure 5), bridging the geodetic height difference of around 20 m between the mine adit and the pond.

The pilot wetland was put into operation in 1998; the average flow rate of mine effluent treated in the wetland was 2 m³/h.

Figure 3 shows the principal elements and their layout, while Figure 4 shows a photograph of the constructed wetland.

Figure 3 Layout of the design elements (cells), with the aeration cascade on the right-hand-side

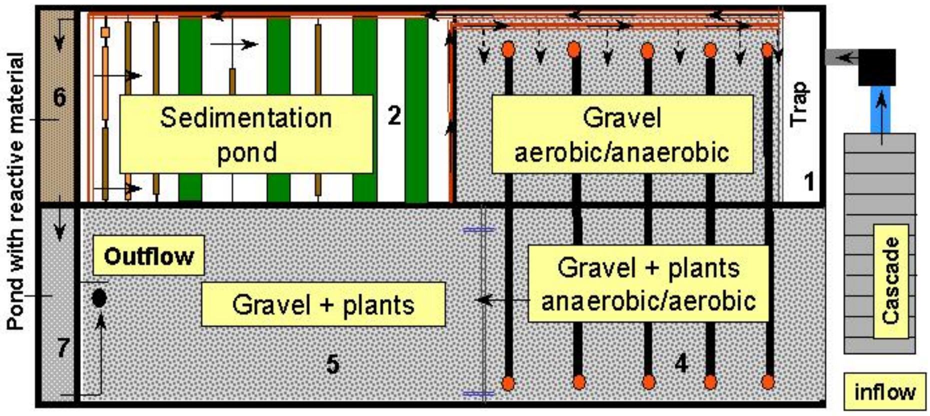

Figure 4 View of the pilot wetland, the aeration cascade is visible in the left lower corner. In the foreground, there are plastic ponds used for Radium sorption tests with algae.

For the removal of Radium, macrophytic algae acting as hyper-accumulators have been successfully tested and used. They are described in more detail in Section 2.3.

Another special feature used in the pilot wetland are floating mats and similar installations to assist the sedimentation of iron precipitates to which arsenic is mainly bound. They can be seen in Figure 6. They have proved to significantly the

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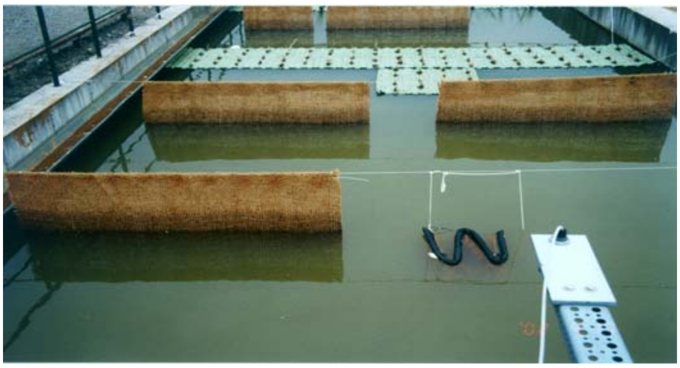
effectiveness of iron and arsenic removal by keeping the pond size to a minimum. This is essential under the conditions already described in the Introduction, namely limited space available at most of the sites.

Figure 5 Aeration cascade between the mine adit and the inflow to the pilot wetland. The dark stain from iron precipitates is clearly visible.

Figure 6 Floating mats in the pilot wetland (so-called "Aquamats")



In a parallel R&D project ("BioRobust") investigating the robustness and resilience of passive water treatment systems under the site-specific conditions at WISMUT (see Kunze et al. 2002), it was shown that although small wetlands which must concentrate their functionality on a very small area can operate reliably under a wide range of external conditions and achieve the permissible discharge standards, their performance also has a tendency to fluctuate if temperature, flow rate or the chemistry of the mine water at the inflow varies beyond certain limits.

This has proved to be the case in reality at the Pöhla mine site, too. For example, peaks of the arsenic concentration from the mine adit have been observed which correlated with flow rate fluctuations due to hydraulic conditions in the mine, which have led to the discharged water exceeding the permitted limits. These findings have prompted the search for counter-measures to guarantee the discharge limits, which is also an important prerequisite to obtain an operating permit and the consent from the authorities to phase-out the conventional water treatment plant.

Therefore, adsorbents which are placed in the last two small sections of the pilot wetland (ponds 6 and 7 in Figure 3) have turned out to be essential to retain residual concentrations of Arsenic and Radium which have not fully been removed by the constructed wetland. The following materials have been successfully used in the pilot wetland to smooth out the performance fluctuations:

- granulated Barium Sulphate in a chemically inert matrix of Alumo-Silicate binder (trade-name Hedulat), which has been developed and patented by WISMUT, (Hermann et al. 2001, see also Kunze et al. 2002a)
- granulated Ferric Hydroxide (trade-name FerroSorp), see Kasting 2005

Other materials were also tested but found inferior to these materials listed above.

Apart from the sorption capacity and cost of the tested materials, an important parameter was their ability to retain the adsorbed contaminants during and after solidification by a hydraulic binder. The reason for this criterion is that all wastes (including spent adsorbents) from the wetland have to be disposed of in a central disposal site pertaining to the mine water treatment plant of Schlema, some 15 km away from the Pöhla site (see Figure 1). The Schlema WTP is expected to operate for at least the next 20 years, i.e., beyond the expected period of time needed for treatment of the Pöhla mine water, so that all wastes generated from the Pöhla pilot (and, later, full-scale) wetland can be disposed of there.

The Pöhla pilot wetland served as basis for designing the full-scale wetland, in particular with respect to

- removal rate per unit area in the different treatment cell types
- hydraulic conductivity of the different cell types
- function of the floating mats and/or floating biomass with extensive roots (see Smith and Kalin 2000)
- measurement of performance fluctuations and their correlation to external factors
- dimensioning of polishing filters (adsorbents)
- sampling cycles for drafting the monitoring plan

Another important function of the pilot wetland is the demonstration of the wetland performance to regulators, which makes it an indispensable basis to negotiate achievable and permissible discharge concentrations.

2.3 Macrophytic algae as hyper-accumulators for Ra

As can be seen from Table 1, while Uranium as the main contaminant has nearly vanished from the effluent due to the reducing conditions in the mine, Radium has

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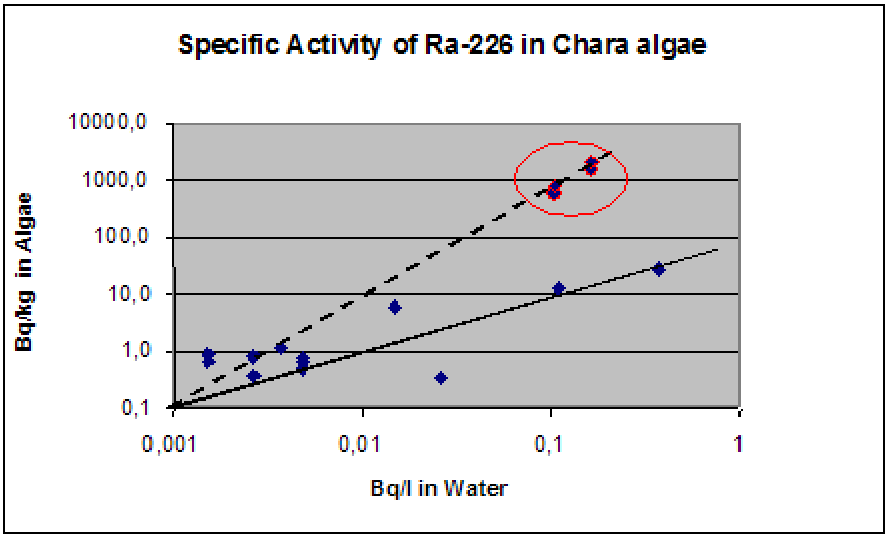
increasingly become a concern.[2] Macrophytic algae such as Characeae have proved to be suited as hyper-accumulators for Radium (see Kalin et al. 2002).

Although their function has not yet fully understood in every detail, it is usually explained by the integration of Radium ions into the calcium-rich lattice and/or formation of Ra/$BaSO_4$ substitute crystals in the plant tissue.

Figure 7 Macrophytic algae *Characeae vulgaris* which are used as hyper-accumulators for Radium from water

Figure 8 Specific activity of Radium in ordinary plants and algae (solid line) compared to Characeae algae (dotted line), showing roughly a linear relationship with the Radium activity concentration in the water



[2] A peculiarity of Radium is that although it occurs in mine water in significant activity concentrations (some Becquerels per litre), this corresponds to a very small mass concentration. A Becquerel of Ra-226 corresponds to only 2.7×10^{-11} grams.

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A more detailed account of recent research results on macrophytic hyper-accumulating algae and their use in constructed wetlands can be found in Kalin et al. 2002a.

2.4 The full-scale wetland for mine water treatment at the Pöhla site

In 2003, the full-scale wetland was built and taken into operation at the Pöhla site. As can be seen from Figure 9, it consists of 2 separate, independent lines, each of them with 3 sequential ponds and polishing filters containing reactive material.

The ponds have a total area of approximately 3100 m^2 and a total pond volume of 2200 m^2, and treats an average of 17 m^3 of mine effluent per hour. The maximum design capacity is 20 m^3 per hour.

The wetland follows the optimal structure identified in the pilot wetland, described in Section 2.2 above:

- Areation cascade
- Settlement pond
- Pond with floating mats (Aquamats) to improve sedimentation of suspended precipitates (2 parallel lines)
- Pond with Characeae algae for the removal of Radium (2 parallel lines)
- Polishing pond (2 parallel lines)
- Adsorption filters for Radium on granulated Barium Sulphate and Arsenic on granulated Ferric Hydroxide (2 parallel lines)

The double-line concept is required to achieve sufficient redundancy.

Figure 9 Aereal view of the full scale wetland at the Pöhla site. The double-line structure can be clearly seen, with one line in the upper part of the photograph and the second line in the lower. In the left lower corner, the aeration cascade is visible, followed by the rectangular settlement pond (concrete structure).

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The monitoring program reflects the still novel status of the wetland and requires substantial manpower and laboratory resources. It was agreed with the regulators (both radiation protection and water resources authorities) and includes the following sampling points and frequencies:

Table 2 Monitoring program (simplified)

Sampling point	**Analytical package**			
	I	**II**	**III**	**IV**
Inflow	w	qu	qu	qu
Outflow of sedimentation pond (2 lines)	m	qu	qu	j
Outflow of Aquamat pond (2 lines)	m	qu	qu	j
Outflow of polishing pond (2 lines)	m	qu	qu	qu
Outflow of reactive filter tanks (2 lines)	m*			
Discharge point into creek	w	qu	qu	qu

Table 3 Analytical packages referred to in Table 2

I	**II**	**III**	**IV**
U_{nat}	Cr	^{238}U	Microbiological screening
Ra	Zn	^{234}U	
As	Cd	^{230}Th	
Fe_{tot}	Pb	^{226}Ra	
Mn	Hg	^{210}Pb	
Cl	Ni	^{210}Po	
SO_4	Se	^{235}U	
NO_3	Cu	^{227}Ac	
Suspended matter	Ba	^{227}Th	
pH	Na	^{223}Ra	
	K	^{228}Ra	
	Mg	^{228}Th	
	Ca	^{224}Ra	
	Al		
	CO_3		
	HCO_3		
	PO_4		
	Hardness		

	Dry residue		
	N_{tot}		
	COD		
	Fish toxicity		

The current analytical program leads to approximately 3000 samples per year which is a major cost factor. Over time and with increasing statistical material, the extent of the analytical program will decrease.

3 Economic and management issues

3.1 Cost structure

In order to assess the cost advantages of the constructed wetland over the existing conventional water treatment plant, the central measure is the payback time of the one-off capital costs of the constructed wetland.

Thus, the construction cost of approx. 700 T€ has to be compared with the difference of the operating costs of the conventional water treatment plant and the wetland:

- Operating cost of conventional plant: 4 €/m³ (see Section 2.1)
- Operating cost of new wetland:
    - first years after construction: approximately 2 €/m³ (where a limited activity of algae and aquamats has to be compensated by a higher loading of reactive filter materials)
    - long-term, steady operation: approximately 1...1.50 €/m³

Taking conservatively the higher operating cost of 2 € per m³ an the average flow rate of 17 m³/h, the annual cost savings are approx. 300 T€, resulting in repayment of the capital cost of 2 to 3 years.

A single figure of operating costs may actually be misleading, as it obscures the difference between fixed and variable (i.e., proportional to the flow rate or contaminant load) costs. It is therefore worthwhile to look at both components separately:

Fixed costs:

- In the first years of operation, operating personnel is required 3.75 hours per day, 7 days per week, at a rate of approximately 30 €/hour, for monitoring (sampling[3]), and visual inspection and minor repair works. These expenses will be reduced over time if more statistical data are available from the wetland operation.
- Supervision of the operations by engineering staff (including reporting, review and evaluation of sampling data, and administration) takes 14 hours per week at a rate of 50 €/h.

[3] Chemical and radionuclide analyses are not contained in these costs.

- General maintenance tasks include adjusting flow meters and measuring equipment, cleaning ponds, mowing grass and winter service, some of them being outsourced to external companies.
- Miscellaneous expenses include telecommunication fees, vehicle costs of personnel, insurance and sundry other expenses which are not related to the flow rate or contaminant load treated by the wetland.

Variable costs:

- Replacement of reactive filter material including disposal, handling, transport and solidification of spent filter material. It must be emphasised that some of the spent filter granulate (especially the Radium adsorbent) must be transported according to the ADR class 7 regulations ("Radioactive material", see Kunze 2003) which considerably adds to the costs due to the special vehicles and safety precautions required. Another issue in this respect is the removal of the spent granulates from the filter tanks which requires special vacuum equipment, a fact that had not been taken into account in the design phase but surprisingly turned out to be quite complicated in the everyday operation of the wetland (see also Section 3.2). This item is the largest single cost component. However, it must also be noted that this component is expected to decrease significantly over time because it is actually intended that the physical and biological components of the constructed wetland are sufficient to achieve the discharge limits without the reactive filters.
- Replacement of plants, floating mats etc., includes removing dysfunctional algae and growing/planting new ones.

Some time is needed for the constructed wetland to operate smoothly and at the intended low cost level. In particular, the algae and floating aquamats need some years to reach full performance, i.e., the filter adsorbents are substantially needed for this period of time (which also means that they have to be replaced more often than in the long-term steady state operation of the wetland), which considerably adds to the costs. Stand-by of the conventional treatment plant which is required by the regulators to cope with any unexpected malperformance is another cost factor which renders the constructed wetland more expensive in the first years of operation.

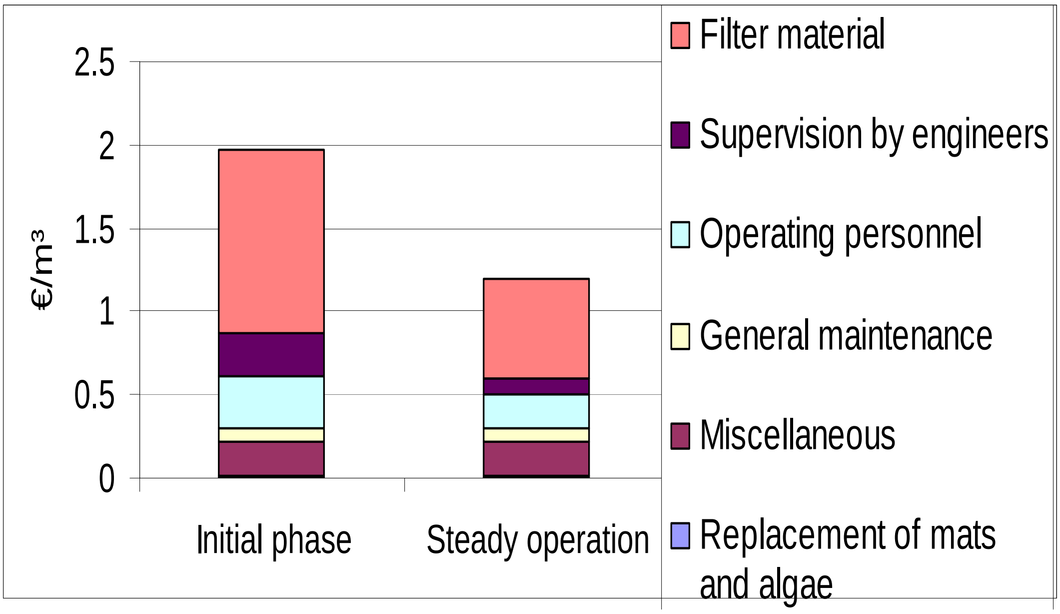
The cost breakdown is summarized in Table 4, which also contains an indication of those components which can be significantly reduced over time.

Table 4 Summary of operating cost breakdown

Cost item	Value (T€ p.a.)	Cost per m³ treated (at an average flow rate of 17 m³/h)	Potential of cost savings over time (see Figure 10)
Fixed			
Workers	41	0.28	yes (0.20)
Engineers	36	0.24	yes (0.12)
Maintenance	10	0.07	no
Miscellaneous	26	0.17	no
Subtotal fixed costs	*113*	*0.76*	*0.56*
Variable			
Replacement and	-	1.20	yes (0.60)

disposal of spent filter material			
Replacement of plants, floating mats etc.	-	0.02	no
Subtotal variable costs		*1.22*	*0.62*
Total		**1.98**	**1.18**

Figure 10 Comparison of the breakdown of operating costs in the initial phase and as expected over the long-term



3.2 Waste disposal issues

A question often arising in the context of passive biological water treatment system is that of waste and waste disposal. The following wastes have to be handled and disposed of in the Pöhla wetland:

1. Ferric hydroxide sludge from aeration cascade
2. Spent filter material
3. Defect floating mats
4. Algal debris

The first three wastes are solidified in the Schlema Water Treatment Plant (see Section 2.2). The costs of solidification and subsequent disposal in a landfill cell on top of a covered Uranium waste rock pile are negligible (approximately 0.01 €/m³).

However, as stated in Section 3.1 above, the technical complications of handling the spent reactive filter material may be considerable and lead unexpected costs. In particular, „sucking“ material out of filter tanks turned out to be not trivial, due to its rheological properties. Moreover, transport of the radioactive material has to be carried out according to the ADR regulations of Class 7 which sets certain requirements to the vehicles used, especially as the filter granulate to be transported is wet.

The handling and disposal of the hydroxide sludge and the floating mats has so far been uncritical.

The amount of debris of the Characeae algae is negligible and does not constitute a major cost component. The algae mineralize and form an inorganic layer at the bottom of the pond. Estimates show that the algal debris which will be accumulated will reach 15 centimeters over a 10 years period. An issue yet to be solved will be how the mineralized algal sludge can be removed without damaging the algae. However, it is likely that there will be no need to remove the algal sludge at all, as the expected operating time will not exceed 15 years.

3.3 Other important operational issues

In the operation of the Pöhla wetland, a number of other issues arose which are briefly addressed below:

- Responsibility for mine water quality and quantity: The mine water exhibits from time to time extreme fluctuations of its quality and flow rate which may lead to overloading the entire system which in turn would lead to non-compliance with the permitted discharge concentrations, which can be only buffered by the reactive filter materials. In this respect, contractual questions must be resolved between the operator of the wetland (WISUTEC) and the owner of the mine water (WISMUT) who is eventually responsible for its treatment and discharge.
- Supply of algae: The hyper-accumulating algae are in insufficient supply, as they are part of the Red List of endangered species. Therefore, the operator must take measures to grow the algae in the required quantity and quality at its own cost and risk.
- The reactive filters have shown hydraulic blockage due to calcite crystal stains on the filter granules. Additional equipment (compressors for pressurized air by which the filters can be periodically back-flushed) had to be installed. Not only does this lead to higher costs due to depreciation of the equipment and more manpower, but also contradicts the very concept of a passive, maintenance-free system.
- The calcite stain on the filter granules also leads to a significantly lower sorption capacity of the reactive filter material. This, in turn, leads to more frequent replacement cycles and higher costs.
- The problems with the filter materials have also led to higher reporting effort required by the regulators than initially planned.
- Organisational issues such as the information chain in case of an emergency or technical problems, responsibility for work and safety instructions, must be clearly resolved between operator and owner of the wetland.

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4 Conclusions

The treatment of mine effluents over the long-term using a passive wetland is possible, and the cost savings are considerable. However, the notion of a maintenance-free, "zero-cost" system is not tenable according to our experience.

Certain basic costs are necessary, due to maintenance and monitoring requirements, but also, and perhaps more importantly, due to technical measures required to guarantee the performance of the system and its compliance with the strict permitted discharge limits.

One of the main points which must be stated are numerous unexpected complications with the hydraulic and sorption properties of the filter materials and the technical solutions for their replacement. Such seemingly trivial issues can lead to additional technical efforts which would be negligible in the case of a conventional water treatment system but are quite disturbing in a system which is based on the idea of passiveness and minimum human intervention.

Initially, the cost advantage of constructed wetlands may be small, or even non-existent, which is due to the stand-by of the conventional treatment plant until the passive system reaches full performance.

5 References

Kießig, G., Kunze, C. 1996: Wasserbehandlung und Rückstandsentsorgung (Water Treatment and Waste Disposal, in German). Geowissenschaften, Vol. 14, Issue 11, November 1996, p. 481

Hermann, E., Dullies, F., Griebel, I., Kießig,G. 2001: Filter material and process for the removal of heavy metals, arsenic, uranium, and radium from contaminated waters. Patents Pending: DE 101 16 951, DE 101 16 953 (2001)

Kunze, C., Glombitza, F., Gerth, A., Kiessig, G., Küchler, A. (2002): Long-term stability and resilience of passive mine water treatment facilities: A joint experimental and simulation approach. In: Merkel, B.J., Planer-Friedrich, B., Wolkersdorfer, C. (Eds.): Uranium in the aquatic environment. Proceedings of the International Conference Uranium Mining and Hydrogeology III and the International Mine Water Association Symposium, Freiberg, Germany, 15-21, September 2002, Springer Verlag, Berlin, Heidelberg, New York, p. 597

Kunze, C., Hermann, E., Griebel, I., Kiessig, G., Dullies, F., Schreiter, M. (2002a): Entwicklung und Praxiseinsatz eines hocheffizienten selektiven Filters für Radium (Development and practical application of a highly efficient selective Radium filter, In German). GWF Wasser Abwasser, Vol. 143, Issue 7-8, 2002, p. 572

Kunze, C. (2003): Handling, treatment and disposal of naturally occuring radioactive wastes (NORM) from mining and water treatment. In: Hebenstreit, C., Kudelko, J., Kulczycka, J. (Eds.): Mine Waste Management – Best Available Techniques, Krakow 2003, p. 186

Kalin, M., Kießig, G., Küchler, A. (2002): Ecological water treatment processes for underground uranium mine water: Progress after three years of operating a constructed wetland. In: Merkel, B.J., Planer-Friedrich, B., Wolkersdorfer, C. (Eds.): Uranium in the aquatic environment. Proceedings of the International Conference Uranium Mining and Hydrogeology III and the International Mine Water Association Symposium, Freiberg, Germany, 15-21, September 2002, Springer Verlag, Berlin, Heidelberg, New York, p. 587

Kasting, U. (2005): Reinigungsleistung von Filtersubstraten zur Behandlung der Abflüsse stark befahrener Straßen (Purification performance of filter substrates to treat the runoff from roads with heavy traffic, In German). Technische Akademie Hannover, Newsletter 02/05 (2005)

Mager, D. (1996): Das Sanierungsprojekt WISMUT (The WISMUT Remediation Project. In German). Geowissenschaften, Vol. 14, Issue 11, November 1996, p. 443

Kalin, M., Smith, M. P. and Wittrup, M. B. (2002a): Ecosystem restoration Incorporating Minerotrophic Ecology and Stoneworts that Accumulate 226 Ra In: Merkel, B.J., Planer-Friedrich, B., Wolkersdorfer, C. (Eds.): Uranium in the aquatic environment. Proceedings of the International Conference Uranium Mining and Hydrogeology III and the International Mine Water Association Symposium, Freiberg, Germany, 15-21, September 2002, Springer Verlag, Berlin, Heidelberg, New York, p. 495

Smith, M., Kalin, M. (2000): Floating Wetland Covers In Biological Wastewater Treatment Systems. Quebec 2000 Millennium Wetland Event, Quebec City, Canada, August 6-12, 2000