Phytoremediation, Wetlands, and Sediments

Editors:

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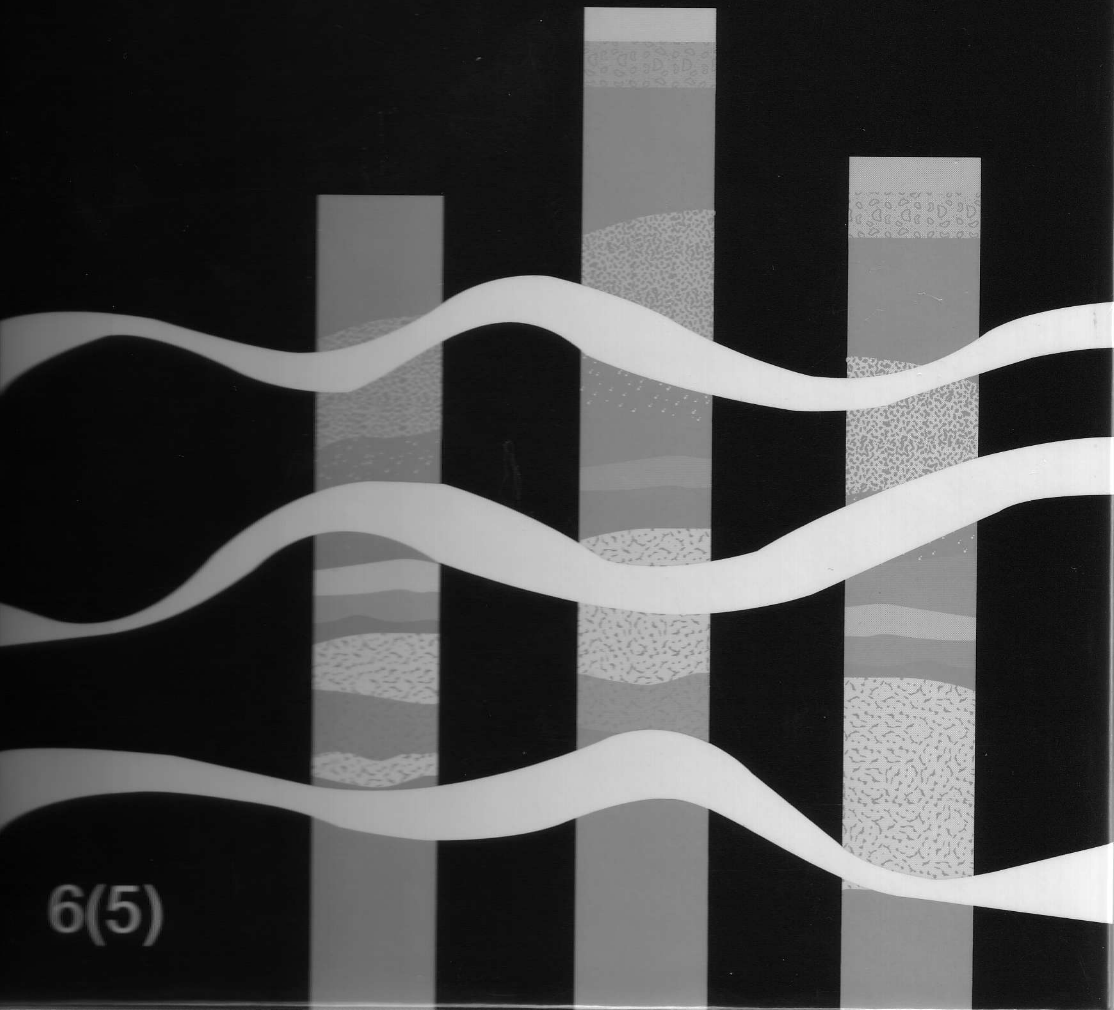

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PASSIVE/BIOLOGICAL TREATMENT OF WATERS CONTAMINATED BY URANIUM MINING

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ABSTRACT: Treatment of radioactively-contaminated and metal-laden mine waters and of seepage from tailings ponds and waste rock piles is among the key issues facing WISMUT GmbH in their task to remediate the legacy of uranium mining and processing in the Free States of Saxony and Thuringia, Federal Republic of Germany. Generally, contaminant loads of feed waters will diminish over time. At a certain level of costs for the removal of one contaminant unit, continued operation of conventional water treatment plants can hardly be justified any longer. As treatment is still required for water protection, there is an urgent need for the development and implementation of more cost efficient technologies. WISMUT GmbH and BioPlanta GmbH have studied the suitability of helophyte species for contaminant removal from mine waters. In a first step, original waters were used for an in vitro bioassay. The test results allowed for the determination of the effects of biotic and abiotic factors on helophytes' tolerance range, growth, and uptake capability of radionuclides and metals. Test series were carried out using *Phragmites australis*, *Carex disticha*, *Typha latifolia*, and *Juncus effusus*. Relevant contaminant components of the mine waters under investigation included uranium, iron, arsenic, manganese, nickel, and copper. Investigations led to a number of recommendations concerning plant selection for specific water treatment needs. In a second step, based on these results, a constructed wetland was built in 1998 as a pilot plant for the treatment of flood waters from the Pöhla-Tellerhäuser mine and went on-line. Relevant constituents of the neutral flood waters include radium, iron, and arsenic. This wetland specifically uses both physico-chemical and microbiological processes as well as contaminant accumulation by helophytes to achieve the treatment objectives. With the pilot plant in operation for three years now, average removal rates achieved are 95 % for iron, 86 % for arsenic, and 75 % for radium. WISMUT GmbH intends to put a number of other projects of passive/biological mine water treatment into operation before the end of 2001.

INTRODUCTION

During and following the remediation of uranium mining and milling operations in the states of Thuringia and Saxony of the Federal Republic of Germany, contaminated waters are produced which contain toxic elements and/or radionuclides and which must not be discharged into receiving streams without prior treatment. This includes waters from flooded mines, supernatant and pore waters from tailings ponds, and mine dump seepage. In addition to of the radionuclides uranium and radium, typical constituents of these contaminated waters include arsenic, iron, manganese, and other heavy metals. Currently, conventional water treatment technologies such as selective precipitation and flocculation as well as ion exchange techniques are used for contaminant removal.

Ongoing remedial activities as well naturally occurring processes entail changes both in the chemism and the volume of feed water to be treated and which also involve a drop in radionuclide and heavy metal loads to be removed. Due to continually decreasing contaminant loads and despite optimization, there will be an increase of specific costs for the removal of a contaminant unit by conventional water treatment techniques. Consequently, development and implementation of alternative "low cost" technologies remains an important task. From the point of view of WISMUT GmbH, at a certain level of loads to be removed, passive procedures based on biological and physico-chemical processes will be a cost-effective alternative to conventional techniques as demonstrated in Figure 1 (Kießig and Hermann, 2000).

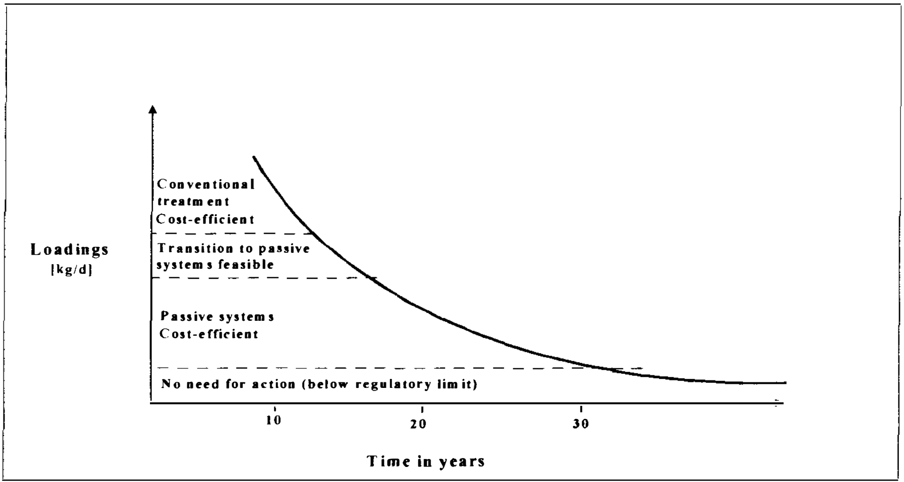

FIGURE 1. Water treatment Strategy as a function of contaminant loadings and time

Accordingly, WISMUT GmbH are studying the appropriateness of constructed wetlands, of microbiological processes in situ, and of reactive materials which are to be used in filters and barriers for mine water treatment and they contribute by their own developments to an improved efficiency of passive techniques.

TREATMENT OF MINE WATERS IN CONSTRUCTED WETLANDS

Studies were performed in conjunction with BioPlanta GmbH to determine to what extent helophytes as a constructed wetland component may contribute to contaminant removal from mine waters.

Investigations were focused on two fields:

- *In vitro* laboratory investigations

- *In situ* tests on mine water
  - small scale tests on planted containers,
  - pilot scale operation of a constructed wetland.

In vitro laboratory investigations. Plant physiology performance represents a decisive factor for the functionality of a planted wetland.

In vitro investigations were carried out using various original waters to determine both pollution tolerance and pollution uptake of the plants. In an *in vitro* biotest, the selected helophytes (*Phragmites australis, Carex disticha, Typha latifolia,* and *Juncus effusus*) were maintained in original waters.

Following analysis of the results, a number of reconmendations could be derived for the site-specific use of the tested helophytes in wetlands for the treatment of contaminated mine waters.

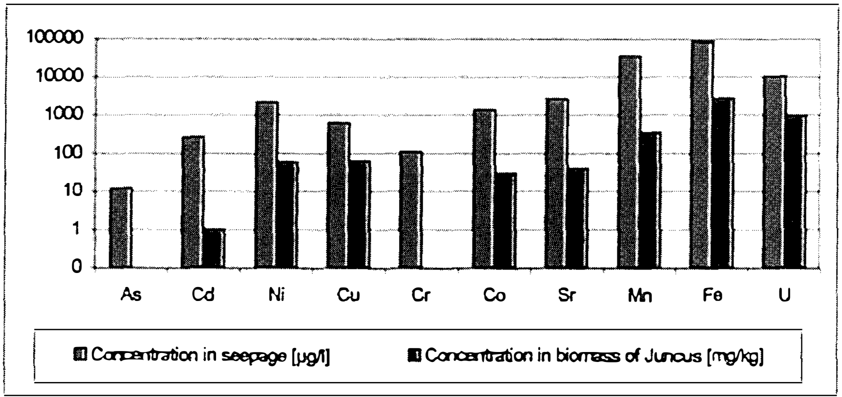

FIGURE 2. In vitro accumulation of arsenic, strontium, heavy metals, and uranium in the biomass of *Juncus effusus*

In view of its radioactivity and chemical toxicity, uranium depletion is of particular interest. The results of the *in vitro* investigations showed a significant increase in the uranium content in the biomass of all tested helophytes. The uranium content of *Juncus effusus,* a species that was not grown on contaminated mine water, was established at 6 mg/kg dry solid matter. After 4 weeks maintained on contaminated mine water, the analysis of the uranium content was 967 mg/kg in the dry solid matter. Iron levels in the biomass amounted up to 3,500 mg/kg.

Site Description. Flooding of the Pöhla-Tellerhäuser mine was compete by June 1995. Since then, approximately 17 m^3/h of contaminated mine water flow out at the surface. At that time, a conventional water treatment plant become on-line to separate the contaminants uranium, radium, arsenic, and iron from the neutral mine water. TABLE 1 lists concentration means of relevant mine water constituents in 2000.

TABLE 1. Flood water characteristics at the Pöhla-Tellerhäuser mine (mean values, 2000)

Element	Unit	Mean	Element	Unit	Mean
pH	-	6.99	Arsenic	µg/L	2299
Eh	mV	105	Sulfate	mg/L	5.1
Uranium	mg/L	0.1	Phosphate	mg/L	0.1
Radium	mBq/L	4531	Nitrate	mg/L	1.0
Iron	mg/L	9.1	Ammonium	mg/L	0.2

Due to the establishment of reducing conditions in the mine, uranium concentrations in the mine water have already dropped to levels where no remediation is required. Iron and arsenic are present in the mine water at their lower oxidation state (Fe^{2+}, As^{3+}). The mine water is low mineralized and extremely poor in nutrients.

Hydrochemical modeling on how mine water loads will develop has established that treatment will continue to be needed for a period of some 15 years. Despite the fact that operation of the on-site conventional water treatment plant is subject to continuous optimization, the specific costs incurred for treatment of about 4.50 DM/m³ mine water are extraordinarily high due to staffing requirements.

Starting out from this situation, WISMUT GmbH has been investigating since 1997 whether a constructed wetland might be a reliable and cost-effective alternative to the conventional water treatment plant.

Small-scale tests with planted substrate. An *in situ* test was conducted at the Pöhla-Tellerhäuser site in order to investigate the plant-substrate-microorganism system (Gerth et al., 2000). The constructed wetland principle was implemented in planted containers.

The test facility consists of five containers, each with a filter volume of 0.8 m^3. These containers are planted with different helophytes (*Phragmites australis. Carex disticha*, *Typha latifolia*, and *Juncus effusus*). Their separation behavior was tested both for intermittent and continuous water supply.

The small-scale tests have been running for about 2 years. TABLE 2 lists the separation rates for defined throughputs.

TABLE 2. Separation rates depending on feed and throughput

Parameter	**Contaminant separation [%]**				
Feed	**Intermittent**				**Continuous**
Retention time	77 h	43 h	34 h	25 h	25 h
Arsenic	99	98	61	65	51
Iron	85	92	98	98	98
Ra-226	99	99	82	82	99

Pilot run of a constructed wetland. Trial operation of a constructed wetland began in summer 1998 to treat a partial mine water flow at the Pöhla site.

This full-scale test work was geared to obtain information on performance of the system in contaminant reduction and gain experience on the facility behavior during year-round operation as well as on maintenance and staffing requirements.

Based on the chemical composition of the flood water (TABLE 1) and the objectives set for iron, arsenic, and radium separation, the design of the constructed wetland gave priority to the implementation of physico-chemical separation which occurs at the beginning of the process. The separation performance of helophytes is investigated in end-of-pipe stages.

The constructed wetland was established in a concrete basin that existed at the site. It was subdivided into five reaction zones which are separated by partition walls. The feed water passes the various stages through overflows and bottom drains by gravity flow. The inflow channel to the wetland contains an aeration cascade.

When the feed water passes the aeration cascade, the dissolved bivalent iron gets oxidized. The trivalent iron is precipitated as hydroxide. The hydroxide flocs will then sediment in the two subsequent basins. Arsenic and radium will be bound to the ferric hydroxide by adsorption.

Afterwards the effluent passes through two basins filled with coarse - to fine-grained gravel with the water flowing at the bottom from the first to the second basin. In essence, the gravel-filled basins serve as filters for finely dispersed ferric hydroxide flocs. The original design called for a microbiologically induced transition from aerobic to anaerobic conditions that was intended for abiotic contaminant fixation. As the feed water is extremely low in nutrients and sulfate, it turned out that in this case microbiologically induced separation processes were of secondary importance only.

The surface of the second gravel-filled basin was planted with helophytes in order to encourage biofilm establishment. In addition, the biomass takes up contaminants. Present in low concentrations in the feed water, manganese undergoes catalytic immobilization as may be observed inter alia on gravel surfaces.

The final stage of the pilot facility is a planted bottom filter. The reaction space is filled with material analogous to compost and gravel, and planted with different helophyte species. The plant material and microorganisms which are present in the helophytes' rooting zone will fix more contaminants.

The second gravel-filled basin and the bottom filter were planted with a variety of helophytes species (*Typha latifolia*, *Juncus inflexus*, *Juncus effusus*, *Phragmites communis*, and *Iris pseudacorus*).

The constructed wetland has an effective volume of approximately 415 m^3 and a surface of about 474 m^2. Figure 4 shows a schematic representation of the pilot plant configuration.

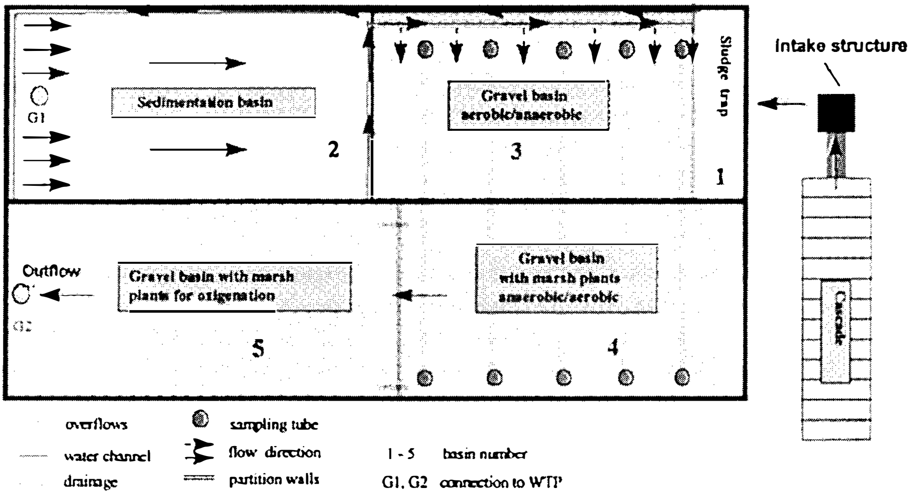

FIGURE 3. Schematic representation of the pilot mine water treatment plant

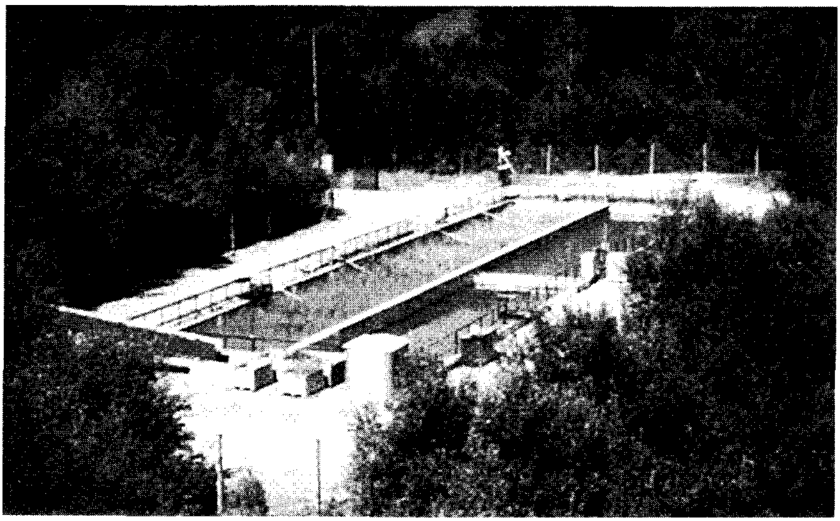

FIGURE 4. View of the Pöhla-Tellerhäuser pilot plant

Up to now, the pilot plant was charged with a feed stream of between 0.5 m^3/h and 5.0 m^3/h. Since August 2000, the average feed is 1 m^3/h. By the end of 2000, some 61,200 m^3 were fed to the pilot plant and underwent passive biological treatment.

Information on oxidation, precipitation, and sedimentation limits were derived at high throughputs ($\geq$ 3 m^3/h). The separation performance of the planted wetland area was investigated at lower throughputs ($\leq$ 1 m^3/h). During its entire period of operation, the constructed wetland proved its capability to separate radium, iron, and arsenic. Under the given site conditions (elevation: approximmatly 552 m above sea level, mean annual temperature: approximmatly 6,4 °C, precipitation: approximmatly 1000 mm/a; 25 % of this as snow) operation of the pilot plant was stable and reliable.

RESULTS

At a throughput on the order of 1 m^3/h, the average separation rate over the entire wetland area is as follows

iron	approximmatly	95 %
arsenic	approximmatly	86 %
radium	approximmatly	75 %

The major part of contaminant separation occurs in the process stages of oxidation, precipitation, and sedimentation (aeration cascade through basin 3). Considerable reductions in radium and arsenic concentrations are observed within the planted wetland areas (basins 4 and 5) on the one hand while the iron concentration within these basins remains either constant or shows a marginal increase on the other hand. TABLE 3 lists average separation rates related to influent concentrations in the various sections.

TABLE 3. Average separation in the constructed wetland as a percentage for a throughput of about 1 m^3/h.

Element	Reduction in percent: Basin 1 to 3 (aeration cascade - filtration)	Reduction in percent: Basin 4 and 5 (planted wetland areas)
Iron	99	0
Arsenic	79	35
Radium	40	37

Separation related accumulation of radium, arsenic and iron in helophytes is demonstrated in TABLE 4.

TABLE 4. Contaminant concentrations in above-ground biomass of helophytes from the constructed wetland

Helophyte species	Iron (mg/kg dry)	Arsenic (mg/kg dry)	Radium (Bq/g dry)
Phragmites communis	128 - 193	5-14	<0.05 - 0.15
Juncus spec.	103 - 953	10 – 187	0.12 - 0.72
Typha latifolia	167 - 230	7 – 39	0.21 - 0.23
Iris pseudacorus	161 - 257	5 – 14	0.05 - 0.63

OUTLOOK

On the basis of these investigation findings, WISMUT GmbH intends to put a constructed wetland into operation at the Pöhla-Tellerhäuser site in April 2003 which will treat the entire mine water yield (about 17 m^3/h) and to decommission the cost-intensive conventional treatment plant.

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