Final Report of the Research and Development Project

Investigations for the sustained closure of landfill sites operated in cavities left over from open lignite mining and exemplified at the Halle-Lochau landfill site

Abridged version of the final report

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Investigations for the sustained closure of landfill sites operated in cavities left over from open lignite mining and exemplified at the Halle-Lochau landfill

Phase I: Basic data and principle solutions

Abridged version of the final report

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Foreword

Ingrid Häußler

Mayor of the City of Halle (Saale)

The investigations and results of the research project conducted from 2002 to 2007 entitled

“Investigations for the sustained closure of landfills operated in cavities left over from open lignite mining and exemplified at the Halle-Lochau landfill site”

established important principles for an environmentally proper, legal, sustained and economically achievable rehabilitation of the Halle-Lochau landfill.

Since it was set up in 1976 the Halle-Lochau landfill has been the most important site for the disposal of domestic and similar commercial waste for the city of Halle and the surrounding districts. The landfill operation was organised on a local authority basis by the city of Halle, with the city of Halle being the sole shareholder.

In 2000/2001 a preliminary decision was made, based on the planned amendments to federal law, to close the Halle-Lochau landfill prematurely on 31.05.2005, notwithstanding previous planning measures. This necessary decision had far-reaching consequences for the city of Halle, because as well as relocating waste disposal facilities it was also especially important to clarify the technical measures involved in closing and subsequently looking after the landfill site as well as financing these measures. Initially it was completely unclear how closing the landfill could be carried out from a technical point of view as the legal provisions were not applicable to landfill locations such as Halle Lochau and permanent rehabilitation could not be ensured.

This is why the city of Halle welcomed the fact that in 2002, following preparations made by Abfallwirtschaft GmbH, the research and development project sponsored by both the regional authority and central government started with the objective of developing an environmentally sustainable, lasting and economic concept for rehabilitation and subsequently looking after the Halle-Lochau landfill site. The city of Halle and the supervisory board provided one another with information on an ongoing basis on the progress of research work and gave the landfill operator the necessary support for carrying out the project successfully.

As a result of the work on the research project that has now been completed an innovative solution has now been developed for rehabilitation the Halle Lochau landfill. The project was at the same time constantly monitored by the various bodies as the rehabilitation strategy was considered in terms of its suitability for approval. Rehabilitation of the Lochau landfill began in 2005 with the particular solution developed and investigated in the R&D project forming the basis for the rehabilitation strategy.

The city of Halle assumes in line with the research results that the closure concept will mean implementing an environmentally proper, sustained and economic solution for the Halle-Lochau landfill site.

I thank all the national committees as well as those from the Land of Sachsen-Anhalt, the rural districts and the city of Halle along with the research institutions and companies involved, and especially also the project’s sponsor, Abfallwirtschaft GmbH Halle-Lochau, for their contribution to the success of the research project.

Ingrid Häußler

Abridged version

This abridged version serves to summarise information regarding the essential results of the research project **"Investigations for the sustained closure of landfill sites operated in cavities left over from open lignite mining and exemplified at the Halle-Lochau landfill site"**. Particulars of the extensive investigation are presented in detail in the final report.

■ Landfill site location

The landfill site site lies about 5 km southeast of Halle in an old opencast mine which came about as a result of the lignite mining conducted from 1901 to 1969.

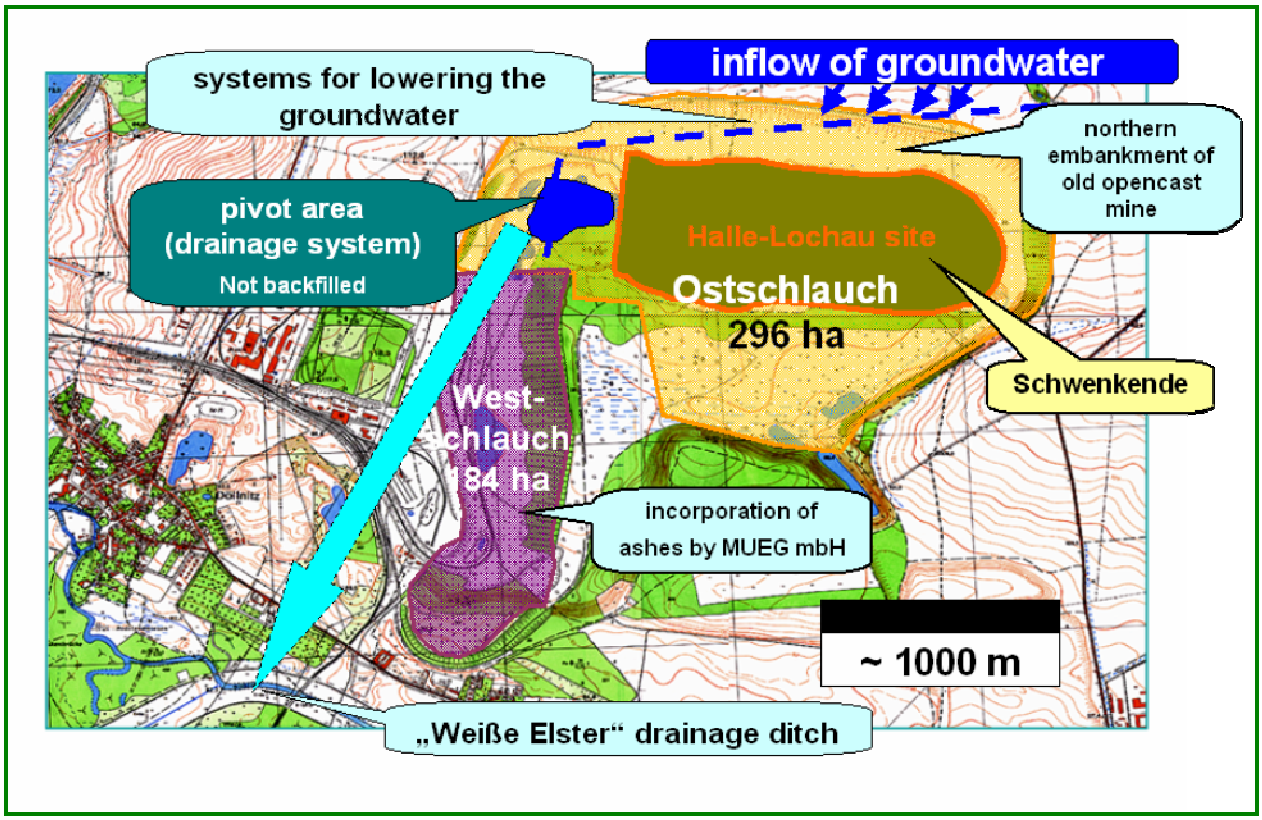


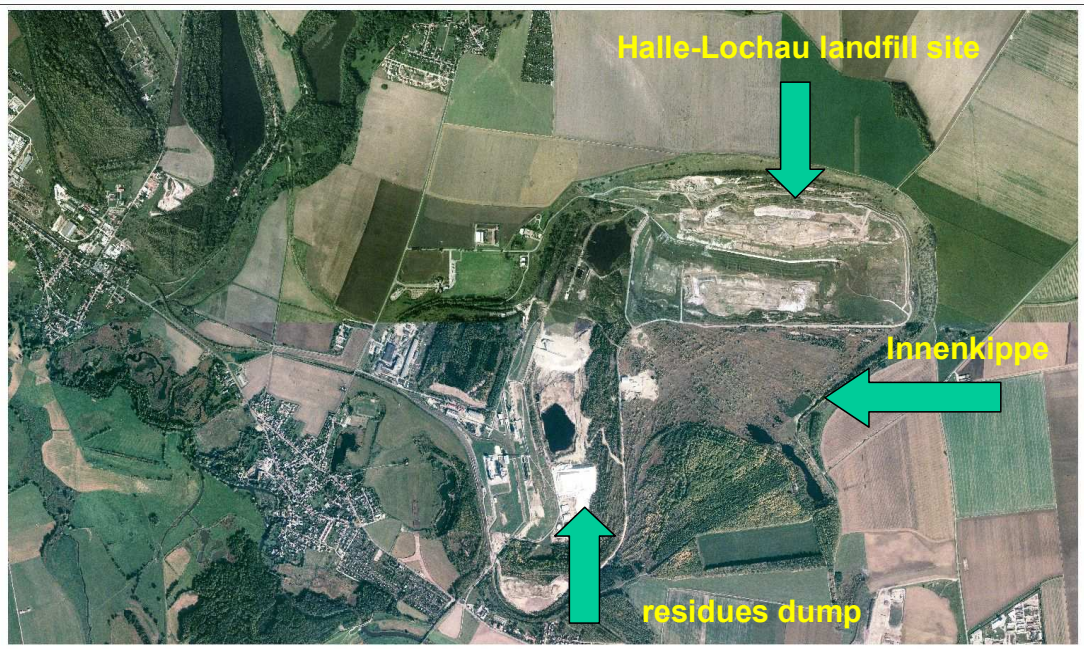
Diagram I: Map of the area of the Halle-Lochau site

The old Lochau opencast mine has a total area of approx. 480 ha. The narrower area of investigation for the Halle-Lochau landfill site comprises the AWH [Abfallwirtschaft GmbH Halle-Lochau = AWH] operating site including the so-called *Ostschlauch* (eastern part of the site) of the old opencast mine with an area of 296 hectares. The area of the old Lochau opencast mine is dominated by the soil groups from the mine dumps and the other banks of spoil, which consist of mixed dump soils of loamy and sandy substrates or of dumped material in the landfill area. In the naturally overgrown soils around the landfill site one mainly comes across black earth and brown-to-black earth. The nearby *Elsteraue* (south of the map) is dominated by colluvial soils and the ground-water influenced semigleys.

In the area of the Lochau landfill there are massive tertiary and quaternary unconsolidated rock formation deposits above the solid rock of the upper Perm (zechstein) and the Trias (mottled sandstone). Mining activities in the old opencast mine have devastated the unconsolidated rock, which has partly been dumped as spoil. Another anthropogenous dumping area in the old opencast mine is that of the Halle-Lochau landfill.

The landfill site lies climatically within the eastern German inland climate, which is in a transitional area between maritime and continental. The hydrogeological situation is marked by the various geohydraulic characteristics of the geological layers or layer complexes. Ground-

water layers (GWL) (= aquifers), minor groundwater layers (= minor aquifers) and groundwater banks or dams alternate with one another in profile and horizontally.



Old Lochau opencast mine with *Ostschlauch* (Halle-Lochau landfill) and *Westschlauch* (residues dump) and *Innenkippe* (inner tipping area)

Diagram II: Aerial view of the Halle-Lochau site

In the centre of the *Ostschlauch* of the old opencast mine the waste has been dumped on an overgrown substratum, which mainly consists of lignite residues with similar underlying strata and horizontal sediments (coarse clay). To the south and the north there is mining spoil up to about 90 m high. In the western area of the landfill the residual thickness of the lignite after the old bore holes is mostly less than a metre, while clays or coarse clays are generally deposited below the remaining strata. In the north-west the thin residual lignite may be underlain by sand. In a few areas no coal has remained after opencast mining came to an end, and there are also presumably cohesive sediments remaining, which are distributed below the coal. Towards the east the residual thickness of the layer rises significantly to more than a metre, and the coal in most areas is also underlain by clays or coarse clays (in part to more than 30 m). According to existing investigations the mining spoil surrounding the landfill functions as a geological barrier.

The *westschlauch* of the old opencast mine is being backfilled by the Eastern German Environmental and Waste-Disposal Company [Mitteldeutsche Umwelt- und Entsorgungsgesellschaft mbH = MUEG] with ash stabiliser manufactured from lignite ash. This ash stabiliser has a stable chemical and physical structure and has extremely low water conductive characteristics (< 1 x 10^{-10} m/s). According to the objective of reuse following mining activities it is intended to use it to fill the entire *westschlauch* to about the natural landscape level (100 to 102 m high). This is expected to take until 2023.

Between the *ostschlauch* and the *westschlauch* lies the so-called pivot area, which was previously used for lining up heavy opencast mining equipment. This is the lowest point in the old opencast mine, which is at the same time important for water retention. The ground- and surface water that collects there is pumped off into the drainage ditch flowing from east to west to the river *Weisse Elster*, which itself then goes on to flow into the river Saale. This means therefore that drainage for the old opencast mine takes place in the centre. The floor of the

opencast mine lies at a level of between 50 and 69 m high, the natural ground level between 95 and 115 m high. Developing and maintaining a water gradient in the direction of the pivot area means that the aquifers will not be impaired by the landfill either at the present or in the future if the measures taken to lower the groundwater table are adhered to.

Without this mine drainage it would form a lake in this approx. 50 m deep hollow. That would mean that parts of the landfill would lie under water, causing discharges of noxious material into the environment.

The Halle-Lochau landfill was approved and set up in the *ostschlauch* of the old opencast mine as a waste dump for domestic waste in 1973. Operation started in 1976.

Up until 1990 approx. 5 - 6 mill. tonnes of all kinds of waste were disposed into the landfill, especially waste from housing areas and building rubble. From 1990/1991 the dumping of domestic and commercial waste has been into two separate landfill areas. Domestic waste was dumped in the northern area and commercial waste in the southern area. Apart from this a special landfill site was set up for asbestos in the western part of the commercial waste area. In 1991 the city of Halle set up the waste disposal company, Abfallwirtschaft GmbH Halle-Lochau, and subsequently took various technical measures to improve the management and development of the landfill. These include dumping waste in separate domestic and commercial waste areas, continuous covering of the landfill surface, backfilling the *Schwenkende* mine drainage area, blocking the mine drainage pivot point against the mass of landfill with a sheet pile wall (traffic and retaining dam, setting up and extending the leachate collection system, leachate treatment, setting up methane gas collection systems and utilization of methane, extending and setting up numerous new measuring points and quality wells to monitor groundwater, leachate and surface water, the establishment of a heavy weight soil body for stability purposes from compacted sediments in the *Schwenkende* landfill area, and locating treatment plant on the site.

As a result of these measures the Halle-Lochau landfill site has a modern infrastructure and high-performance technical facilities, which it may be possible to use, possibly in a modified form, for rehabilitation and subsequently looking after the site at the end of the dumping phase.

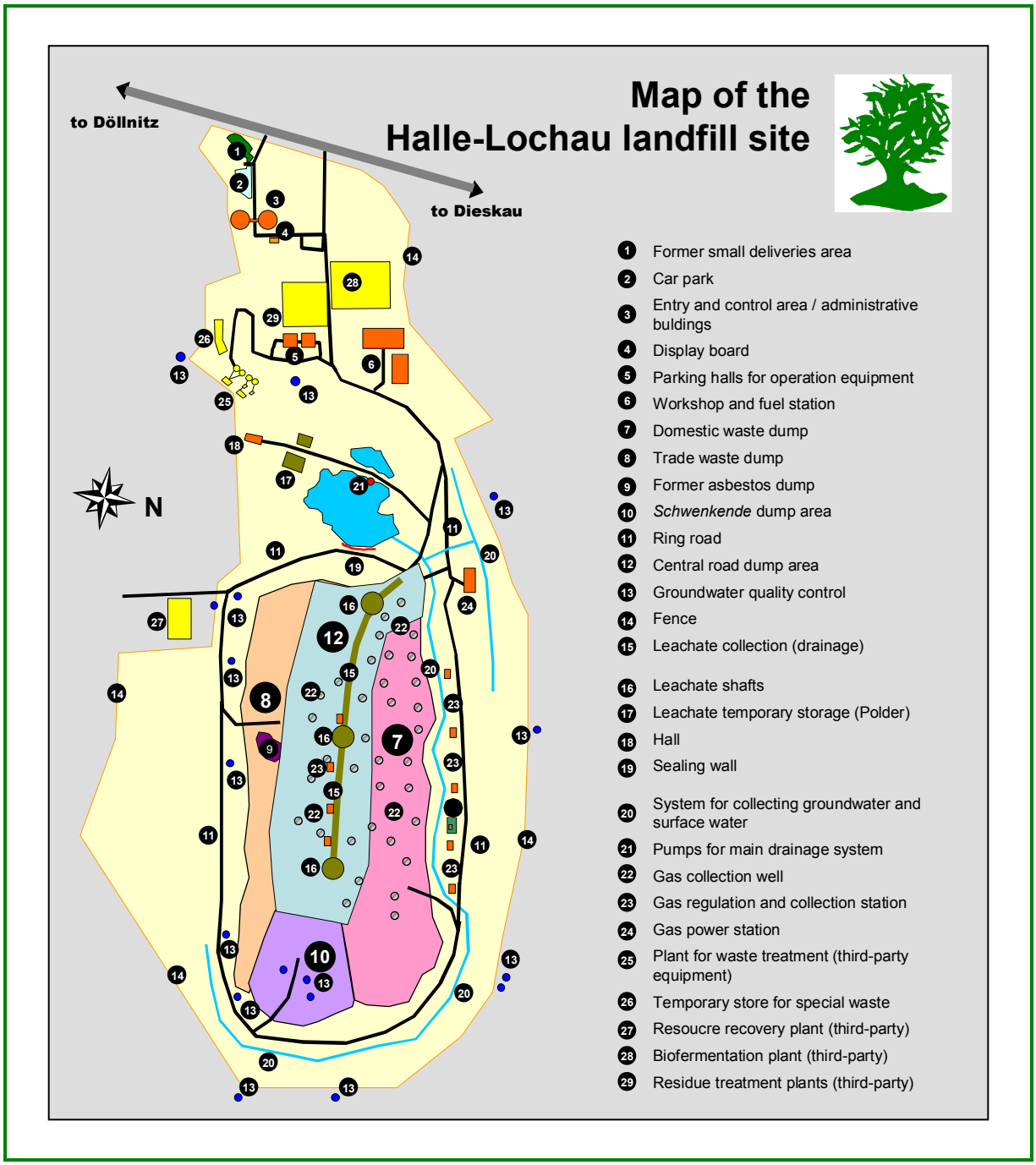


Diagram III: Technical facilities at the Halle-Lochau landfill site

In the dumping operation up until 05/2005 the waste was disposed over an area of approx. 82 ha, the backfilled volume was approx. 18 mill. m^3. The deposited waste has reached a maximum thickness of 35 m.

As a contribution to reducing emissions and stabilising the landfill a facility was set up to recover and use the gas from the landfill in the domestic waste area. Gas arises as a result of the high proportion of organic materials predominantly in the domestic waste sector as well as in the area of the former central roadway. There is a system of landfill gas wells via which the gas is collected and subsequently utilized. All in all a total of 8.4 million m^3 gas was recovered in 2003. This gas consists of methane (50-55 vol %), carbon dioxide (30-38 vol %), oxygen (0.1-0/9 vol %), nitrogen (4-10 vol %) with the most significant trace substance being sulphur (0.3-1.3 mg/m^3), which occurs almost entirely as hydrogen sulphide. No significant volumes of gas were discovered in the commercial waste area in the period up until 2003.

■ The legal situation

Subsequent use and recultivation of the surface affected by the old opencast mine was laid down on the basis of the Mining and Agriculture Acts of the former German Democratic Republic in 1973. The relevant official decisions were based on the submission of the phasing out programme of the Lochau landfill site of 28.06.1973 pursuant to § 13 Mining Act of the GDR for the District Planning Commission of the Council for the District of Halle and the "Complex report on ordered landfill in the Lochau opencast mine" by the Office for Territorial Planning of 10.09.1973. The phasing out programme was confirmed on 01.10.1973 by the district planning commission with subsequent use as an "ordered waste dump" with the old opencast mine being completely backfilled up to surface level. The resolution of the council of the district of Halle of 01.10.1973 on the subsequent use of the Lochau opencast mine as an ordered waste dump specified the complete backfilling of the old *Ostschlauch* mine section up to terrain level (approx. 113/115 m high) in two phases [Phase 1: backfilling up to 90 m high; Phase 2: backfilling level with the terrain up to surface level (approx. 113/115 m high to the north and east bank)]. Phase 2 was linked to certain conditions, which involved a provision for a new specialised and official examination after the conclusion of Phase 1 and before the commencement of Phase 2.

It was intended to backfill the neighbouring *Westschlauch* with industrial material and energy supply material (Leuna plant).

The phasing out plan of 28.03.1973 in particular licensed the structuring of the old opencast mine as landfill in accordance with the mining law of the former GDR by Halle mining authority. The dumping operation commenced in the *Ostschlauch* on this legal basis in April 1976, and shortly after this a start was also made in backfilling parts of the *Westschlauch*.

After the collapse of East Germany in 1990 a closing operational plan was devised in accordance with the Federal Mining Law for the old opencast mine. In consultation with the Halle Mining Office this was subdivided into Part A – *Ostschlauch* and Part B – *Westschlauch*. The indefinite licensing of this closing operational plan took place with the relevant additional provisions on 19.11.1993. In implementing the additional provision and adjusting the development status from a time aspect the closing operational plan was updated, made more precise and supplemented, as a result of which there are so far more than 30 licensed additions and numerous amendments to these additions predominantly for the *Westschlauch*.

To legitimise the ongoing work at the Halle-Lochau landfill in the *Ostschlauch* of the old opencast mine the necessary notifications were made in accordance with the unification treaty law and the appropriate administrative acts were passed following the reunification of Germany. The notification on continuing to run the Halle-Lochau landfill in the *Ostschlauch* in accordance with the Unification Treaty Act (observing the vested rights in terms of licensing law) were submitted to the relevant authority by Abfallwirtschaft GmbH Halle-Lochau as landfill operator on 24.12.1990.

On 21.07.1994 Halle Mining Office confirmed the protected existence of the Halle-Lochau landfill under licensing law in a declaratory notice. Halle government officers issued a special licence in 2001 in accordance with the dumping order approving the further dumping of untreated waste until 05/2005. For the dumping operation separate notices were passed by the relevant waste authority for individual technical measures such as the collection of gases and utilization as energy, the collection, diversion and treatment of leachate, and dumping waste in the area of the former central roadway. As far as the introduction of mine waters from the mine drainage systems in the *Ostschlauch* and *Westschlauch* into the drainage ditch is concerned relevant licences exist under water legislation for water management usage rights. The same applies under building law for the erection of buildings. There are also licences and notices for the other legal areas as required.

The licences and orders to be applied from the applicable legal areas along with standards, especially from mining law, waste disposal law and water legislation determine the basic conditions for the proper final structuring and subsequent use of the old Halle-Lochau opencast mine.

■ Subject of investigation

In principle the groundwater conditions artificially set up for mining and subsequent landfill operations could be maintained in the old opencast mine for an unlimited period. Then action could be taken in line with the TASi (German waste technical ordinance) when the disposal operation came to an end. Nevertheless this procedure is not in line with the environmental principles of sustained activity and minimal aftercare, which are aimed at ensuring after the landfill operation has come to an end that a landfill site can in the last resort be left to itself without prejudicing public interests.

After a landfill has been closed at a location where the groundwater lowering facilities retained for the landfill operation, it must be assumed when the groundwater lowering comes to an end that the original natural groundwater levels will re-establish themselves and at least partially flood the old body of the landfill.

This requires, alongside the measures for rehabilitation and aftercare laid down by TASi, that other action be taken to ensure that either contact between the body of the landfill and the groundwater can be ruled out or that there can be no discharge of noxious material into the environment.

Consequently the research project was centred on identifying possible risks for people and the environment in setting up ongoing mine drainage facilities, developing cost-effective solutions that are technically achievable and in line with the demands of environmental protection and the sustainability of the action to be taken to minimise possible emissions of noxious substances. The preparation of a strategy for the rehabilitation, aftercare, recultivation and after-use of the landfill should also meet the demands of future generations.

The procedure to be developed should be soundly based from a legal point of view and be acceptable for all those involved as well as meeting the requirements of proportionality in terms of reasonable expense (cost) and compatibility with public interests (social benefit).

At the same time the objective was pursued of ensuring that these measures were as self-financing as possible, without having recourse to the direct liability of the controlling shareholder for public bodies that might otherwise become necessary (City of Halle as shareholder of the landfill operator or the State of Sachsen-Anhalt or central government).

The aspects of subsequent use of the old landfill site were also to be borne in mind to open up longer-term prospects of the site for sensible subsequent use, developing the site and safeguarding jobs.

The requirements were to be created for this, to implement the rehabilitation and aftercare measures at the Halle-Lochau landfill site, which would largely involve existing personnel and so contribute to safeguarding jobs in a region suffering from high unemployment.

Within this context the following range of questions were to be answered by the R&D project:

a) The *Ostschlauch* will not be backfilled with waste by 2005. This means that there is a remaining deficit of mass so that after the water drainage system between the incorporation of ashes in the *Westschlauch* and the Halle-Lochau landfill in the *Ostschlauch* has been switched off a body of water will form in the pivot area. Depending on the volume of waste up until the time of closing and how it was disposed it is possible that in its final state the body of the landfill may lie under water. A decision had to be taken on what was more suitable for the subsequent use of the old opencast mine and what was the importance of the lake's hydraulic altitude for the inversion gradients appearing on the surface. The possibility of backfilling the remaining cavity with suitable inert material was also to be considered as a option, while the problem of obtaining the material (80 mill. tonnes of material would be required for a complete backfill!) also had to be taken into account.

b) The lowering of the groundwater cannot be halted until the status of the rehabilitation and configuration measures permit or closure is brought into line with other plans. An

investigation had to be carried out to determine what influencing factors must be taken into account.

c) A rise in water levels can mean that environmentally significant materials can be washed out of the Halle-Lochau landfill. That is why it is important to clarify what substances are released in the course of this rise in water levels, in what volumes and concentrations, where they are being transported to and what their final impact is on the environment.

d) The opportunities for using the groundwater and the drainage ditches close to the landfill depend on what impact the leachate being released has on the water quality.

e) The opportunities for using the flooded old opencast mine also depend on what the quality of the water will be in the resultant lake if the cavity is not completely backfilled. The water quality can also be influenced by the manner in which the body of landfill is handled after disposal has come to an end. Discharges can also be reduced by deliberate changes to hydraulic conditions, sealing systems, removing noxious substances from the body of the landfill or a combination of these.

f) The more the discharges have to be reduced, the higher will be the costs of the necessary action. These costs must be set against the advantage of raising the quality of the possible subsequent use of the old opencast mine, as well as the groundwater and the drainage ditches close to the landfill. The question of what reduction in the effluent can be achieved at what cost and what the resultant cost benefit ratio looks like, should be examined as a further important point at the closure of the Halle Lochau landfill.

g) Discharges must be seen in connection with legal requirements, as from a legal point of view it is only permissible to a limited extent. Permissibility depends among other things on what the relevant legal basis is, such as laws relating to mining, waste disposal, old dumps or water. It is however not only necessary to recognise possible legal conflicts, but also potential socio-ecological conflicts, the resolving of which are an immediate requirement for the acceptance and practical implementation of the research results.

   Carrying out the R&D project should bring answers to the following questions:

   (1) What will the old opencast mine or landfill finally look like?

   (2) What subsequent uses are essentially possible for the old opencast mine, the groundwater and the drainage ditches in the vicinity and what water quality must be achieved for them?

   (3) What discharges from the landfill are reasonable from a legal aspect?

   (4) What materials are washed out of the body of the landfill when the water rises, in what quantities and concentrations, where do they go and what impact do they eventually have on the environment?

   (5) How far can these discharges be reduced using various technical measures and what are the costs involved?

   (6) What is the relationship between the costs of reducing discharges of material and the resultant benefit for the good of the community?

To analyse and answer these questions the following work packages were assembled and processed.

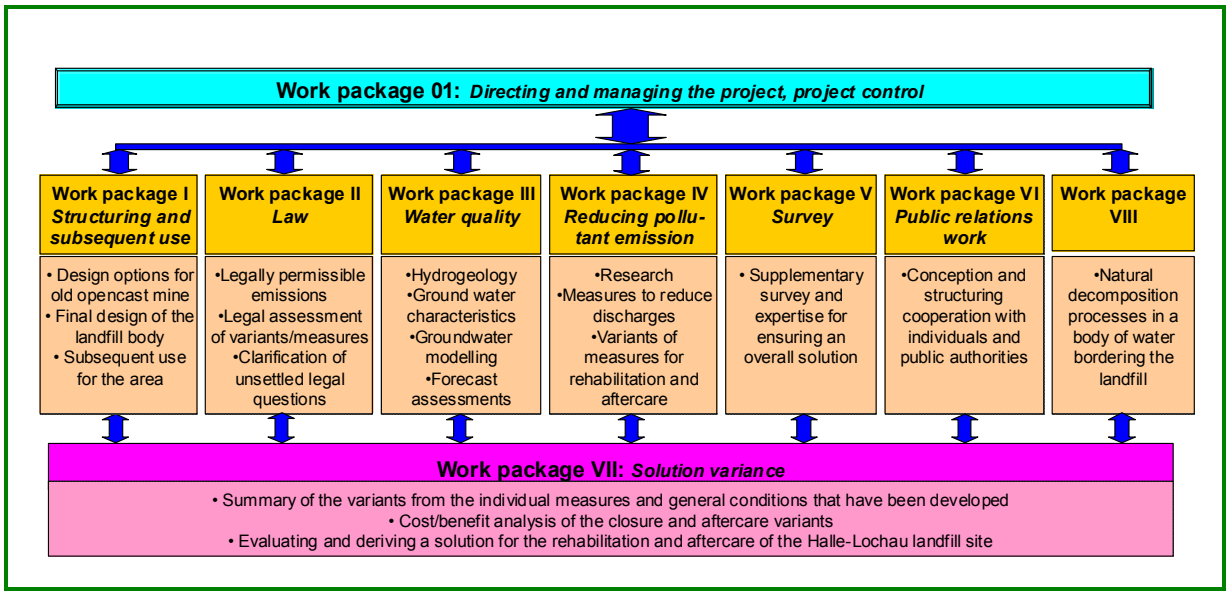


Diagram IV: Structure of the work packages

In carrying out the research work recourse was made to the existing documentation relating to the old Lochau opencast mine and its environs, publications and results from ongoing mining activities and environmental monitoring with the help of the monitoring and metering networks of the AWH, the MUEG and the LMBV [Lausitzer und Mitteldeutsche Bergbau-Verwaltungs-gesellschaft mbH = LMBV].

Experts on the project advisory committee who queried the procedure and the interpretation of interim results provided important food for thought and gave many suggestions for the research project in the course of intense discussions.

■ Selected research results

• Evaluation of risk for the initial status

Based on the current hydrodynamic situation in the area of the landfill it can be shown that in its initial status and under the present hydraulic framework no impairment of water as a resource is possible. The available water analyses from the various groundwater layers show that there is no impact from noxious materials arising from the landfill outside the old Lochau opencast mine and that the chemical quality of the groundwater is relatively stable. Within the old opencast mine the waters are collected in the main drainage system. This does not show any impact from the landfill either.

• Technical variants for arranging the closure of the landfill

In identifying the technical variants for arranging the closure of the landfill the most important approaches that were developed were those which enable the landfill and the entire old opencast mine to be reintegrated into the landscape at a reasonable economic cost and with good results from an ecological point of view.

The following method for considering the system was developed for this purpose:

Table I: Target system and target criteria

Target system		Target criteria Contrasting variants to judge whether objectives have been met	Sub-criteria Verbal argument evaluating investigation variants
Sustainability	Minimal aftercare	Geotechnical safety	Permanent static stability of embankments
			Risk areas
		Water catchment	Diverting direction of flow of groundwater and surface waters (drainage)
			Free connection to drainage ditch
	Totality	Evaluation of environmental consequences	Air as a resource
			Groundwater as a resource
			Surface water as a resource
			Soil as a resource
			Flora/fauna as resources
			Human beings as a resource
			Landscape as a resource
		Subsequent use	Landscaping
			Requirements according to environmental planning
			Requirements according to mining law
			Public interest
	Economic efficiency	Mass-market requirements	Landfill area
			Pivot point area
			Embankment support [bund, berm]
			Westschlauch
			Recultivation
		Time	geotechnical measures
			Mass introduction
			Rise in water levels
		Costs	geotechnical measures
			Mass tendering, dumping
			Rise in water levels
Ecofriendliness of rehabilitation and subsequent care plus legal risks			Mining law
			Waste disposal law
			Water law
			Environmental planning
			Conservation

A minimal care requirement and avoiding the use of disproportionately technical means of encapsulation are the essential target criteria for a commercially and ecologically acceptable long-term solution. The minimal care requirement means that the chosen variant will consist of a sequence of steps that involve managing without continual repairs to conserve the condition of the landfill structure on a permanent basis and will ensure after the closure phase has come to an end and in the subsequent aftercare phase that there will be no impairment to the environment in the course of that phase or at least only impairment that is ecologically acceptable. The approaches must be effective in the long-term, largely self supporting and aimed at integrating the body of the landfill into its natural environment.

Zero-maintenance and sustainable approaches can be defined by the following basic conditions and premises:

1. Emissions that could lead to an impairment of resources (water, air) are to be reduced to a socially acceptable level. This means that mine drainage systems cannot be decommissioned until only legally permissible residual emissions can be anticipated.
2. The protection of groundwater is guaranteed on a permanent basis and free diversion of the ground water and surface water into the drainage ditch is permissible in terms of water management.
3. Account will be taken of settlement by the body of the landfill when backfilling and landscaping, which will be essentially complete by the end of the rehabilitation and configuration measures and subsequent use.
4. The stability of the embankment systems and the carrying capacity of the surface of landfill are guaranteed on a long-term basis.
5. Reincorporating the old landfill and the old opencast mine into the landscape is achievable based on an strategy for subsequent use that is acceptable to the public at large.

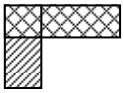
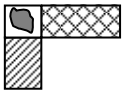
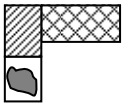
Based on these principles a number of variants were developed for closure of the landfill, which took account of the situation of the entire old opencast mine with its *Ostschlauch* and *Westschlauch*.

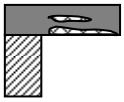
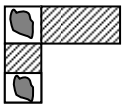
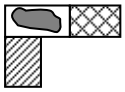
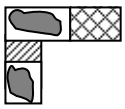
Completing the rehabilitation phase depends on the variant employed and has been regarded a tantamount to finishing the landscaping or achieving the final water level for the groundwater when it rises back up again. The aftercare phase comprises control, monitoring and maintenance measures, with subsequent use commencing at the time that release from the aftercare phase occurs.

As far as engineering work on the neighbouring *Westschlauch* is concerned account has been taken of the requirements laid down by mining law and the closing operational plan, i.e. the planned safety measures for reclamation and reuse have been included.

Once a cultivation layer has been applied, it has greened over and the facilities and equipment no longer required have been demolished these mining measures in the *Westschlauch* are complete. The surfaces can then be given over to their subsequent use. Apart from this account has been taken of the areas of the old opencast mine where tipping took place during the mining phase (Inner tip 1011).

Table II: Summary and overview of the rehabilitation variants to be identified

Variant in terms of design and use	**Brief description of the variant**
Rehablitation variant 1 “Land variant” 	Complete backfilling of the old opencast mine up to 90 m high surface area approx. 221 ha Water surface: none Mass required: approx. 38.5 mill. m³
Rehablitation variant 2 “North lake” 	Partial backfill of *Ostschlauch* with clearing of pivot area (body of water) and backfilling the *Westschlauch* to 90 m high Surface area approx. 174 ha Water surface area approx. 47 ha (volume approx. 7.1 mill. m³)Mass required: approx. 29.2 mill. m³
Rehablitation variant 3 “South lake” 	Backfilling the *Ostschlauch* and the pivot area and partially backfilling the *Westschlauch* up to 90 m high while keeping open the southern opencast mine area (body of water) Surface area approx. 163 ha Water surface area approx. 58 ha (volume approx. 12.5 mill. m³) Mass requirement approx. 24.6 mill. m ³

Variant in terms of design and use	Brief description of the variant
Rehablitation variant 4.1 “Landfill lake” 	Carrying out the most necessary consolidation and landscaping work after landfilling has come to an end 05/2005 in connection with keeping the entire *Ostschlauch* (body of water) free and backfilling the *Westschlauch* up to 90 m high surface area approx. 100 ha Water surface area approx. 110 ha (volume approx. 11.5 mill. m³) Mass requirement approx. 21.35 mill. m³ Problem: embankment areas not permanently secure
Rehablitation variant 4.2 “Lake landscape” 	Backfilling the *Ostschlauch* while keeping the pivot area (body of water) free and part-filling the *Westschlauch* while keeping the southern old opencast mine area (body of water) open Surface area approx. 125.5 ha Water surface area approx. 82 ha (volume approx. 7.1 mill. m³) Mass requirement approx. 20.2 mill. m³
Rehablitation variant 4.3 “Shifting the landfill” 	Shifting the waste deposited up until 05/2005 within the *Ost-schlauch* from west to east while keeping the pivot area (body of water) free and backfilling the *Westschlauch* Surface area approx. 140 ha Water surface area approx. 80 ha (volume approx. 9 mill. m³) Mass requirement approx. 24.9 mill. m³
Rehablitation variant 4.3.1 “Sub-variant for shifting the landfill” 	Shifting the waste deposited up until 05/2005 within the *Ost-schlauch* from west to east while keeping the pivot area (body of water) free and partly backfilling the *Westschlauch* while keeping the southern area of the old opencast mine open (body of water) Surface area approx. 84.5 ha Water surface area approx. 116 ha (volume approx. 18 mill. m³) Mass requirement approx. 15.5 mill. m³

The rehablitation variants were modelled to take account of different technical steps taken in terms of their impact.

To measure the reduction in discharges from the subaquatic body of the landfill (residual emission) and the water quality of the drainage ditch connection in the forecast final condition account had to be taken of current water pollution legislation for the site and protection of the water management regime. In assessing the eco-friendliness of material discharge with reference to the anticipated quality of the body of water in the pivot (87.5 m high) or of the waters linking the drainage ditch with the river *“Weisse Elster”* the criteria (monitoring or discharge values) of the water licence (WRE 03/01) of Abfallwirtschaft GmbH of 27.03.2001 for the discharge of purified leachate, surface water and sump water from the landfill site into the river *“Weisse Elster”* were applied to the forecast variants.

The forecast for discharges from the landfill is being carried out as part of these investigations for selected guide parameters (CSB, NH_4-N, AOX, Cl).

The following scenarios were considered for closing the Halle-Lochau landfill and subjected to forecast calculations:

0. Closing the landfill 05/2005 including setting up mine drainage facilities without carrying out engineering or other rehabilitation measures (zero variant)

I. Variants with measures for engineering work on the old opencast mine without other rehabilitation measures (cf. Table II)

II. Variants with measures for engineering work on the old opencast mine and other rehabilitation measures

To implement the range of investigations referred to under II. various rehabilitation measures were developed based on the results achieved up to that point, to which the respective design variants were applied and investigated by using models and forecasts aimed at a further reduction in emissions. As well as assessing and evaluating the environmental impact the rehabilitation measures that had been developed were also looked at in terms of sustainability and economic efficiency along with the legal aspects.

The rehabilitation measures considered in shaping the old opencast mine will be listed in the abbreviations for identifying variants by using the following lettering system:

a – Securing and backfilling the *Ostschlauch* with permeable material in the upper zone at 87.5 – 88.5 m high, topped by recultivation and drainage layer up to 90 m high

b – for Variants 2 and 4: Shifting waste from areas above 87.5 m high to areas below 87.5 m high
for Variants 1 and 3: Drainage ditches on the landfill

c – Pivot with partitioning and support cover system up to 90 m high

d – Pivot with partitioning and support cover system up to 87.5 m high (87.5 – 90 m high permeable)

Combinations of letters indicate combined measures.

In the course of the comparisons and evaluations carried out for the design variants and the rehabilitation measures that had been developed the range of variants promising success as far as achieving the goal is concerned has been reduced by justifiably excluding unsuitable variants and measures. While taking account of the results, combinations of variants have finally been developed, which include applying several suitable rehabilitation measures to the relevant design variant. These were also investigated by modelling and forecasting in terms of achieving the intended reduction in emissions. Finally, in the course of this optimisation process, three possible variants crystallised for closing the Halle Lochau landfill. These three variants were assessed and compared with each other both extensively and in detail.

As a result of the evaluation one of these variants was inferred as being the most suitable solution for rehabilitation the Halle Lochau landfill. Finally a more extensive investigation and description was worked out for this variant.

- **Evaluation of the results of the model prognosis**

1. Closing without any further technical measures (so-called zero variant) after 2005 leads to an increase in emissions and entails a content of approx. 33 mg/l NH_4-N in the waters of the drainage ditch connection.

   ⇒ This means that the discharge criterion of water licence (WRE 3/01) cannot be achieved.

2. For the rehabilitation variants 1 and 3 with a complete backfill of the *Ostschlauch* (no formation of a body of water in the *Ostschlauch*) the modelling result showed, that these variants meet the requirements even without additional measures. For Halle-Lochau both variants fail to come into consideration because of the high shortages in terms of mass, but they do present possible solutions for similar practical instances as a result of generalising the R&D results.

3. The rehabilitation variant GV 4.1 (“landfill lake”) was not considered in view of the geotechnical risks, especially because of the unstable embankments and the modelling results on negative trends in water quality.

4. By applying a water balance and recultivation layer, the discharge and ammoniacal nitrogen content of the waters of the drainage ditch connection to a body of water adjacent to the landfill can be reduced with the remaining variants being investigated to about 8 mg/l.

   ⇒ This action alone is not sufficient to meet the discharge criteria of WRE 3/01.

5. Vertical retention walls to the north and east of the landfill do not will not have a significant impact on reducing the discharge from the landfill from a hydraulic point of view because of the weak flow processes. The in part very slight flows of groundwater or leachate cannot justify the cost of building retention walls in the apron of the Halle Lochau landfill site. Sealing would involve separating the groundwater and the landfill water, which cannot be seen as progressive in terms of long-time security and low-maintenance.

6. By the additional construction of a technical partitioning and support system with barrier characteristics ($k_f < 1 \cdot 10^{-9}$ m/s) at the contact layer between the body of water and the landfill up to a level of 90 m high the discharge and the concentration of drainage ditchwater can be reduced to ammoniacal nitrogen levels that match the discharge criteria of WRE 3/01.

   ⇒ Although this combination of measures adheres to the discharge figures, the field distances in the area of the landfill are nevertheless too small to rule out harmful waterlogging of the landfill surface. Further measures consisting of several individual elements are necessary to guarantee an integrated, secure system that is effective over a long period of time.

   This solution would be combined with long-term structural maintenance work, which would make the time horizon for rehabilitation and aftercare unmanageable.

7. An additional security and backfill strategy [optimising flow by limiting the waste inserted in the dumping phase to a maximum of 87,5 m, geotechnical consolidation and backfilling with a balancing of settlement to 87.5 m high by utilising the masses suitable for the site (k_f-values variable approx. $=10^{-4}$ to $=10^{-6}$ m/s; $= 1 \cdot 10^{-6}$ m/s), more permeable backfill materials from $> 5 \cdot 10^{-5}$ m/s between 87.5 m high and 88,5 m high and a recultivation and drainage layer with woody vegetation] concentrations on the run-off to the river *Weisse Elster* of approx. 3,0 mg/l NH_4-N can be achieved. The field distances that have been forecast are approx. > 1.5 – 2.5 m below ground level, so that no extensive waterlogging is anticipated.

   ⇒ The discharge criteria pursuant to WRE 3/01 will be adhered to and the requirements for subsequent use guaranteed.

8. By using the recycling of leachate on the landfill site, biochemical inertisation can make a further contribution to accelerating the breakdown of pollutants within the landfill. The concentrations of NH_4-N to be discharged at the drainage ditch will be further reduced to ensure that rehabilitation will be environmentally friendly and provide additional safety.

9. The objectives for rehabilitation and aftercare will be most sensibly achieved from a technical and economic point of view by considering and/or implementing the above basic conditions and rehabilitation measures in combination with

   ⇒ installing a partitioning and support system (height of development 87.5 m; eastern embankment pivot with areas of the body of water bordering the landfill; barrier: $k_f < 1 \cdot 10^{-9}$ m/s)

   and

   ⇒ creating permeable backfill areas in the upper zone of the secured body of the landfill with a k_f-value of $5 \cdot 10^{-5}$ m/s

   .

10. This combination of measures would separate the deeper landfill areas from the body of water with a partition system acting as a barrier so as to reduce the direct transfer of materials from the deep layers contaminated by pollutants. Infiltration and the volumes of material discharges caused by water pressure will be significantly reduced by a recultivation and drainage layer made up of woody vegetation. The flow through the landfill and consequently the discharge of material would predominantly take place through the less polluted, permeable backfill areas to the body of water. Apart from this the upper, permeable area creates an increase in the field distances (approx. > 1.5 – 2.0 m below surface level), which can support and ensure recultivation (woodland) and the objectives of subsequent use (carrying capacity).

11. As a consequence of the prognosis the rehabilitation measures that have been identified are sufficient mathematically, to ensure the quality requirements in the long term for connecting the drainage ditch for guide parameters NH4-N, CSB, AOX and chloride during the aftercare phase without any further additional technical measures. As additional, sustainable support components for the aftercare phase the natural decomposition and detention processes in the dewatering plant in the pivot area and the body of the landfill will also become effective.

- **Comparing the various options**

As a result of the investigations of the rehabilitation variants with technical measures three options were identified, which were subjected to a more extensive comparative evaluation. These were the following three variants, which contained a further common feature of establishing a term management and recultivation layer.

2c: Design variant 2 “North Lake”, pivot partition and support system 90,0 m

2a+d: Design variant 2 “North Lake”, pivot partition and support system 87.5 m, backfilling 87.5 m to 88.5 m with permeable material

4.3c: Design variant 4.3, pivot partition and support system 90.0 m high

To make a comparison the cost of implementing the three variants was also assessed. The total cost of rehabilitation and aftercare measures is taken from the subtotals for necessary technical and associated measures:

1. Cost of technical measures for rehabilitation and aftercare

2. Cost of rehabilitation operation
   - Entry inspection / self inspection
   - Apron draining operation
   - Infiltration leachate recycling
   - Leachate treatment

3. Collecting and utilization of landfill gas (methane)
   - Cost of collecting gas

- Cost of using gas
- Proceeds from converting to electric power

4. Costs during the water rising phase
   - Recycling
   - Controlled rise in water level

5. Costs in the aftercare phase
   - Aerating body of water (optional)
   - Maintenance measures (water management and recultivation layer; ditch systems etc.)
   - Monitoring and supervision

Table III: Review of comparative verbal arguments for a cost-benefit assessment of the variants for rehabilitation, aftercare and subsequent use of a subaquatic landfill in an old opencast mine exemplified by the Halle-Lochau landfill site.

Valuation criterion		**Variants**		
		2a+d [1)]	**2c** [2)]	**4.3c** [3)]
1	Sustainability due to a largely self-supporting, zero-maintenance final state (minimal aftercare) ensuring aftercare objectives	Sustainability due to largely self-supporting, zero-maintenance solution	Sustainability due to largely self-supporting, largely zero-maintenance solution	Sustainability due to largely self-supporting, largely zero-maintenance solution
1.1	Functionality	Functionality due to using the regenerative power of nature and landscape	Functionality due to using the regenerative power of nature and landscape	Functionality due to using the regenerative power of nature and landscape
1.2	Permanence of the solution	Permanence of the solution with reduction in the discharge, protection of the ground water and ensuring a stable flow of the groundwater	Permanence of the solution with reduction in the discharge, protection of the ground water and ensuring a stable flow of the groundwater	Permanence of the solution with reduction in the discharge, protection of the ground water and ensuring a stable flow of the groundwater
1.3	Zero maintenance	Zero maintenance due to self-supporting drainage ditch connection to high tide and compliance with WRE 3/01, use of natural decomposition and retention processes in the landfill and water body	Zero maintenance due to self-supporting drainage ditch connection to high tide and compliance with WRE 3/01, use of natural decomposition and retention processes in the landfill and water body	Zero maintenance due to self-supporting drainage ditch connection to high tide and compliance with WRE 3/01, use of natural decomposition and retention processes in the landfill and water body
1.4	Ensuring the aftercare objectives	Ensuring the height of the contour 90 m, long-term security of the embankments of the old opencast mine	Ensuring the height of the contour 90 m, long-term security of the embankments of the old opencast mine	Ensuring the height of the contour 90 m, long-term security of the embankments of the old opencast mine
2.1	Technical feasibility of the measures	technically achievable	technically achievable	technically achievable
2.2	Appropriacy of monetary investment and financial backing	100 %	104 %	209 %
2.3	Manageability and reasonable timescale	Closure phase completed by 2021, aftercare from 2022 until approx. 2031	Closure phase completed by 2021, aftercare from 2022 until approx. 2031	Closure phase completed by 2021, aftercare from 2022 until approx. 2031

Valuation criterion		Variants		
		2a+d [1)]	2c [2)]	4.3c [3)]
2.4	Residual risks	No perceptible geotechnical and hydraulic risks if variant is implemented	Residual geotechnical risk remains due to permanent state of hydraulic pressure between the body of water 87.5 and the body of the landfill approx. 89.5 m and the encapsulation of the source of the noxious material ("conservation", without clear decomposition of noxious material, neglecting the generation commitment)	Residual geotechnical risk remains due to permanent state of hydraulic pressure between the body of water 87.5 and the body of the landfill approx. 89.5 m and the encapsulation of the source of the noxious material ("conservation", without clear decomposition of noxious material, neglecting the generation commitment)
3	Totality – shaping and subsequent use			
3.1	Shaping the landfill while bearing in mind the old opencast mine	Criterion met by water surface and woodland as well as usable relevant load-bearing surfaces in the landfill area (accessible on foot or by vehicle)	Criterion met by water surface and woodland; but restrictions to use because of waterlogging, with restricted access on foot or by vehicle possible	Criterion met by water surface and woodland; but restrictions to use because of waterlogging, with restricted access on foot or by vehicle possible
3.2	Subsequent use and integration into the landscape	Water surface, forest area no restrictions recognisable	Water surface, forest area with damp areas: Subsequent use and access on foot limited	Water surface, forest area with damp areas: Subsequent use and access on foot limited
4	Ecofriendliness of rehabilitation and subsequent care plus legal risks [4)]			
4.1	Licencing exceptional provision in accordance with DepV § 14 para. 6	Ecofriendly and no legal risks apply (see WP II)	Ecofriendly and no legal risks apply (see WP II)	Legal risks not yet finally clarified due to health risks (see WP II)
4.2	Projection for people and the environment (protection of groundwater, connection of drainage ditch, geotechnical internal and external security after settlement has come to an end)	Groundwater protection is ensured, WRE 3/01 is complied with	Groundwater protection is ensured, WRE 3/01 is complied with	Groundwater protection is ensured, WRE 3/01 is complied with
4.3	Protected existence (structures, plant, protected areas and, planning intentions etc.)	Protected existence and planning intentions affected	Protected existence and planning intentions affected	Protected existence and planning intentions affected

Notes:
[1)] Results are transferable to design variant 4.2a+d
[2)] Results are transferable to design variant 4.2c
[3)] Results are transferable to design variant 4.3.1c
[4)] Eco-friendliness and legal risks pursuant to the exceptional provision in accordance with DepV § 14 para. 6 and KrW-/AbfG § 10

For the implementation of Variant 2a+d compared with Variant 2c there is an economic cost saving. Both Variants are comparable in their basic approach, but differ in the height of the development of the partitioning and support embankment in the pivot area (Variant 2a+d: 87.5 m; Variant 2c: 90 m). The increase in expenditure between Variant 2a+d and Variant 2c results along with the slight discrepancies in technical measures (such as drainage material, backfill material, recultivation layer etc.) in particular from the additional expenditure in the aftercare phase. These are necessary in Variant 2c, as an increase in expenditure can be assumed for subsequent maintenance in terms of surface sealing (waterlogging, carrying capacity, vegetation etc.).

The total cost saving between Variants 2a+d (TSD 87.5 m) and 2c (TSD 90.0 m) is approximately 4 %.

In the case of Variant 4.3c as far as costs directly attributable to decommissioning and the aftercare operation are concerned and by comparison with Variant 2a+d there is a relative rise of an additional 109%.

- **Identifying the most suitable variants**

According to the model variants a complete hydraulic separation of the body of the landfill from the body of water by a partition system at the western side of the landfill with a developed height of 90 m result in very low flows from the landfill (discharge of material, residual emission) and means that the run off to the river "*Weisse Elster*" is only slightly polluted. A disadvantage however would be the impeded drainage above the landfill and the landscaping associated with this [groundwater levels close to the surface with increase in evaporation; risk of waterlogging; restricted carrying capacity (access by vehicle and on foot); limiting vegetation etc.]. Apart from this the solution would involve encapsulating the body of the landfill with the residual pollution from noxious materials, which would involve a certain lack of manageability and mean postponing the solution into the distant future. This would be equivalent to delegating the residual risks to following generations. Along with the "preservation problem" the steady hydraulically-related load between the landfill (water level maximum approx. 89.5 m) and the body of water (approx. 87.5 m) involves a long-term latent residual risk (difference in water levels approx. 2 m).

A partition and support system to a level of 87.5 m, which screens the deep zones of the landfill sector from the body of water hydraulically, would both severely restrict water flow through the waste and allow a free run-off from the backfill area above the landfill in the direction of the body of water so as to regulate groundwater levels above the landfill. The level of effluent occurring in this scenario is dependent on the initial concentrations and the level of pollution in the masses of material in the consolidation and backfill areas. Consequently the contents and concentrations (eluate values) permissible for the material used for consolidation and backfill are determined in line with the site-related estimate for closure pursuant to § 14 Subsection 6 DepV and guaranteeing the run-off concentrations of the waters in the drainage ditch connection in accordance with WRE 03/01.

For rehabilitation and aftercare using a partition and support cover system to a level of 87.5 m a similar forecast model was used for a rise in the water level in the pivot and the landfill being saturating with water or topped up. Assuming backfilling of the landfill generally below the height mark of 87.5 m until 6/2005, geotechnical consolidation of the landfill by backfilling up to 88.5 m including smoothing out the settlement in the landfill and covering the surface with a recultivation and drainage layer up to 90 m with wood vegetation the model forecast the process of water rising water in the pivot and saturation of the landfill. The results show the necessity of taking into account and adjusting the changes in water levels in the pivot area (rising water) and the landfill over time. For this it is necessary to implement appropriate technical measures at the time at which the regime of mine drainage systems is changed and a technically supported saturation of the landfill as an option.

Deducing effective technical measures for the Halle-Lochau landfill was considered in the course of the various forecast model calculations while bearing in mind the settlement that would take place as a result of the loading and the subsidence caused by microbes before the final state was reached. If the whole package of measures for rehabilitation the Halle-Lochau landfill is used the discharge criteria provided for under WRE 3/01 for guide parameters (NH4-N, CSB, AOX and chloride) can be achieved. There are sufficient control measures for achieving the rehabilitation and aftercare objectives.

Employing the concept with an opportunity in the overall package for applying technical measures provides adequate safeguards for achieving the rehabilitation and aftercare objectives. The discharge of noxious material will be reduced to an ecologically compatible level in terms of the basic legal and economic conditions. The forecast proves that the efficient solution on which the variant is based can be projected, is feasible and represents the most effective combined package of measures if the advantages and disadvantages are taken into account.

Diagram V provides an overview of the detailed investigations carried out for what has been determined to be the most suitable variant of all the solutions for rehabilitation the Halle-Lochau landfill.

The figures obtained for the forecast as a result of modelling investigations prove that the variant arrived at as a result of all investigations and optimisation is the most sensible solution for handling the rehabilitation and aftercare of the subaquatic Halle-Lochau landfill. The discharge of noxious material can be reduced to a legally permissible and ecologically compatible level in terms of the ecological and economic objectives.

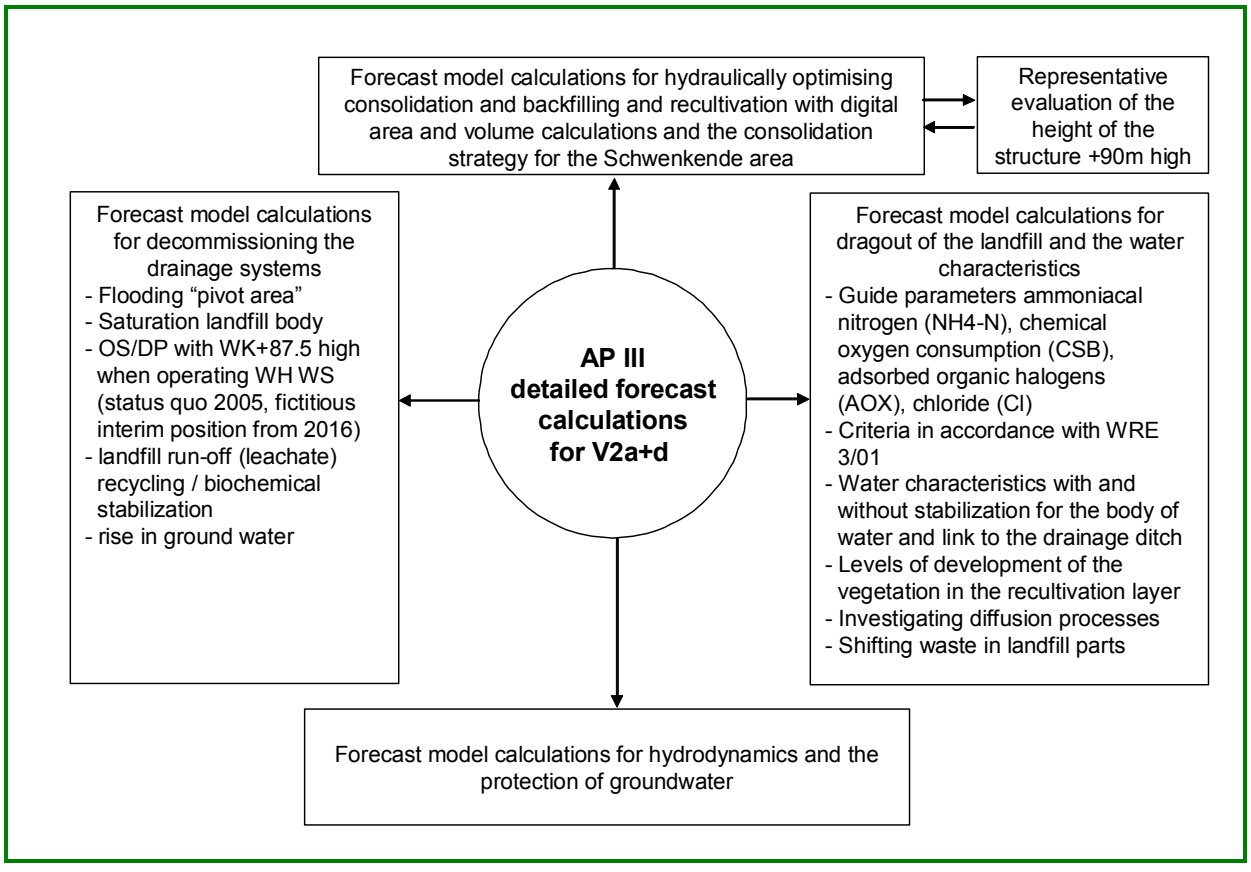


Diagram V: Overview of forecast model calculations for assessed solution variant

- **Strategy for measures to be taken from the deduced variant for rehabilitation the Halle Lochau landfill**

- Geotechnical consolidation and backfilling with hydraulically optimised structuring of the landfill bearing in mind settlement for reducing discharge
- Setting up partitioning and support cover systems on the landfill for reducing dragout
- Developing a recultivation and drainage layer with wood vegetation to reduce dragout
- Continuing to operate, with modified, optimised use of existing technical plant for rehabilitation the Halle-Lochau landfill (collecting leachate, collecting and recycling methane) during the closure phase and recycling leachate to reduce discharge.
- Hydraulic consolidation of the landfill by continuing to operate and modify existing technical plant (e.g. drainage, connecting the drainage ditch, control and systems for dealing with major accidents)
- Natural decomposition in the landfill by optimising gas discharge and stimulating biochemical stabilization by means of supplementary technical measures to reduce discharges
- Removing old equipment and facilities
- Monitoring, supervision and control

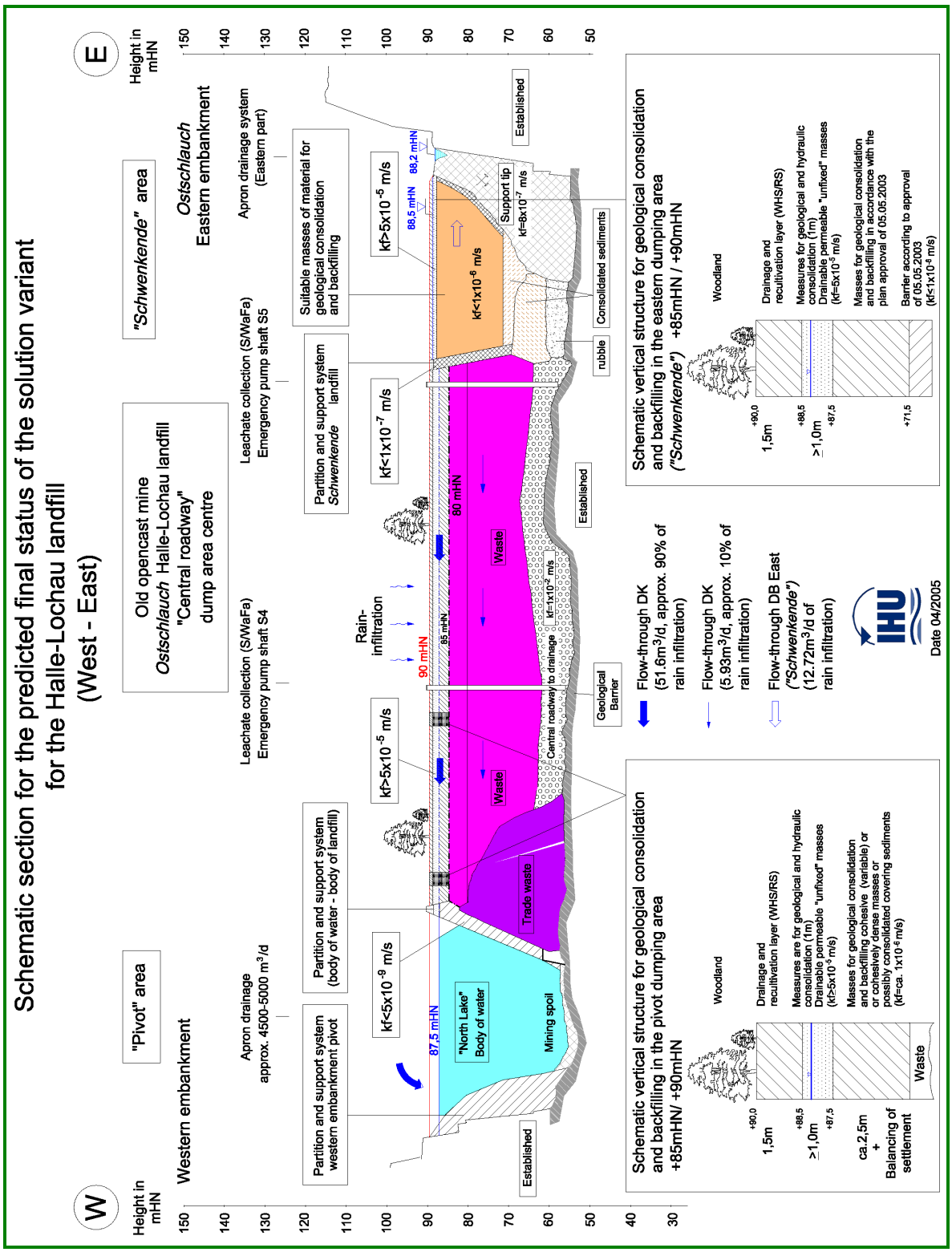


Diagram VI: Schematic section for the predicted final status of the selected variant for the Halle-Lochau landfill

While the technical measures are being implemented it is important to ensure that individual measures are constantly updated and adjusted to take account of the way in which the body of the landfill behaves in the course of rehabilitation and aftercare. Should changing basic conditions, such as for example settlement and concentrations of noxious materials differ from predicted levels, additional temporary and appropriate technical measures can be taken to achieve the final status aspired to.

Such measures would for example be

- the subsequent adjustment to disposal levels using suitable materials,
- temporary, active water catchment in the body of the landfill and treatment of the leachate.

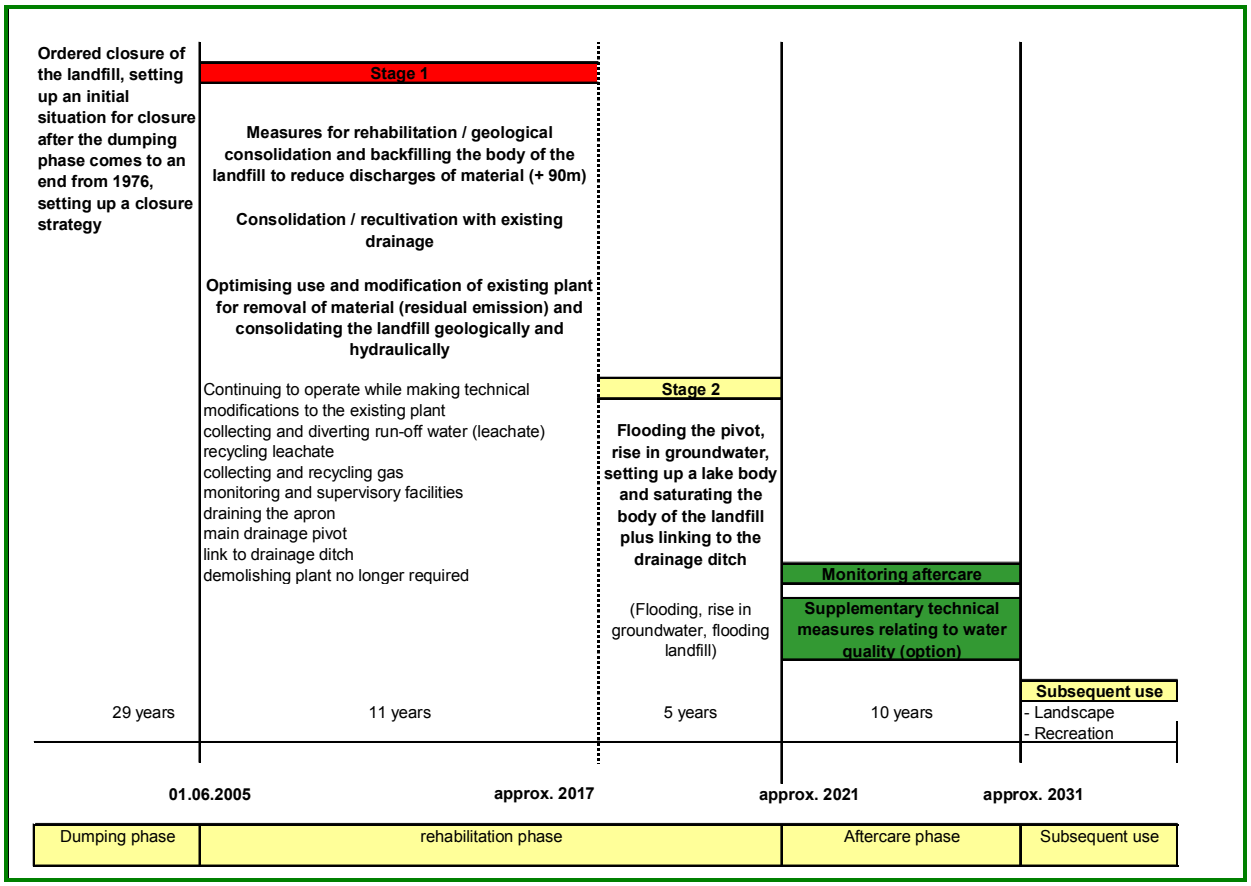


Diagram VII: Schematic overview of the measures to be taken from the selected variant for rehabilitation the Halle Lochau landfill

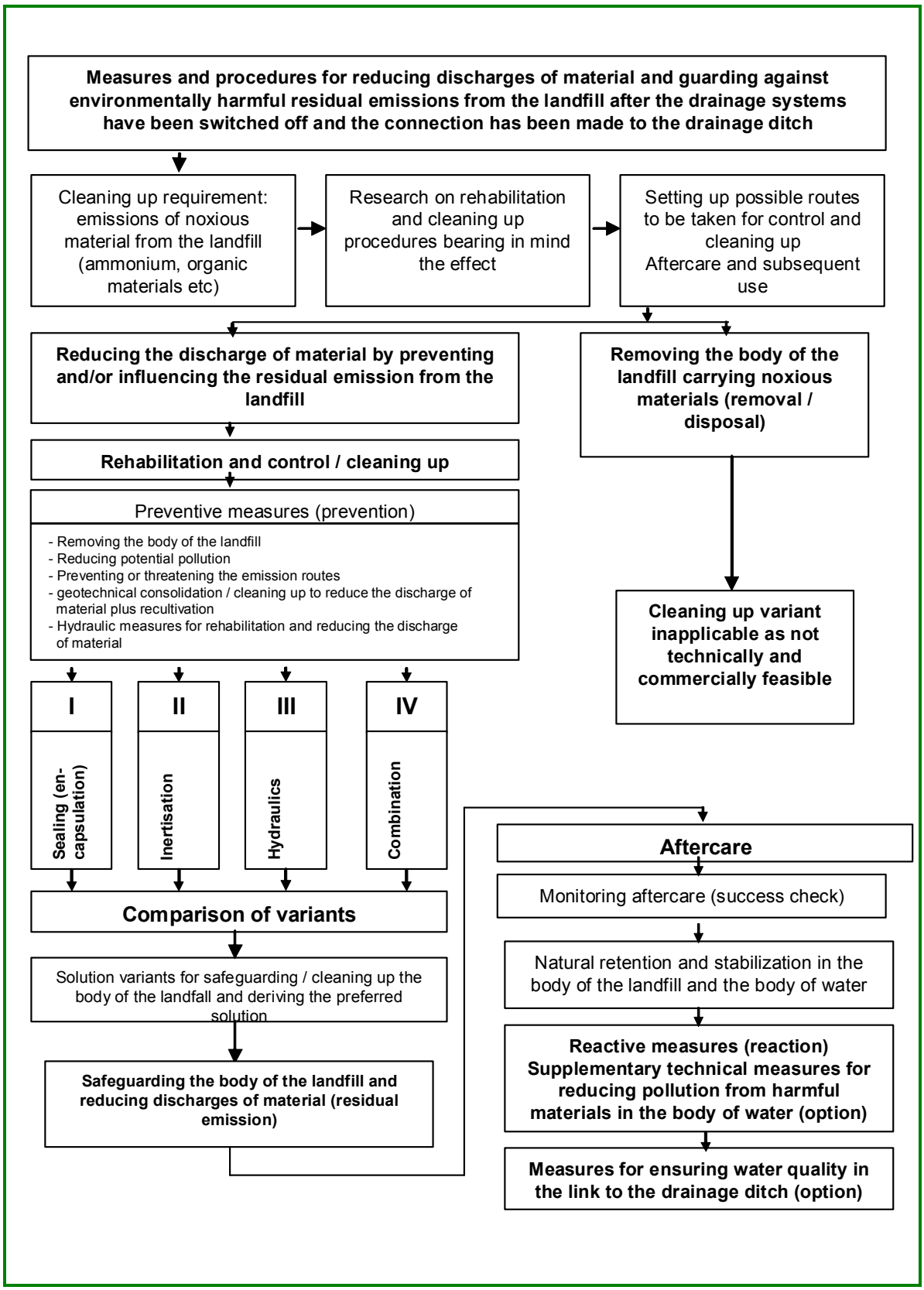


Diagram VIII: Strategy scheme for selecting the final variant

Table IV: Technical measures to be taken from the selected variant for rehabilitation of the Halle Lochau landfill

No.	Rehabilitation measures	Duration		Brief description of the rehabilitation measures	
		Stage 1	Stage 2	Stage 1	Stage 2
I	Geotechnical consolidation and backfilling with a balancing of settlement plus recultivation, developing partioning and support cover systems	06/05 – 12/16	01/17 – 12/19	Northern part (domestic waste); central part (central roadway) and southern part (trade waste) plus eastern area (north-eastern part and *Schwenkende*); recultivation, afforestation Geotechnical consolidation of the landfill (partioning and support cover system “pivot” area and ”Schwenkende” area) *Nordgraben* [northern ditch] (backfilling, consolidation) Stability of embankment systems (“pivot” area)	Recultivation, afforestation, *Nordgraben* [northern ditch] (backfilling, consolidation)
II	Measures for removing and reducing discharges of material (residual emission)	06/05 – 12/16	01/17 – 12/20	Continuing and modifying the collection of leachate (SiWaFa) S4, S5, retention (S3), S1 und S2 Leachate recirculation Continuing and modifying the collection and utilization of methane	Continuing and decommissioning the collection of leachate Leachate recirculation Continuing and decommissioning the collection and utilization of methane
III	Demolition of technical plant and structures	01/16 – 12/16	01/17 – 12/21	leachate *polder* [drainage dike] “pivot” area; <87.5 m Demolition of plant	Demolition of plant >87.5 m outside “pivot” area
IV	Drainage measures Decommissioning mine drainage and rise in water level, rise in groundwater, adjustment to saturation of the landfill	06/05 – 12/16	01/17 – 12/21	Running the apron drainage system 85 m to collect the inflow of groundwater and divert to “pivot” area; Modifying the VFE to 88 m (construction); Running the modified apron drainage system 88 m; Running the main drainage system pivot WH DP) 60 m; Running the drainage ditch link to river „*Weisse Elster*“; diverting the water from the “pivot” area pump system	Decommissioning “pivot” area/drainage ditch link Water rise in pivot Modifying drainage ditch link (construction) Adjustment to saturate body of landfill
V	Supervision and monitoring	06/05 – 12/16	01/17 – 12/21	Monitoring and supervising the closure phase	

No.	Rehabilitation measures	Duration		Brief description of the rehabilitation measures	
		Stage 1	Stage 2	Stage 1	Stage 2
VI	Mining inspectorate and mining measures to recultivate the *Westschlauch*	06/05 – 12/16	01/17 – 12/21	Hydrological monitoring TRL Lochau *Ostschlauch* (OS) – *Innenkippe* (IK) – *Westschlauch* (WS); LMBV and MUEG Geotechnical consolidation and backfilling the site Lochau Westschlauch (recultivation) with adjustment to mine drainage systems and the depression amounts to the backfill level of the WS and the rehabilitation measures in the *Ostschlauch* (OS); (MUEG)	

- **Effectiveness of measures to be taken from the selected variant for rehabilitation of the Halle Lochau landfill**

As a result of considerations of the effectiveness of the proposed technical measures for rehabilitation and aftercare it is possible to make the following comments:

- The technical expenditure is efficient. The duration for the whole package of measures is manageable with about 16 years for the closure phase and about 10 for aftercare.
- The projectable concept for the variant for rehabilitation and aftercare takes account of the following premises:
  ⇒ Sustainability (economy, minimal aftercare, totality)
  and
  ⇒ Ecofriendliness of decommissioning and subsequent care plus legal risks
- The remaining discharge of material and residual commissions from the landfill will be effectively reduced in the long term to an environmentally acceptable level by the technical measures provided for under water management requirements (WRE 3/01). There will be no negative impact on public welfare and resources.
- Protection of the groundwater will be ensured at all times from the initial position (12/2003) over the period of the closure phase, in the aftercare phase and at the final stage.
- After a body of water has formed in the vicinity of the landfill itself a “free” diversion of the ground and surface water into the river “*Weisse Elster*” drainage ditch appears possible.
- Geotechnical consolidation has meant that the landfill itself has been put into a safe long-term condition.
- To conclude the rehabilitation measures there are long-term and stable embankment systems in the *Ostschlauch*, the marginal areas of the landfill itself, the *Westschlauch* and the *Innenkippe*.
- This means that the rehabilitation measures will provide a basis for the aftercare phase.
- Based on the technical rehabilitation measures the site will be available for future use in terms of landscape and nature.

To summarise: as far as the closure phase is concerned, both in terms of the sequence of measures and the timescale it can be assumed that requirements relating to final rehabilitation will be guaranteed in accordance with DepV.

- **Assessment of the forecast developments**

After extensive saturation (= 87.5 m) of the geotechnically consolidated and completely recultivated landfill body and the rise in water in the pivot has come to an end the aftercare phase will commence (total duration: approx. 10 years). The core of the aftercare phase is checking the effectiveness and sustainability of the measures carried out in the closure phase.

The aftercare phase at the Halle-Lochau landfill site is identified by the following conditions and circumstances:

- Technical measures to recultivate the body of the landfill have been concluded
- Hydraulic conditions are stable resulting from the apron drainage system, the body of water, the saturated landfill itself and the link to the drainage ditch; the groundwater is protected if there is an inflow to the body of water and/or the apron drainage system.
- Reduction in the remaining emission from the body of the landfill as a result of technical measures to reduce the input of material to an environmentally acceptable level by using natural decomposition and retention processes (in accordance with WRE 3/01)
- The pivot area has a control function by taking appropriate technical measures.
- The partitioning and support cover system, which functions as a barrier up to a level of approx. 87.5 m, has been set up
- Body of water is used as an operational facility
- Reducing the infiltration of the recultivation and water management layer caused by precipitation by using wood vegetation.
- Body of water (87.5 m) with a self-supporting discharge to the drainage ditch
- *Weisse Elster* drainage ditch link 87.5/85.5 with run-off volumes of approx. 5000 m^3/d and concentrations of material in the run-off water NH_4-N: approx. = 3 mg/l (meeting guide parameters for NH_4, CSB, AOX and Cl in accordance with WRE 3/01)
- mining measures for rehabilitation

Depending upon the results of the check it appears possible that there will be a release from aftercare according to the forecast data for 31. 12. 2031. Supplementary technical measures may be carried out as an additional option if necessary.

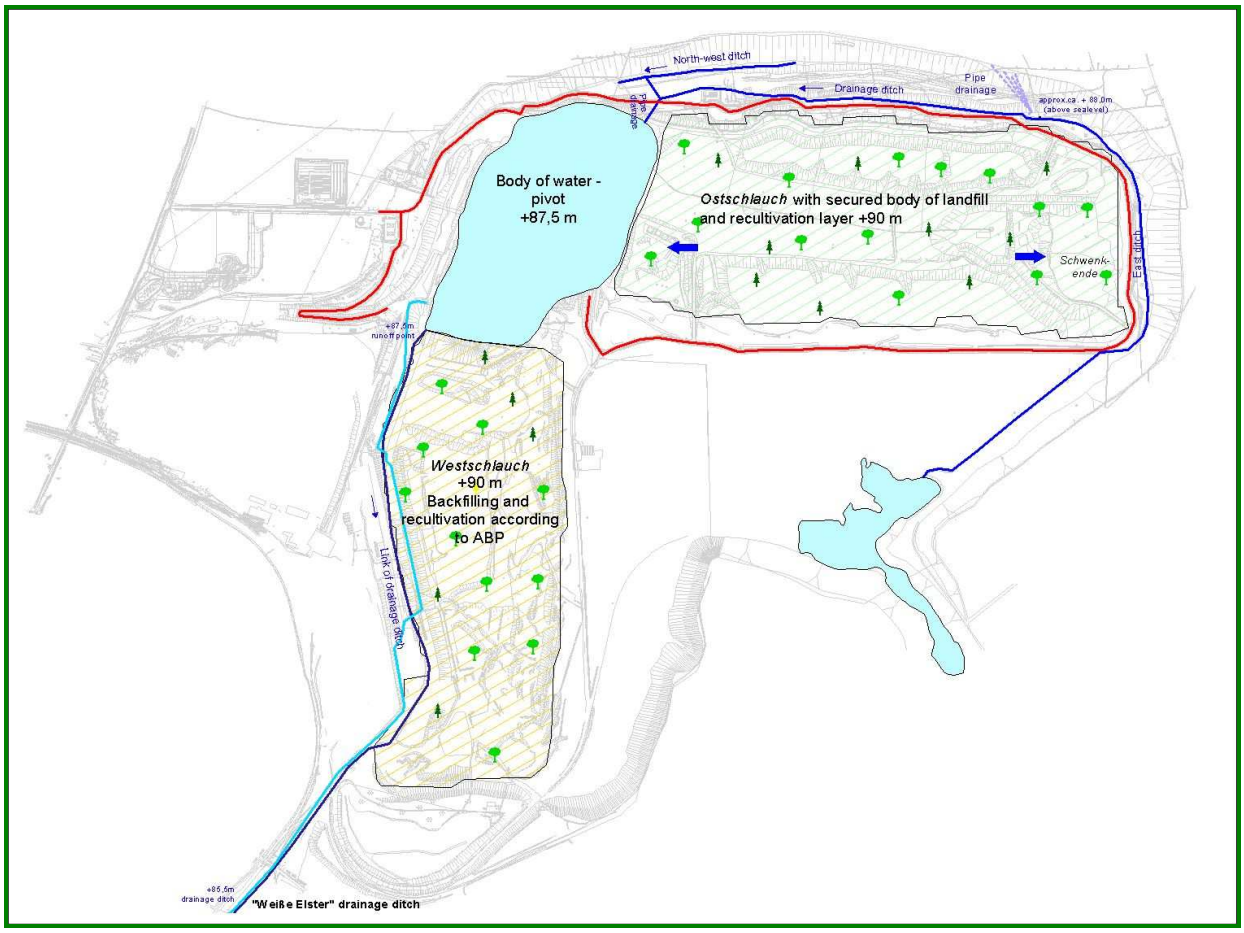


Diagram IX: Final status for the selected variant for rehabilitation of the Halle Lochau landfill

- **Safeguards for the rehabilitation concept**

After the landfill has been saturated (= 87.5 m) the natural discharge of material from the landfill to the body of water and the apron drainage system takes over. The also effective, natural decomposition of material and retention potential (“natural attenuation” – NA) for the aftercare phase, natural resources and human beings makes it much more certain that there will eventually be no further need for aftercare.

The body of water has a natural, biochemical capacity via nitrification for for decomposing material especially as far as ammoniacal nitrogen (NH_4-N) is concerned as a guide parameter originating from the landfill. In case of need there is provision for additional technical options for stimulating or initiating natural decomposition and retention processes

The development of water quality in the body of water can be monitored at any time under the conditions of the aftercare phase and may be controlled using suitable technical measures.

Measuring the effectiveness of technical measures for the closure phase meets the requirements for ensuring the aftercare objectives, i.e. the discharges of material from the saturated, consolidated and recultivated landfill and landscaping (90 m) are reduced to a tolerable, environmentally acceptable level as far as residual emissions in terms of the water management requirements for the water in the drainage link ditch (WRE 3/01) are concerned.

There is no risk emanating from the landfill for groundwater as a resource under the basic conditions as they are defined, which is also true for the other resources.

To demonstrate the effectiveness and sustainability of the rehabilitation and aftercare for the Halle-Lochau landfill site a forecast was made of the trends in water quality for the body of water and the water in the drainage ditch link in the aftercare phase.

A forecast of the water quality evident in the body of water in the pivot sector at the final stage under basic conditions was carried out with the help of a material volume balance model. The guide parameters selected and typical of the location were considered in accordance with the water licence (WRE 3/01) (discharge monitoring values: NH_4-N: 5 mg/l, CSB: 90 mg/l, CSB: 0.1 mg/l).

For the component NH_4-N as the relevant guide parameter for evaluating the residual emission from the landfill and a harmless, environmentally compatible link to the drainage ditch an additional, natural decomposition of ammoniacal hydrogen into nitrate (nitrification) in the body of water is expected.

For the decomposition of nitrogen, alongside the conservative approach predicting no decomposition, a nitrification rate of 2 µg/l*d is assumed for the body of water.

In the body of water, according to the forecast assessment for the selected variant, when pollutants begin to be discharged from the saturated body of the landfill there will be a slightly increased concentration of the components, with the concentrations of guide parameters NH_4-N, AOX und CSB in the water of the drainage ditch link at the end of the aftercare phase lying below the discharge values of the water licence WRE 3/01:

- NH_4-N (discharge without decomposition): approx. 2.88 mg/l
- NH_4-N (discharge after stabilization of the landfill): approx. 2.25 mg/l
- NH_4-N (discharge of material without inertisation, with decomposition in the body of water): approx. 1.50 mg/l
- NH_4-N (discharge after stabilization of the landfill, with decomposition in the body of water): approx. 0.89 mg/l
- CSB (with decomposition in the body of water without stabilization): approx. 28 mg/l
- AOX (with decomposition in the body of water without stabilization): approx. 0.038 mg/l
- Cl (with decomposition in the body of water without stabilization): approx. 295 mg/l

The ammoniacal nitrogen entering the body of water can, according to the forecast assessment and current knowledge, be so nitrified or decomposed by natural decomposition for it to be possible to adhere to the discharge criteria required by WRE 3/01 for NH_4-N in the water of the drainage ditch link even in the long term.

During the aftercare phase a relevant monitoring program (groundwater – body of landfill – body of water – drainage ditch link) will be carried out for the body of water, so that suitable optional measures may be taken in line with the intended strategy to cover any unforeseen impairments to the water quality that may occur (e.g. hypolimnium aeration, phytotechnology, use of emergency system for landfill body, treatment of run-off water etc.).

Monitoring the actual behaviour of the landfill, as well as observing residual gas emissions, monitoring internal and external load-bearing capacity and stability, and ongoing settlement measurements also involves the biomonitoring of measures for recultivation and greening over the site.

The technical measures for rehabilitation can produce a sustainable, economic, low maintenance, comprehensive and legally acceptable final status for the Halle-Lochau landfill site for the aftercare phase, i.e.

- the essential settlements in the body of the landfill have subsided
- geotechnical stabilisation, backfilling and recultivation have taken place,
- the removal of noxious materials guarantees the necessary degree of reduction in the discharge of material for the water-saturated conditions

- the body of the landfill has an acceptable level of stability and load-bearing capacity and
- the long-term stability of the embankment systems is guaranteed.

The residual emissions from the landfill can be effectively reduced in the long term to an environmentally acceptable level by the technical measures provided for under water management requirements (WRE 3/01).

- **Aftercare phase**

The aftercare phase begins when the water rise in the pivot area is complete. At this point in time the saturation of the landfill (90 m) that has been completely secured from a geotechnical point of view and recultivated has very largely taken place (planned duration of aftercare: 01. 01. 2022 – 31. 12. 2031; total duration: 10 years).

The basic concern in the aftercare phase is checking the effectiveness and sustainability of the technical measures carried out in the closure phase.

Monitoring in the aftercare phase concentrates on the following main issues:

- Monitoring groundwater and body of landfill (decomposition and discharge of dissolved compounds, landfill gas [methane], settlement), surface water (body of water, link to drainage ditch), geotechnology (stability, bearing capacity), natural environment (flora, fauna), system- and process-monitoring, forecast control model etc.
- Taking account of the natural decomposition and retention in the body of water (natural attenuation / enhanced natural attenuation)

Alongside the self-supporting link to the drainage ditch (VFA) and pivot and body of the landfill the following optional measures are planned in the aftercare phase:

- Systems for dealing with major accidents in the body of the landfill and for combating risk (temporary collection and diversion of the water from the landfill), monitoring and site security
- Supplementary aftercare measures for the body of water: technical measures to stimulate and/or initiate the natural decomposition processes (e.g. hypolimnium aeration, phytotechnology on the body of water)
- Supplementary technical, temporary measures to adjust the landscaping and landfill body heights with suitable materials
- Supplementary aftercare measures for treating the run-off water from the link to the drainage ditch (e.g. vegetable sewage treatment plant, water processing).

- **Legal evaluation of the selected variant**

Legal evaluation of the variant concentrated on the following main aspects:

- Residual emission after rehabilitation with reference to the requirements of water pollution control:
    - Drainage strategy and long-term discharges
    - Water pollution and waste control legislative criteria
    - Protecting the groundwater
    - Protecting surface waters
- Biochemical stabilization (recirculation of leachate)
- Landscaping
- Partition and support cover between the body of the landfill and the pivot
- Plant-related and operational arrangements for water pollution control

- Formation of the body of water at the pivot
- Licensing and procedural aspects
    - Licensing requirements under water pollution legislation
    - Linking to the rehabilitation procedure under waste disposal law
    - Public works planning procedure under waste disposal law as a sponsored process
    - Public works planning procedure under waste disposal law and partial rehabilitation
    - Linking to the mining law procedure and on conclusion of the west site *Lochau-Westschlauch*

As a result of a comprehensive discussion of these main issues the following points should be given special attention when the landfill rehabilitation strategy is implemented:

The selected variant for the rehabilitationof the Halle Lochau landfill has a potential for conflict with existing water pollution law, but is nevertheless acceptable from a legal point of view. The noxious materials are not retained but discharged over a long period of time, with the water emanating from the landfill mixing with other water.

There are no misgivings from the point of view of groundwater protection.

According to WRE 2001 the discharge of pollutants into the river *„Weisse Elster“* is acceptable or tolerable if the discharge criteria are adhered to in terms of water quality management. WRE 2001 is to be examined and adapted by the responsible authorities as part of the landfill rehabilitation and aftercare.

The long-term residual emissions in the surface water are in line with waste and water pollution regulations, if a more far-reaching reduction in the discharge of pollutants is impossible or inappropriate. From the standpoint of necessity and appropriateness the selected variant is the most suitable compared with the other design variants that were investigated and should be used for this reason. The technical suitability and effectiveness and the economic appropriateness of more far-reaching measures to reduce residual emissions should be investigated in more detail if appropriate.

Although the concept of surface sealing departs from the generally applicable standards, especially as far as surface sealing is concerned, according to § 14 para. 6 DepV there are nevertheless other suitable measures even without evidence of equivalence that are legal and achievable, if they ensure a permanent protection of the environment, especially of the groundwater.

At representative ground water metering points in the down flow from the body of the landfill ground water monitoring wells should be set as trigger thresholds for action to be taken. Since, under the conditions of the selected variant, the ground water continues to flow into the landfill so that a down flow in the narrower sense does not exist even in the predicted final status, metering points will be set up or used where the accuracy of these forecasts can be safely checked.

There are various legal opinions as far as the formation of the body of water at the pivot is concerned.

- According to the first view the body of water has the characteristics of an above-ground water feature pursuant to § 1 para. 1 WHG. This assessment also applies to the time when the body of water fulfills a function as part of rehabilitation the landfill. Only for the “good status” of the EC Basic Water Guideline in terms of morphology and physical chemistry would it be possible to claim exceptional powers for less strict quality objectives. To what extent less strict quality objectives can be set for NH_4-N, depends on what lake water quality can be achieved at reasonable expense.

- To establish the pivot lake water feature a public works planning procedure is to be carried out in line with the first view before the rise in the water level (incl. shaping the embankment, building the partition and support cover). A planning approval procedure is possible, if the project is not subject to an environmental compatibility test, where pre-examination of the individual instance is necessary.
- According to the second view the body of water does not have the characteristics of an above-ground water feature pursuant to § 1 para. 1 WHG but must be regarded as a non-water feature because the body of water can be "separated from the water cycle insofar as no landfill effluent can penetrate and the cleaning processes function in a completely controlled fashion. It also appears certain that the conditions of use for introduction into the river *„Weisse Elster"* can also be met. The rehabilitation process under waste management law pursuant to § 36 Recycling management and waste law can control the body of water as an ancillary system under waste management law in rehabilitation phases 1 and 2 so that saddling it with planning permmission under water pollution legislation appears superfluous. Not until the aftercare phase will planning permission under water pollution legislation pursuant to § 31 WHG for setting up an artificial water feature become necessary."

- **Public relations**

A description based on practice has been developed for the waste management sector, which emanates from the actors, participants, positions of interest, basic conditions and the sequence of typical procedures for public relations aimed at achieving a consensus.

Following analysis of the most important actions of the landfill operator and compiling the results achieved in the course of public relations work an assessment was made of the social and ecological changes in the years 2002 to 2005 before the Halle-Lochau landfill was closed.

The concept provides for a mediation process to present interests and conflicts after the working phase has been concluded. This will be followed by preparing information on individual topics that give rise to conflict, backing up the results of the negotiations and passing on results to the public.

As far as public relations work for waste disposal plants aimed at achieving a consensus is concerned this can be summarised by listing the following findings:

With waste disposal plants the main priority is to achieve a consensus with those involved, with the activities being aimed at the following target groups:

- waste disposal organisations,
- policy and administration of neighbouring authorities and districts along with technical planning organisations,
- permitting authorities,
- political parties of the local authorities and districts affected
- representatives of agriculture,
- those living close by and property owners,
- local pressure groups,
- recognised nature conservation associations

As part of the public relations work important preparations can be made for decisions significant to the procedure if these are relevant to the permitting authorities in the compromise and deliberation process and actual decision-making.

Between 2002 and 2005 there were no serious conflicts and obstacles preventing the preparation or commencement of the rehabilitation measures. It proved possible to achieve this favourable state of affairs, as drawing up a strategy for public relations work by Abfallwirtschaft GmbH occurred promptly and purposefully, the most important interest groups were involved at

an early stage in finding mutually agreed solutions to the existing conflicts of interest, there was an acceptance of the rehabilitation by the development of feasible compromises for keeping jobs for the workforce of Abfallwirtschaft GmbH, there was effective roundtable technical work, scientific and technical collaboration in the project advisory committee functioned outstandingly well and socio-ecological conflicts were of a minor nature.

- **Need for further research**

The necessary further considerations for carrying out the rehabilitation measures must be scientifically proven and further supported. These more extensive investigations essentially serve to evaluate and optimise measures that are being taken so that they can be adapted to ongoing findings in the course of the project. As the project proceeds necessary parameters must be established and verified on a large industrial scale with the necessary technical and structural facilities.

Further scientific considerations are also centred among other things on the trends in material concentrations in the body of the landfill and the body of water at the pivot and optimising the reduction in discharge from the body of the landfill and the landscape as a whole. Consolidation measures should be prepared by well-founded monitoring and supervision of the project and supported by a scientific check on the level of success achieved.