GUIDE

UTILIZATION OF ALTERNATIVE MATERIALS IN MINING WASTE COVER STRUCTURES

LIFE12 ENV/FI/000592 UPACMIC

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Date	**25.09.2022**
Prepared by	**Pyry Potila** **Emmi Ilonen**
Checked by	**Harri Jyrävä**

Ramboll Finland Oy
Y-tunnus 0101197-5, ALV rek.
Kotipaikka Espoo

CONTENT

GLOSSARY OF TERMS

Adsorbent	Material that attracts particles often by electro chemical reaction where material attract cations or anions.
Adsorption	Particle attach on top of adsorbent material with chemical bond.
By-product	Secondary product which is produced as side stream from primary production.
Fiber clay	Fiber clay is paper recycling industry’s secondary stream.
Recovered material	Waste or surplus material that can be utilized instead of landfilling or burning.
Redox-potential	Redox-potential is a measure how oxidative (or reductive) an environment is, and the unit is mV.
Surplus soil	Excavated soils, which can’t reuse directly on site.
Virgin material	A raw material, which are non-renewable like moraine soil.
Water permeability	Water permeability of a soil is a measure of the ability of soil to allow water to pass through it. Water permeability’s unit is K-value.

1. INTRODUCTION

UPACMIC (Utilization of by-products and alternative construction materials in new mine construction) has been funded by the EU Life 12 program (LIFE12 ENV/FI/000592). UPACMIC project aims to promote utilization of industrial by products in mines cover, bottom and reactive structures. Utilization of alternative recovered materials reduce need for virgin materials and prevent CO_2-emissions.

Target of the project was to find solutions for mining site, in which are utilized as much is possible materials directly from the mining site. Properties of those materials can be improved with suitable waste materials. Structural solutions utilized as well industrial waste materials. The waste materials can be for example fly ash from power plant, fiber clay from paper industry or surplus soil from the other construction site.

This guide’s purpose is to notify what need to take in consideration when considered traditional materials replacing with recovered materials. In the guide is presented different phase of project. Waste and surplus materials near construction site suitability and quantity for earth construction are point of interest for making material and cost-effective project. In the beginning of the project can be clarify suitability of the materials and permits necessity based on pretesting and environmental qualification testing. Only partly replacing of natural material will save non-renewable resources and it may save costs as well. Saving non-renewable resources generate positive imago impact which should be evaluated as well when considered material replacing.

Each mine is unique in the form of waste rocks, tailings, metal enrichments which they are produced and environmental permits. This guide is universal, and all the presented issues doesn’t apply to every mine and the guide doesn’t include all special properties of the mining sites.

When new mine is designed and prepared the recovered materials should take in consideration as early as possible. If including those possibilities already in permitting process, there can be saved time and money in the project. Those materials should note when planning and permitting at least bottom and cover structures, noise/cover barriers, banks, backfills and water treatment solutions.

2. BASELINE

All phases in mining sector consumes huge amounts of natural resources like rock and covering materials. At the same time there are forming lot of materials in industry and other construction sites that are earth construction suitable. The target of the UPACMIC project was to develop structural solutions, by which different material producers could answer mining sites’ material needs.

Depend on mining area and type also the environmental impacts varying. Mining industry causes load to nature in form of dusting, noising, vibration and pollution. Mining waste like tailings, excavated soil, enrichment process waste and water treatment sludge need large storage areas, which cause changes in landscape. Mining law in Finland (621/2011) chapter 15 says: *”No later than within two years of the termination of mining activity, the mining operator shall restore the mining area and the auxiliary area to the mine to a condition complying with public safety; ensure their restoration, cleaning, and landscaping; and perform the measures specified in the mining permit.”* Closing activities depend on how hazardous the waste is. Usually, amount of sulphate minerals effects to hazardousness of waste. Sulphate minerals are decomposed by oxygen and reaction formed sulfuric acid. Mining waste, which include sulphate minerals, may cause acid, metal and sulphate-rich runoff water. Environment loading doesn’t end although mining has been suspended or finished. Uncovered waste storages can cause soil pollution and/or acidification by dusting and harmful elements spread by runoff water. Sulphate bearing rock materials must cover by material that prevent oxygen getting contact with waste material. Non-hazardous wastes had to cover and landscape using material that is suitable for it.

When building new mining sites, it’s important to take into account water management. Appropriately constructed bottom, dam and cover structures can reduce amount of runoff and seepage water, and this way can be minimized the amount of acidic and metal-rich water access to environment. Structure’s lifetime performance is the main thing when environment is protected. Performance can be check by adequate monitoring. When badly sealed tailing ponds’ bottom leak, it doesn’t show in groundwater immediately, but affect might be significant later. In environmental permits are issued boundary conditions and closing plans for the cover structures which have to make after mining project ends. From these permits can be found different waste and waste areas required cover layers and types and also parameter for the structures. In practice the parameter can be structure’s water permeability requirement.

2.1 Test construction and new solutions approval

In many cases the environmental license and closing plan aren’t necessarily up to date, so new solutions test constructions and new structure solutions’ approval process must start as early as it’s possible, since approval of new solutions can take time. The rational method is to construct and compare pair of new solution and traditional one. Compared structures must be same size and large enough, so investigated properties can be estimated. At same time can be compared multiple solution candidates. There must be observed differences in the handleability between materials. Those are for example mixing properties, amount of work the compacting needs and homogeneity of the structure.

From the compared pairs can be measured for example water permeability, properties in seepage water and oxygen migrating in the structure. Other case-by-case properties for to research can be bearing capacity, erosion susceptibility, consolidation, suitable working methods and machinery, reachable technical quality and quality varying. Long time monitoring of compared pairs gives valuable information about the structures long time performance for example constancy of the properties in long time in the real conditions, frost susceptibility, water permeability of the structure, bearing capacity and deformation. Results of the long-term monitoring can be necessary for the approval of the new solution.

2.2 Permitting of the new materials

In Finland sometimes utilizing of the new material may need notification procedure or environment permit. Materials, which need notification to environmental protection database are specified in Government Decree on the Recovery of Certain Wastes in Earth Construction 843/2017. From materials, which needs environmental permits, can get more information from local Centre for Economic Development, Transport and The Environment and Regional State administrative agency. Case by case it can be possible that utilization can be executed by experimenting permit or Declaration of Cleansing Soil. Amount of the utilized material also effects to the permit procedure. There can be local variation in practices of authority, so it is recommended to take contact to the local authority. Local supervisory authority gives more information about procedures and other things which needs to be noticed.

3. MATERIAL TESTING

There are requirements to the materials, depend on the planned structure. Definite technical and environmental properties demands must fulfil, before materials are suitable for the using in the structure. Additionally, the new solutions must be competitive options by cost-efficiency. In this part of the guide are presented in general used technical and environmental qualify tests. Based on those materials suitability for the structure can be estimated. Material can be tested also with prototype or pilot structures if it's necessary to verify material's performance in real conditions, before the full-scale structure. It's important to take into account that material testing is always designed case-by-case, and this procedure doesn't fit for every case.

3.1 General tests

General properties of the material are determined by standardized technique in the begin of the testing phase. Based on the results of the tests can be preliminary estimated tightness properties of the material, suitability for the designed structure and limits for the varies of the quality of materials and/or mixed materials. Usually used tests and their example standards are:

- **Water content** tells amount of water in the material, it's necessary data from the sight of tightness. Standard can be for example SFS–EN ISO 17892-1.
- **Grain size analysis**, coarse materials wet and/or dry sieving, fine materials hydrometer test. Materials soil type can be analyzed based on the grain size analysis. Grain size distribution tells amount of different sizes grains in the material in percent. Standard can be for example CEN ISO/TS 17892-4.
- **Loss on ignition** means amount of organic/burning substance in the material. Standard can be for example SFS-FI 1997-2 (burning in 800°C) or SFS 3008 (burning in 550°C).
- **pH-determination** gives information about material possibilities for example the material neutralizing properties. Standard can be for example ISO 4316 tai ISO 10390.

3.2 Technical tests

Bottom structures need to remain stable under heavy loading for example under tailings. In additional, water seeping through the bottom structure must be negligible. Usually, researched properties from bottom structure materials are compression strength and water permeability. Also, properties' constancy in the long term and loading factors during construction work must be considered. For example, structures possible freezing before taking in use and its effects to the quality. Same properties are needed in some extent with materials, which are designed for cover structures. And additional, there can be done research about frost susceptibility and frozen-smelting-resistance and for those effect on the structure's properties in long term. Bottom- and cover structures' pressure-, moisture- and temperature conditions varies, these things must be considered when planning structure and estimated suitability of the materials. Optimum water content for compaction and required level of tightness of compacted material or material mixture are estimated based on technical testing. Required tightness of the structure will be set based on water permeability target. When there are got tighter structure, it causes smaller water permeability. During the testing is examined also material sensibility for the variety of water content and tightness level, variety of mixture ratio and also variety of number of extra components. Based on previously mentioned tests results can be estimated accepted range of fluctuation for quality controlling.

Water content is the main variable when compacting waste materials. Optimum water content of the material is that water content, where the material achieves maximum dry density when it is compacted. It can be evaluated by proctor-test in laboratory. Proctor-test can be implemented by standard SFS-EN 1997-2 5.10. Optimum water content importance is pronounced with some recovered materials, like flying ash, which doesn't compact when it's too dry or too moist. In optimum water content compacting requires less work, when can achieved time and cost saves and most of all high-quality final structure. The results are used in construction work of sealing structures where for example can be added water into the material for make tighter structure. Drying of the material is not usually possible to implement during construction work, and heterogeneity of the final material can cause variety in quality in the final structure.

Frost susceptibility properties of the material can be researched by frost susceptibility test, where water saturated material is exposed to freezing in specific laboratory setup. Based on the test there have been evaluated frost boil rating from the segregation. Alongside the frost susceptibility testing is recommended to test how freezing and possibility frosting effects to water permeability and compression strength properties constancy and long-term resistance.

3.3 Suitability tests

Materials', which are going to use in reactive structures, reactivity can be tested in laboratory for example to evaluate material's amount of neutralizing substance, like calcium oxide concentration. Potential of the material can be tested in different ways, for example monitoring percolated water pH-change, concentration of soluble substances, electrical conductivity, temperature and/or redox-potential. Final structure's target properties defined, which test methods are selected, and reactive structures functioning must be monitored regularly.

Ashes reactivity can be researched by heat production test. Test methods isn't standardized but there have been verified correlation between heat production and consolidation potential. More heat production can mean the more consolidation potential, especially when small amount of ash is used as adhesive. Powerful reaction might made final structure weaker, so it's important to evaluate case-by-case ash' properties. Test method is implemented by mixing fixed amount of room temperature water in the room temperature ash. After mixing, the heat production will be monitored in tight and thermally insulated container. Monitoring time is usually six hours.

With active calcium evaluating can be estimated neutralizing potential of the material. Analysis can be used for example comparing mixture components, when the target is pH changing. When there are designed neutralizing structure, the analysis is necessary to determinate most suitable material for application and as well that transportation and storing capacity is sufficient. Analysis can be done for example by standard SFS 5188 or SFS-EN 12945:2014 + A1:2016.

Material and material mixtures and their usability can be research by flow through test, where can get information about passed water quantity and quality and as well its suitability and probable impact or working time. There are adjusted material layers in the column which passed water is analyzed. There can be measured for example pH, electrical conductivity and redox-potential, which tells some of the properties changes in passed water during flow through test. Solution metals total- and/or soluble concentration analysis can produce information about hazardous elements solubility. The method can be used when evaluating environmental qualifications.

3.4 Environmental qualifications

Tests of hazardous elements leaching from the materials are essential part of environmental quality tests. In general, there are for landfill qualification the two-step batch leaching test, where are analyzed from material to water leached elements in standardized liquid-solid ration (usually L/S=10) mixture. Mixture has been mixed usually 24 h before water sampling. Leaching of elements can also be researched by percolation test, where water flows through columns which is filled with researched material. In the column can be one type of material or different material layers. From the percolated water will be taken samples after fixed L/S passthrough which are analyzed.

Total concentration of elements in solid material can be analyzed in laboratory. Based on the total concentrations there can be evaluated in some extent leaching potential of elements from the material. For example, ashes included small amounts of heavy metals, which amounts varying by burned material. Research of the material doesn't tell, what kind of combined effects or hazardous elements concentrations are with the covered material and material/material mixture, which are used in cover layer.

3.5 Adsorption materials testing

There are many kinds of adsorption materials, and all doesn't assort to the same conditions. Properties, which effects to the suitability are for example, water pH and ion distribution. Next are focused on testing of adsorption materials, which are suitable for to the water environment. Testing of suitability of the adsorption materials usually start by batch leaching tests between adsorbent and polluted water. If there isn't available the water from the site, it could be prepared synthetically for example by using previously collected data about the water on the site. Adsorption capacity is detected by batch leaching tests. Adsorption capacity tells maximum capacity of the material in the current conditions. Based on that results it's possible to continue development of the adsorbent or cut out unsuitable materials from the further research.

Next phase in adsorption test is to sort out necessary contact time. Contact time tells, how long adsorption material need to be in touch with the water, so the targeted of hazardous elements decreased concentration is achieved. That can be clarify with percolation or batch tests. Percolation test is repeated with different flow rate and batch test is stopped after varying time. Based on contact time there can be estimated necessary amount of material based on the flow rate of water in designed location.

When contact time is estimated next step is to monitor material performance in a long-lasting field test. This can be carried out in a field test by using separated small flow as side stream from to the real flow. By monitoring in and out-coming water can be determined and conformed performance of the material in real conditions. At the same time can be follow up material possible decaying or clogging.

4. MATERIAL SURVEY

Based on material needs and the properties which are required from the material can be started materials survey about suitable materials. From the material for the sealing layer are required considerably more properties than for example material for waste rock piles landscaping. Material with the suitable properties allocating to the right place is important when optimize structure's quality and costs. In additional, there is a reason to take in consideration varies environmental impacts of the materials which are caused by material producing, excavating, transportation and possible preconditioning. Also, size of covered areas and land level of the areas must chart before preparation of work planning, so the material needs can be calculated.

Utilizing of recovered materials as near as its possible is main objective for the material survey. Virgin materials can be replaced with recovered options without affecting to the quality of the structure. Recovered material can be surplus soil from the other construction site or previously excavated soil from under tailing ponds. Even in partial virgin material replacement with recovered materials can be saved nature and it could affect beneficially to the total costs and greenhouse gas emissions of the project. In UPACMIC project material testing were confirmed that it's possible to utilize local soil which doesn't fill quality criteria (water permeability) by mixing additional component (fly ash) in it which enhances its properties. Results of the material testing for UPACMIC project is presented in report *"A3 Final report of materials 2022"*.

In the material survey phase, the things that need to take into consideration of the material are its properties, availability, distance, cost and other special characteristics. Also, intermediate storing possibilities onsite or/and at producing site need to clarify. Properties of the material will determine where material can be utilized. Availability establishes, how big part of needs could fill in with each material. Speed of material production and storing procedure effects on availability. If material can't store in pile without covering, availability of huge amount in short term is usually limited. Transportation distance affects to the costs and emissions of the project, which limits utilization signifyingly at some point onwards. Long distances can also cause challenges for the timetable. So, that is a reason to start material survey from near construction site and expand as needed, until transportation distance's cost is uneconomical. Recovered materials are available free or cheaper than traditional materials and that price difference can compensate longer transportation distance. It should also note that materials disposing as waste generate costs to producer as form of transportation and disposing payments. That will increase producers' interest to participate partly in transportation costs.

4.1 Material on mining site

On the mine area can be found materials that can be utilized in earth constructions. Those materials are for example topsoil which has removed out of the way of tailing ponds. Usable material can be at least gravel, clay, silt or waste rocks from mining operations. Benefit of using surplus materials from nearby or from mine's area is that transportation distances are exceptional short. If material can't be utilized directly maybe its properties could be improved with right processing. Example waste rocks or some cases tailing sand can be used directly or enhanced with additional component in construction projects. With added component can be improve material load-carrying capacity, handling and/or water permeability. Acid producing waste materials acid production can be reduced by mixing alkaline material such ash or lime in it. Utilization of material mixtures recipes need designing and testing before full scale applications which need to take in account in the beginning of project.

5. BOTTOM AND TOP COVER STRUCTURES FROM RECOVERED MATERIALS

5.1 Bottom structure

Bottom structures materials properties demands are similar with top structures. Beside right water permeability properties the material need to stand more mechanical stress. During UPACMIC-project there are not tested bottom structure. However, during the project there were designed bottom structure which would have been build using fiber clay. The designed structure and its cross-section figure are shown in annex 1. Fiber clays elasticity and compressibility could be utilized in bottom structures, which assumed to be beneficial under mechanical stress.

Ash, limestone, steel mill slags and gypsum have consolidation properties which can be utilized in bottom structures. For example, in material testing phase, above mentioned materials mixed with local soil has got good results as strength and water permeability wise. Those results could be utilized in designing of new type bottom structures. When material strength increases its elasticity decreases. It means that material stress hold against shape deformation decreases, and structure is more vulnerable against deformation and cracking caused by movement. However, in bottom structures the risk of remarkable deformation is much smaller than in top cover structures. The material mixtures needs more researching and testing before full scale applications in structures.

Instead of bottom structure in UPACMIC project has constructed separating structure which is called vertical sealing barrier. Demanded properties of separating structures is mainly low water permeability. This is result of structures dedicated purpose to stop water seeping through it. Sealing layer structure constructed from surplus clay with a mould as assistant for compacting. Structure and its cross-section draft is shown more in detail in annex 5.

5.2 Cover structure

During UPACMIC project multiple material has researched for top cover structures, and pilots are presented more detailed in report *"B1 Final technical report on piloting 2022"*. Ash and gypsum usability were tested in pilot cover structures in Pyhäsalmi mine area. Test setup and methods are presented more in detail in annex 2. In annex is presented different material layer alternatives which are tested. Gypsum utilization should be considered its possible low pH <3, which may lead acidic seeping waters after construction, but acidifying effect weaken when time pass. With gypsum can be replaced some of natural resource usages such as natural moraine, but before utilization it needs still more researching. Material mixtures hasn't tested in bigger scale than laboratory and small pilot during this project. There are tested many recovered materials and material mixtures in laboratory in material testing phase.

During the project fiber clay is noted to be suitable for cover structures sealing layer material, and with right compacting method structures properties are better than traditional moraine soil cover structures properties. Fiber clays utilization is presented in case example of annex 3. In annex 3 is presented the cross-section figure and material layers of cover structure. Fiber clay is less dense than traditional groundworks materials which need to note when designing transportation procedure. Light weight allows to use of peat or wood chips transportation trucks, which allow larger transportation volume than traditional earthmoving trucks. Earthworks of sealing layer can be executed using common machinery. Needed working methods for achieving demanded density can be established for example with test compactions before large scale application. Fiber clays properties slightly change between sources, so source and application specific testing is necessary.

Soils, which are removed out of the way of mine area, can be used in different cover and closure structures, depending on properties of the soils. Properties can be improved using recovered materials. Surplus soils availability can vary but utilization of those in massive construction projects can reduce natural resource usage of project and may reduce material costs. Surplus soil utilization is presented as case example in annex 4. There can be found the cross-section figure and material layers.

Steel mills foundry sand and its dust mixed with poor quality soil is show promising results in laboratory (*A3 Final report of materials 2022*) as lower water permeability value. Utilization in larger scale needs more researching. Foundry sands properties and environmental impact vary a lot by source which needs to note in designing of structures with it. Lime products mixed with aggregates due to consolidation properties are also suitable to use in top and bottom cover structures. Lime products can affect to material water permeability and seeping water to make it alkaline. Lime's alkalinity need to take account when designing rate of mixtures and considered structures environmental impacts.

6. REACTIVE STRUCTURES

When designing reactive structures is essential to know amount of flowing water, its properties and impurities. Passive reactive structures can be used in mine area especially for point source pollutions treatment. From recovered materials lime products are already in commercial use for acidic waters pH neutralization. When water pH rises at neutral level metals, which are soluble in acidic conditions, become solids in neutral conditions. A limestone barrier pilot in Hitura mine, where water flowed through the barrier, it removes well nickel and other metals from the water about 1,5 months. After that performance dropped. Nickel concentration were >5 mg/l in incoming water. The pilot structure and the simple principle figure is shown in annex 6 and more in detail and monitoring results in report *"B1 Final technical report on piloting 2022"*. Limestone structures can be constructed using traditional earthwork machinery and methods, but limes alkalinity need to be noted for work safety and in possible intermediate storing.

Geopolymers may be usable solution for pH neutralization and adsorption in the future. Geopolymers can be modified to fit for designated usage case like point pollution sources. Those can be produced using waste streams from other industry. The tested polymer adsorbent worked until its adsorption capacity were used in Hitura pilot test. Geopolymers need a lot more improvement about materials lasting, production cost efficiency and availability before those are usable in full scale. In annex 6 has introduced the geopolymer test setup and the cross-section figure. Commercial products such as adsorption mats are easier to design to fit for different conditions. Adsorption mats were tested during UPACMIC project and those last about 2 months in tested conditions, before capacity runs out. The pilot setup and the cross-section figure are presented as case example in annex 7. Adsorbents researching and improvements are important topic in the future for developing effective, selective and environment friendly mine water treatment solutions.

7. QUALITY CONTROL AND FOLLOW UP

Quality control during construction phase is even more important when used recovered materials than traditional earthworks. Quality control can be done using mainly same utilities than normally. Example fiber clay layers density can be monitored during construction by using Troxler-meter. During UPACMIC project there were also collected information about weather conditions affect to the construction work, and there were noted that heavy rain stopped works when constructed with fiber clay. There were also collected observations and experience when structures were constructed with new materials, and new materials mixtures procedure and composition in UPACMIC.

With reactive materials conditions such as temperature and available oxide and contact time affect to occurring reactions. In water treatment also need to noted seasonal varying incoming water volume which causes occasionally different stress for structure. Suitability of materials that are tested previously in laboratory is essential to test in small scale in real application to conform it suitability and designing before full scale application. When are designed to use adsorption material or other pollutions retaining structures is crucial to take account of material adsorption capacity. Adsorption capacity define the maintenance interval and material replacing cycles. Designing of reactive structure needs always to be done case by case.

8. SUMMARY

In UPACMIC project multiple recovered materials utilization for in new type of mine areas sealing structures in top and bottom structures and reactive structures were researched. From wide range of material testing phases in laboratory results could be selected most promising and interesting materials for large scale piloting. Material testing includes basic properties testing, water permeability testing and compression testing. Materials environmental impacts has also estimated by solubility test and percolation test. In additional several materials frost susceptibility and reactive materials effectiveness has been tested. This kind of test procedure gives lot of information about material suitability for designed structure.

With a pre-testing and material survey can be selected most usable materials based on economic feasibility, technical quality and environmental impacts. In designing phase should be noted the lower price of most of recovered waste materials compared to commonly used materials. The purchasing price of recovered materials is mostly generated from loading and transportation. Distance from production facility of recovered material to utilization site has been noted to be the limiting factor for utilization of recovered materials. Long transportation distance generates more costs and greenhouse gas emissions. In the other hand waste material producer avoid the waste tax, cost of intermediate storing, transportation to disposing site and disposing costs, when the material is utilized instead of landfilling.

Recovered materials utilization will be one part of climate neutrality and zero emission objectives. Utilization of those also increase material efficiency of earthwork and mining sector. Less environmental impacting material choices can affect to negative environment image of mining sector by being one step to the better way to become resource wise operator. After mining operation, the areas right landscaping and afterlife actions designing is experienced to be important in the future to prevent widespread areas to be unused. When previously heavily natural resources consuming mines widespread covered tailings pond areas could be utilized in the future it will change substantially conception towards the area.

Annex 1. Designed bottom structure pilot plan in Orivesi

One of the UPACMIC projects planned pilot sites located in Orivesi Dragon Mining Oy's mine area. There were designed to construct expansion for waste rocks landfilling area on its west side. During designing there were updated the general plan, bottom sealing layers soil was changed to fiber clay. The plan was to pilot fiber clay as bottom sealing layer material and demonstrate that it will be suitable for bottom cover structure. Designed layer structure is shown in figure 1. From the structure is demanded < 1 x 10^{-8} m/s water permeability value. However, mining activity was stopped before expansion was able to construct.

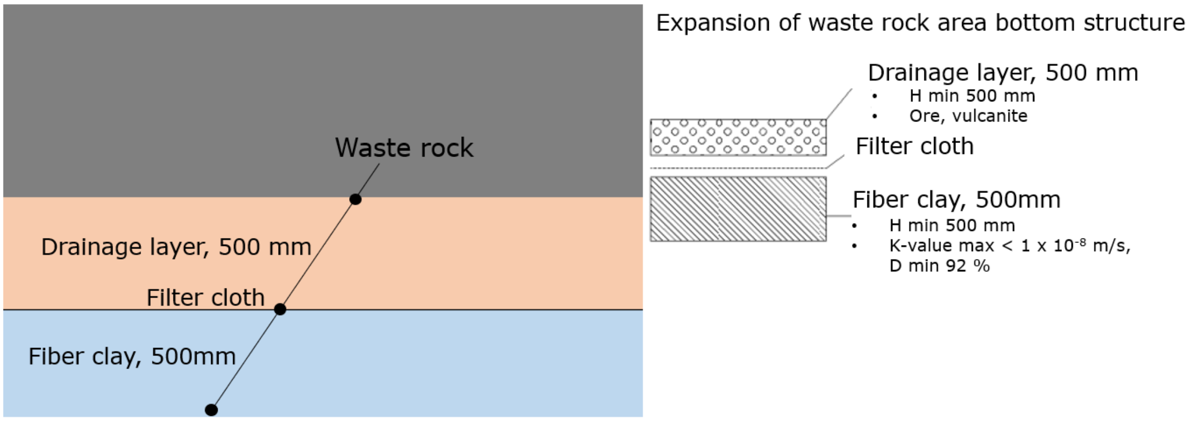

Figure 1. Designed bottom structures cross-section and layers with thickness.

Annex 2. Top cover structures piloting in Pyhäjärvi in Pyhäsalmi mine

New kinds of cover structures were tested in Pyhäsalmi mine. New materials were gypsum and ash, and comparison structures were common soil structure and only growth layer structure. Two different types of uncovered tailings were followed as well. Follow up was made by lysimeters which collect seeping water that goes through structures. The quality and quantity of water were monitored. Quality monitoring includes redox, pH and electric conductivity measurements and occasionally analyzed the concentrations dissolved elements in the water. When pilot structures were disassembled there were taken pH measurements layer by layer. pH-level in layers verifies how tailings are oxidized and how deep oxidation has advanced. Piloted material layers are shown in figure 2 and realized structure in figure 3.

Materials were tested before piloting for technical feasibility and environmental impact by solubility tests. Tailing contains high concentration of sulphate and some copper, nickel and zinc. With covering layers tried to affect to acid generating tailings oxidation. If oxidation and acid formation are prevented, metals that are soluble in acidic conditions doesn't leach.

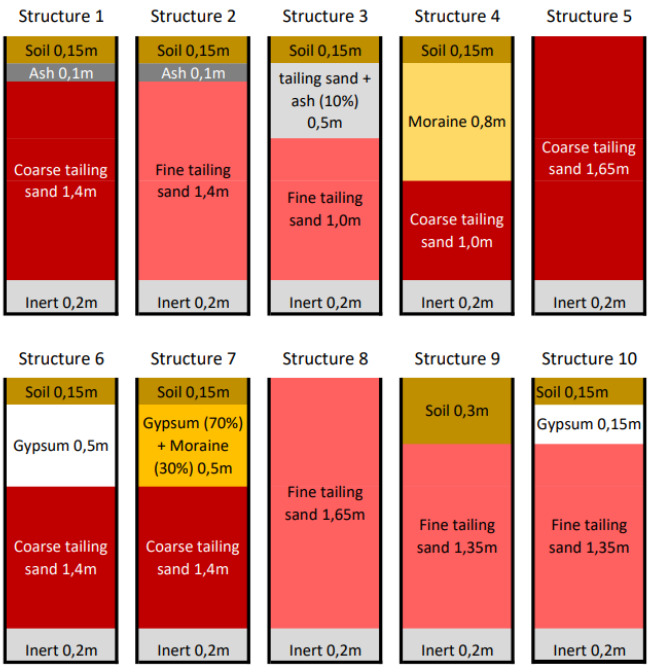

Figure 2. Pyhäsalmi mine's pilot structures and material layers.

Figure 3. Test tank on left and layer structure on right from disassembly phase.

Annex 3. Fiber clay sealing layer pilot in Nivala in Hitura mine

Hitura mine's second tailing ponds cover structures construction is carried out by Fortum. Used sealing layer materials were fiber clay and moraine soil. Sealing layer must be homogenous and water permeability value k < 1 x 10^{-8} m/s. Layer thickness must be at least 200 mm with moraine and 250 mm with fiber clay. On top of sealing layer has put 100 mm growth layer. Structures cross section cut and realized structure are shown in figure 4.

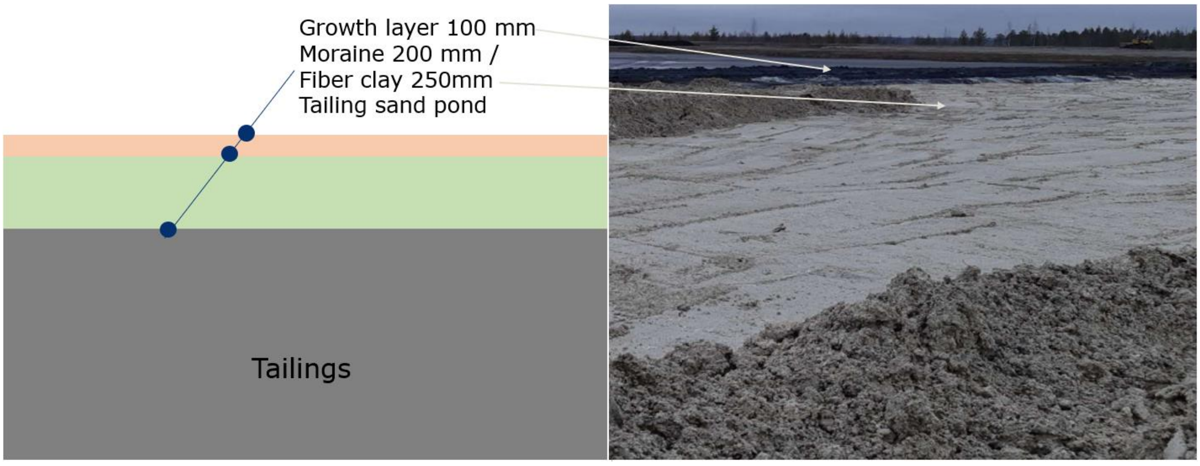

Figure 4. Cover structures cross-section cut on left and realized structure on right.

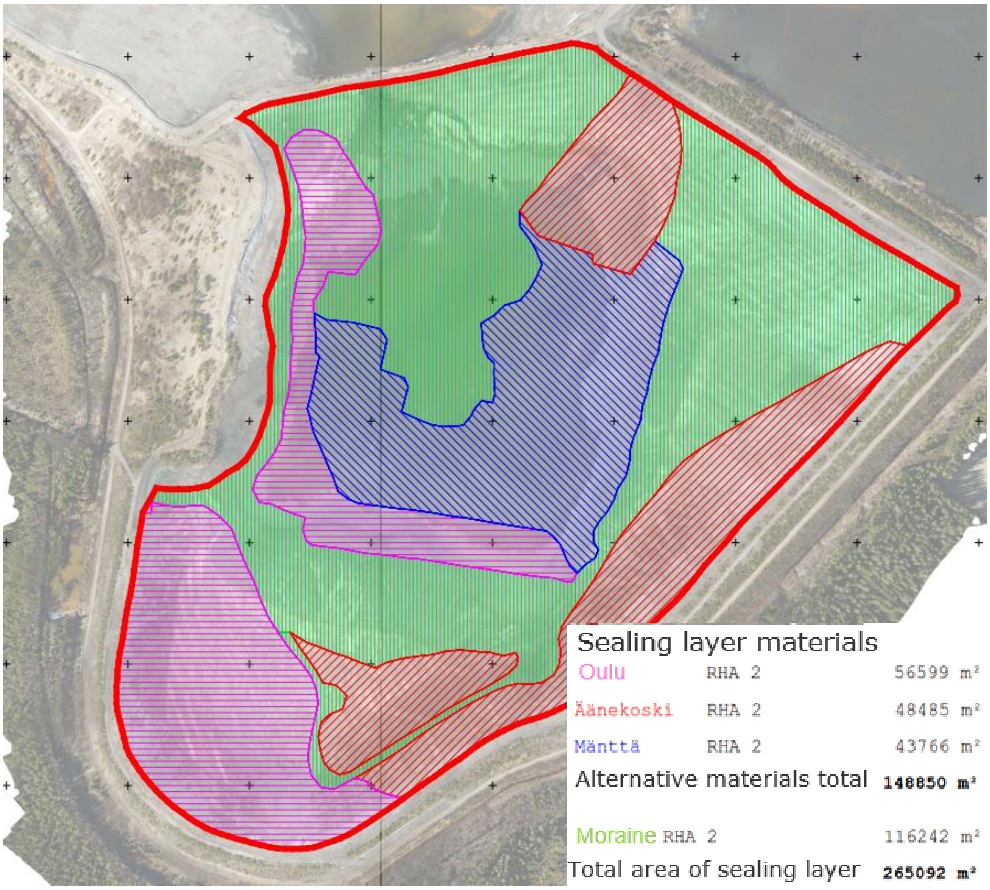

Figure 5. Sealing layer materials.

Fiber clays for sealing layers were got from three producer who were Metsä Tissue Plc Mänttä, Stora Enso Plc Oulu ja Metsä Board Plc Äänekoski. With every three of them were made test compactions in small scale test plots and environmental impacts were analyzed before full scale application. Based on results all the materials were accepted for sealing layer. Piloted areas are shown in figure 5. Sealing layer was compacted by crawler excavator by driving three times over it. After compaction, the layer thickness of the fiber clay was at least 250 mm. Fiber clay layer was thicker than moraine soils 200 mm because it is partly biodegradable. The quality controlling was executed by Troxler-measurements during construction phase. The performance of cover structures were monitored by using lysimeters after construction phase.

The growth layer on top of sealing layers were constructed by sieved surplus moraine soil from Hitura mine's area, composted digestion from Äänekoski and waste knots from Stora Enso factor. Growth layers' materials location is shown in figure 6.

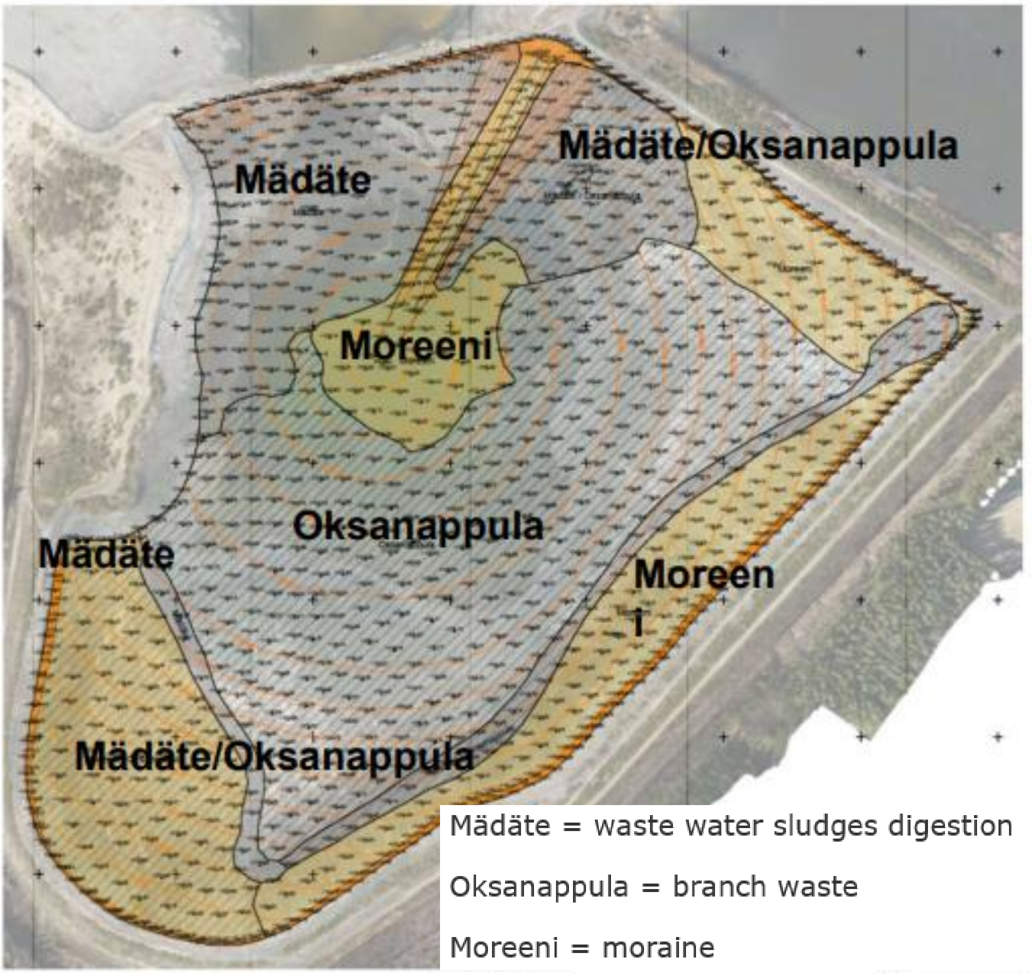

Figure 6. Growth layer materials.

Annex 4. Surplus clay cover pilot in Nivala in Hitura mine

There has been constructed about 3,4 ha cover layer for pre crushing site using surplus clay in Hitura mine. Structures clay layer was 500 mm thick and on top of clay was 100 mm growth layer. Structures layers are presented in figure 7 and realized structure is presented in figure 8. The purpose of cover structure was landscaping, so there is no demanded water permeability or density values. Only demands were that cover structure must be homogenous, and water shouldn’t stay on it. During construction the layer thickness were monitored by using onboard monitoring. Purpose of the pilot is to demonstrate the potential of surplus soils utilization compared to traditional virgin rock material.

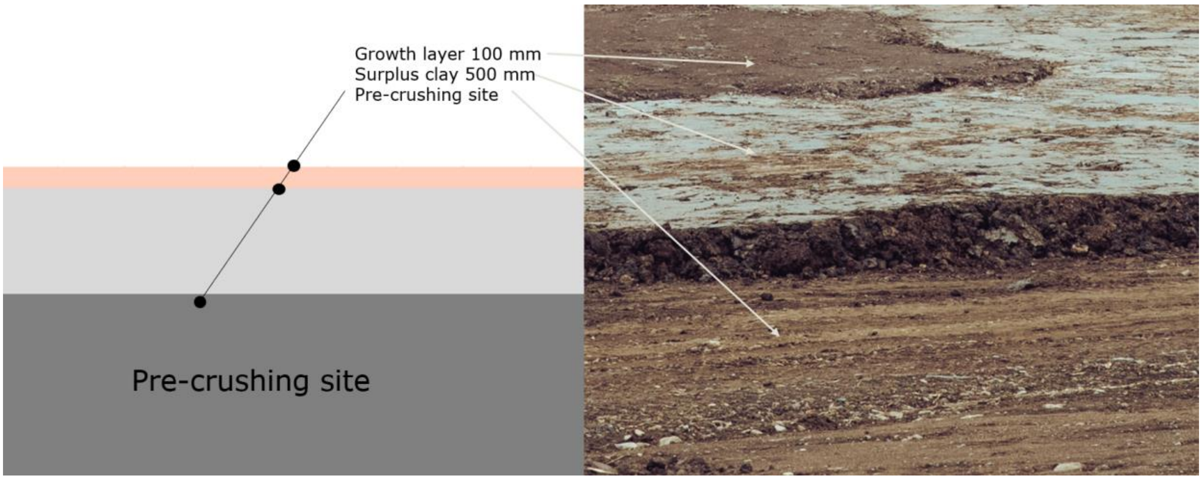

Figure 7. Cross-section cut of surplus clay cover structure on left and realized structure on right.

Figure 8. Clay cover structures construction from left to right towards finished structure.

Annex 5. Vertical sealing barrier pilot in Kuopio in Sorsasalo

In Fortum's Sorsasalo's industrial waste disposing site in Kuopio has piloted vertical sealing barrier structure. Purpose of the barrier is to prevent seeping water flowing from hazardous waste area to non-hazardous waste area. From the sealing layer which has constructed by using surplus clay has demanded water permeability value k ≤ 1 x 10^{-9} m/s and thickness of >1 m. Compacting was made by using a mold as assistance to achieve demanded k value. Drainage layers were made of coarse bottom ash and layer thickness was 0,5 m. Water flow vertically through drainage layer to the bottom where is drainage pipes and through those out from the structure. On both side of the structure is supporting backfill, which thickness were about 4-6 m and those were made of disposed materials. Supporting backfill keeps structure straight. The cross-section cut and layers are presented in figure 9.

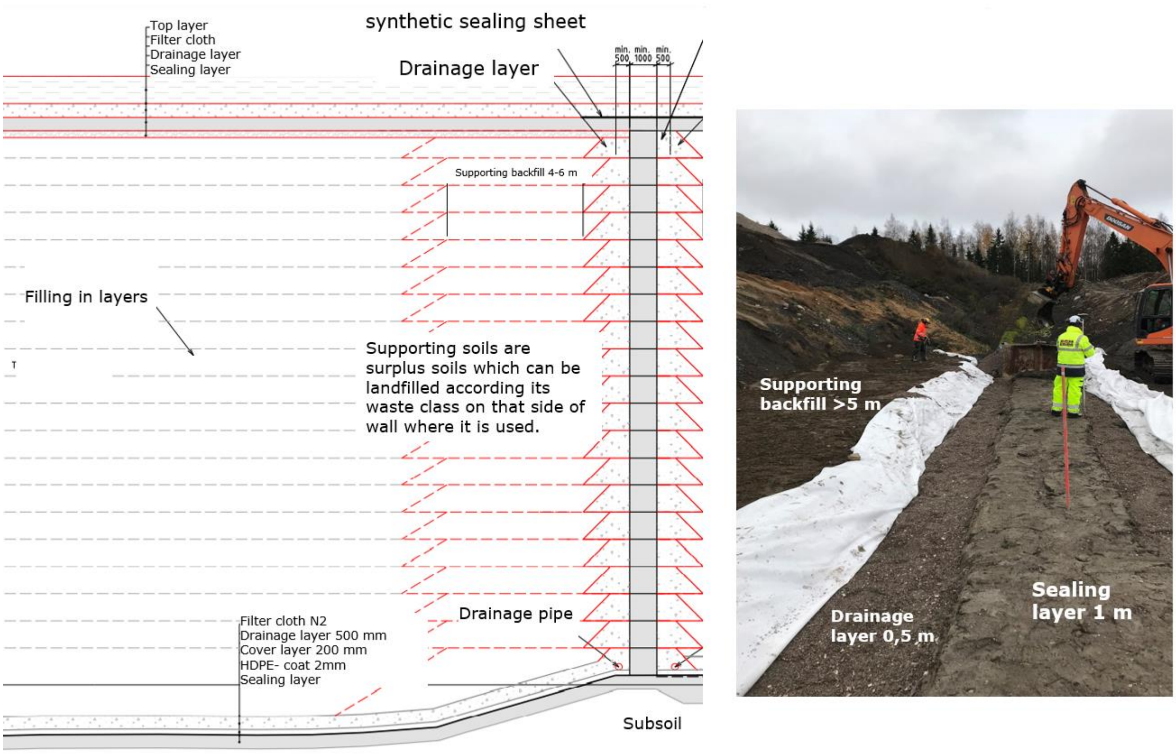

Figure 9. Kuopio's vertical sealing barrier's cross-section cut and layers of structure.

Annex 6. Reactive structure's piloting in Nivala in Hitura mine: recovered materials

Reactive structures has piloted in Hitura mine's area. Different structures were used as water treatment for acidic and nickel contaminated leachate from mica gneiss pile. Pilot was monitored about half a year. Tested materials were surplus limestone from limestone mine which grain size was 2-20 mm and industrial waste based geopolymer adsorbent. Water flows through the structure passively without need of energy need from outside. Water has taken from ditch by daming and redirecting the flow toward the pilot structures. The flow was adjusted to 4 m^3/d. Structure is presented in figure 10.

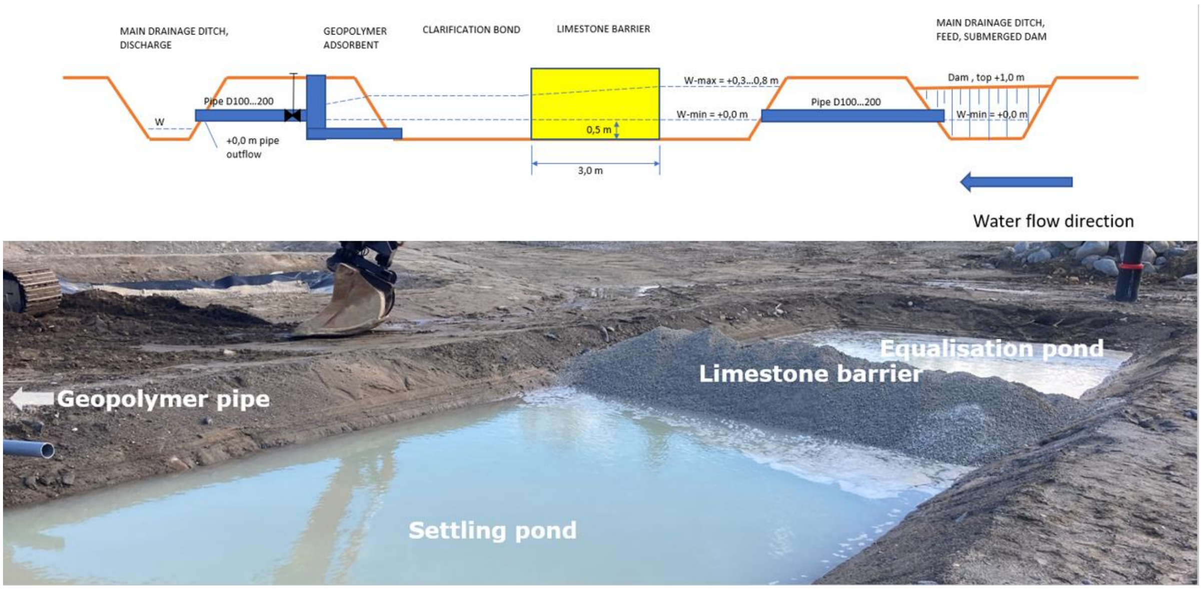

Figure 10. On the top recovered materials pilot structures cross section cut and below realized pilot structure.

At first pH of incoming water is adjusted by lime stone barrier. Metals, which are soluble in acidic conditions, precipiate when water pH turn to neutral level. So metals precipiate in side barrier and the settling pond after it. From the settling pond water flows to the geopolymer well where metals were retained on the polymerparticles surface. The operating of geopolymer well is presented in figure 11. Structures performance was monitored by water samples which were taken from incoming water, after limestone barrier and outcoming water from geopolymer well.

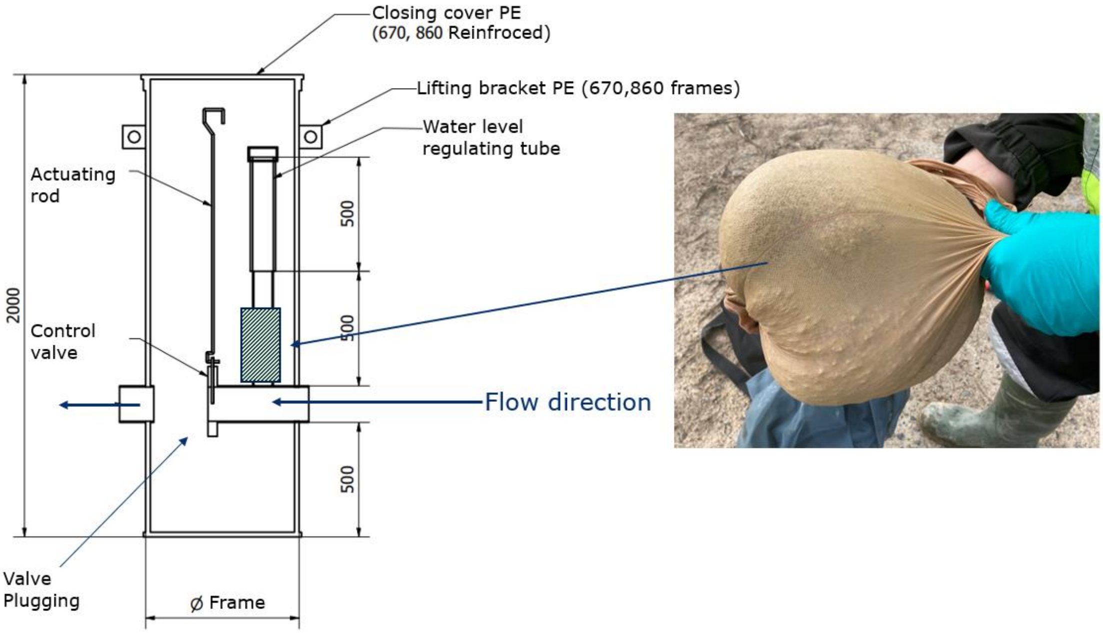

Figure 11. Geopolymer well and adsorption material.

Annex 7. Reactive structure's piloting in Nivala in Hitura mine: commercial mats

Commercial reactive structures has piloted in Hitura mine's area. Commercial product was the mat, which keep granular adsorpent in it. The mat adsorps metals from water that flow throught it. Pilot structure contain two identical pond in bararrel order. The mats were installed in the pond between gravel layers. Water flows through first mat in first pond by gravity to second pond and through second mat, and out from the system. Flow was kept constant value of 4 m^3/d. Pilot was monitored about an year when water samples were taken from incoming water and after each pond. Mats were changed once during monitoring period. The pilot structure is shown in figure 12.

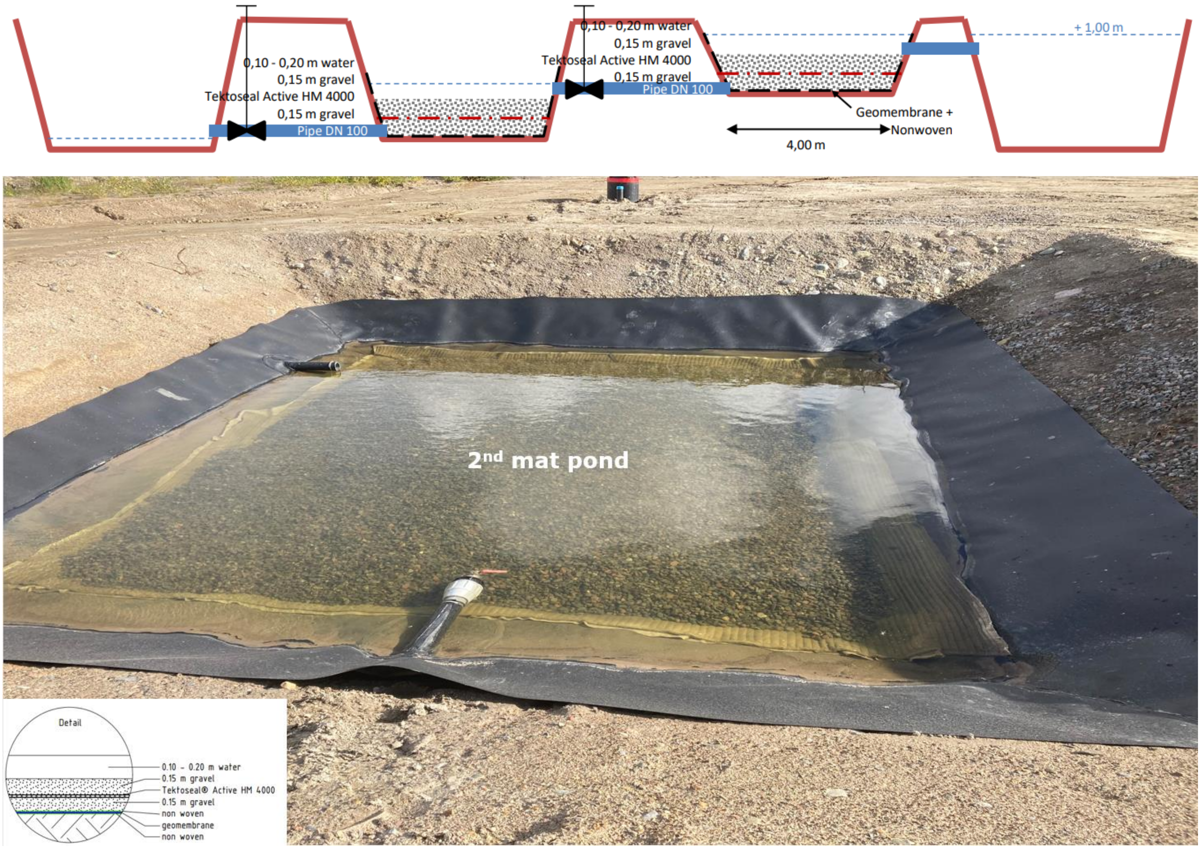

Figure 12. On top reactive mat ponds cross section cut and below realized pond structure.