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SUGGESTIONS TO IMPROVE OIL SHALE INDUSTRY WATER MANAGEMENT BASING ON INVENTORY ANALYSIS OF LIFE CYCLE ASSESSMENT

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Principles of Life Cycle Assessment (LCA) are implemented for the investigation of the Estonian oil shale energy production system. The energy produced on the smallest of Estonia's thermal power plants is studied as a product. A brief description of the inventory analysis and material balance for this product system is presented.

A possible change in water management of investigated life cycle is discussed. Implementing these suggestions will diminish the pressure on local water resources in an economically effective way.

Introduction

In the 1940s it was decided to use Estonian oil shale in the chemical industry and for energy production for both Estonia and northwestern Soviet Union (now St. Petersburg Region of Russia). This extensive usage has caused tremendous consumption of various local natural resources and generated much waste. Nowadays the annual amounts of oil shale used and electricity produced are remarkably less (Fig. 1), but the characteristics of emissions have not changed, and the northeastern Estonian environment is still drastically affected by the oil shale industry.

Chemists, engineers and environmentalists have studied the environmental problems caused by this industry for many years as the area has been polluted for decades. These problems have been looked at separately by various experts based on their expertise and knowledge in the respective fields. For example, improving the oil shale burning technology, recultivation of ash fields and treatment of wastewater from the oil shale chemical industry were investigated [1, 2].

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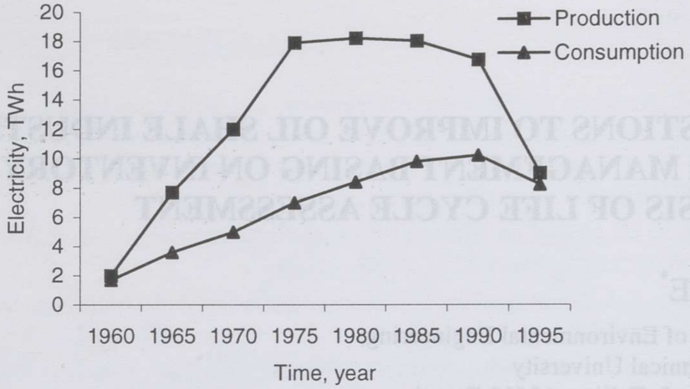

Fig. 1. Electricity production and consumption, 1960–1995

In the planning stage of the study described in this paper it was considered whether a new approach could be implemented. By using the analysis method Life Cycle Assessment (LCA), it is possible to assess the total environmental impact caused by a product through its lifetime [3]. The most important feature of the LCA is that it generates, during the inventory analysis of the product, unambiguous values for each of the inputs and outputs in a product's life cycle in terms of raw materials and energy consumed, and gaseous, liquid and solid wastes produced. The inventory analysis can serve as the basis of environmental action programmes and it is necessary for performing the impact and improvement assessments of LCA.

According to the methodology of LCA, the life cycle system of a product should be defined with all inputs and outputs. The oil shale mining, its burning at a thermal power plant (TPP) and energy consumer supply network were studied in their entirety as the life cycle of the studied product – Estonian energy. Main inputs and outputs of the system were considered while performing the inventory analysis of investigated LCA and presented [4]. A brief overview of this analysis and material balance is described in the first part of the present article.

However, the main emphasis of this paper is laid on the possibility to improve the water management, a problem that arose during the study of the integrated life cycle system.

Overview of Inventory Analysis of LCA

Goal and System Definition

The goal was to define and investigate the Estonian oil shale energy system by LCA methodology.

The energy produced at the smallest Estonian TPP (Ahtme TPP) that co-produces heat and electricity was chosen to study Estonian energy. TPP receives oil shale from the adjacent *Ahtme* mine. Heat is consumed in neighbouring settlements and electricity is delivered to a common network. The mine, TPP and energy delivery system (Fig. 2) are the stages of built life cycle. The inputs and outputs to the system were evaluated for one month – November 1997.

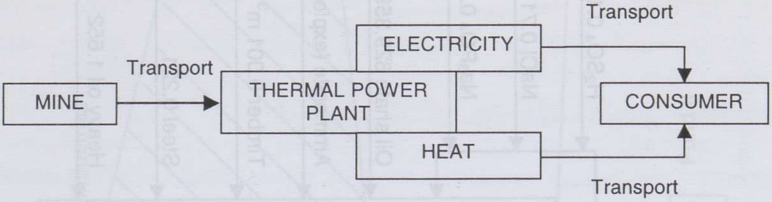

Fig. 2. Steps of the investigated life cycle

The production process and transport of auxiliary materials (water treatment reagents, steel, etc.), general infrastructures, accidents, immaterial commodities and human labour were not studied during this investigation.

Description of Investigated Life Cycle

The oil shale used at investigated TPP originates from the Estonian Deposit and is mined in an underground mine adjacent to TPP. The mining technology used is room-and-pillar mining [5]. One of the problems during the mining activities is the wetting of the rock massive as it continually gets water from precipitation. It is necessary to pump out 10 – 20 m^3 of water per every oil shale ton mined.

In the studied life cycle the chain conveyor carries oil shale from the mine directly to the plant. At the plant, oil shale goes through the bunker and dosing machine for additional milling in the hammermill before burning in boilers. For steam production the pre-treated (mechanical and ion-exchange filters) technological water is used. The steam is led to turboaggregate for generation of electricity. Surplus steam is used partly in steam-water heat exchangers and some of it at both TPP and the mine.

Heated water from the heat exchanger is utilised in the district heating systems of neighbouring settlements. The central-heated houses are multistory flat dwellings built without any concern for energy conservation. The old Soviet electrical equipment still used at homes is quite inefficient, too.

As a result of inventory analysis, the material balance with main inputs and outputs of the life cycle system is presented for 1 MWh consumed energy (Fig. 3). The usage of energy by TPP itself and the mine and transport losses (15 % [6]) are already subtracted. Thus the real effectiveness of energy production over the whole life cycle is estimated to be 49 %.

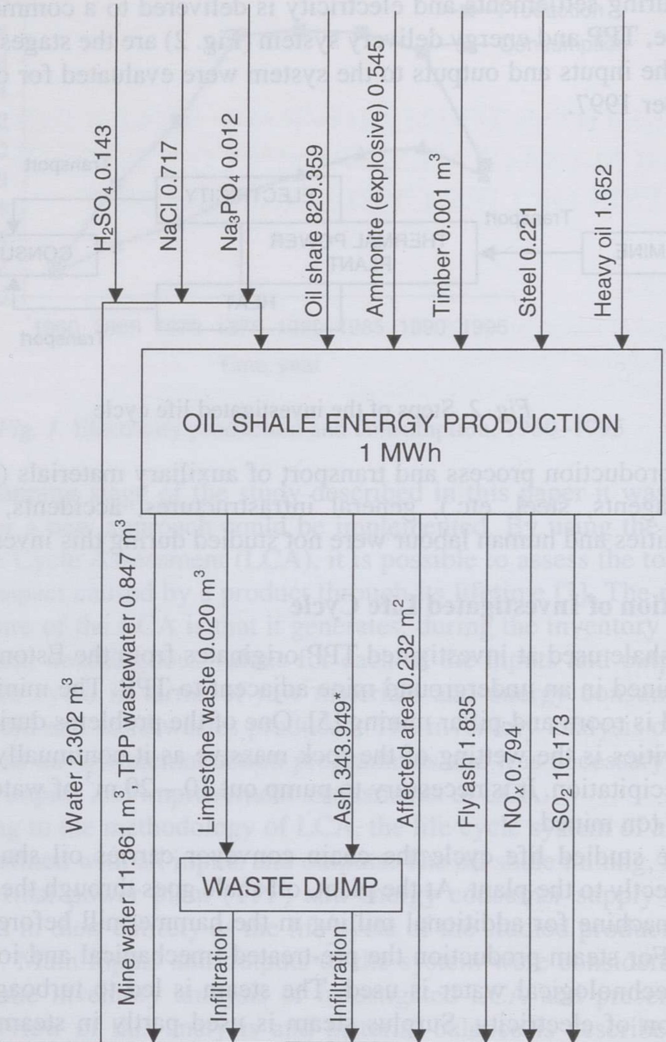

Fig. 3. Main inputs and outputs of 1 MWh oil shale energy production at heat and electricity co-production plant, kg/MWh

*According to the calculations, this ash contains heavy metals as follows, kg/MWh: As – 0.006; Pb – 0.020; Zn – 0.028; Ni – 0.012; Cu – 0.008; Cr – 0.020; Cd – 0.001

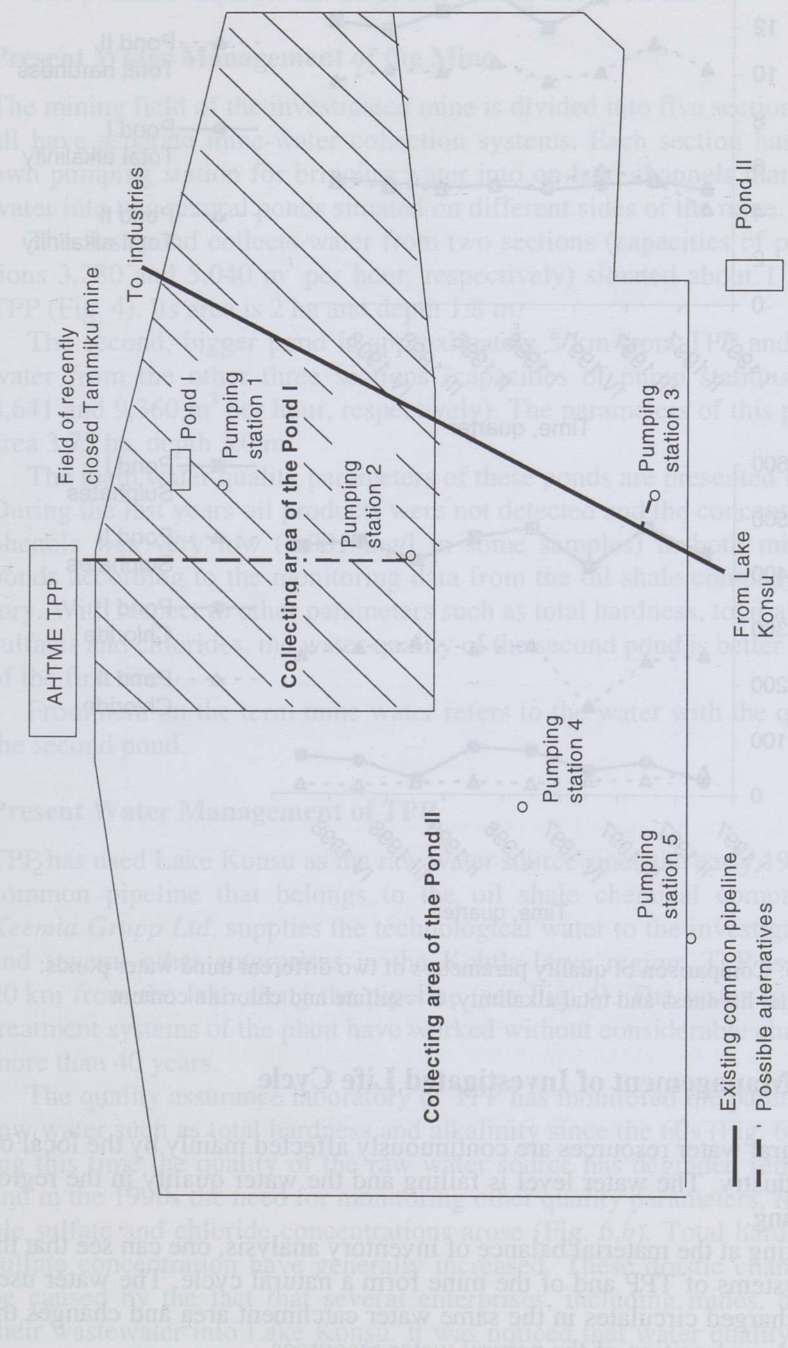

Fig. 4. Schematic plan of the *Ahtme* minefield and pipelines

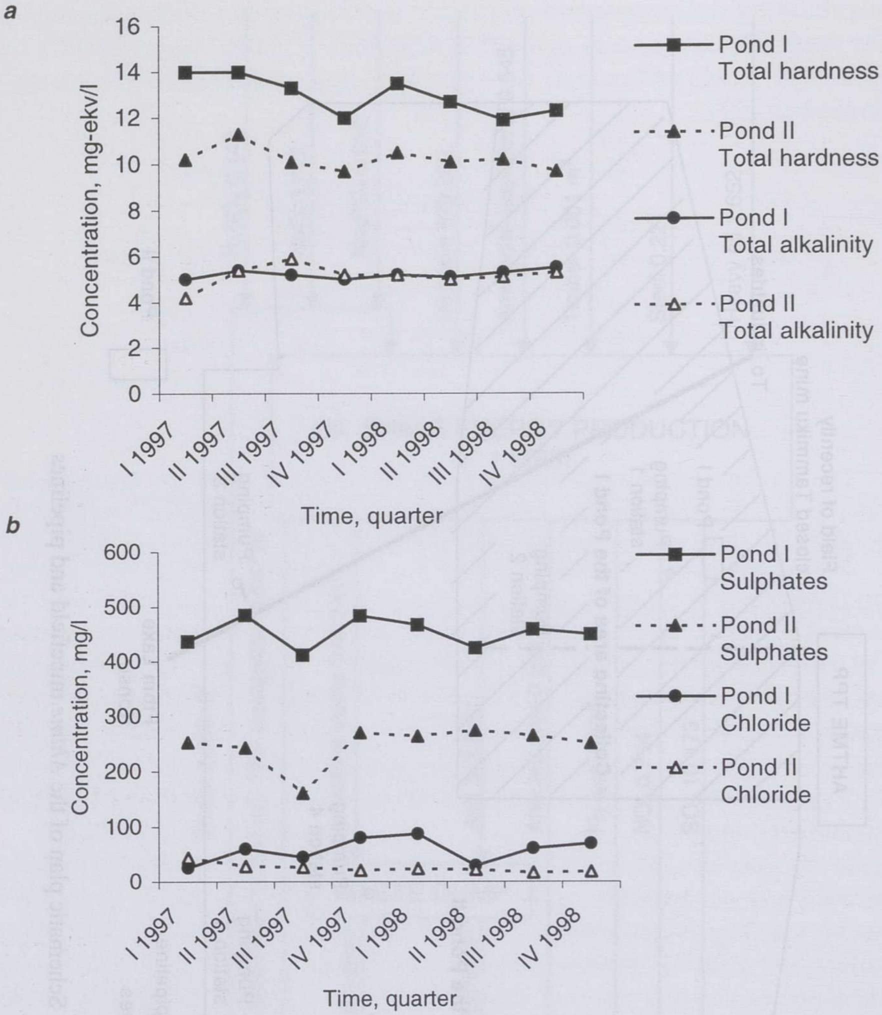

Fig. 5. Comparison of quality parameters of two different mine water ponds: *a* – total hardness and total alkalinity; *b* – sulfate and chloride content

Water Management of Investigated Life Cycle

The natural water resources are continuously affected mainly by the local oil shale industry. The water level is falling and the water quality in the region is lowering.

Looking at the material balance of inventory analysis, one can see that the water systems of TPP and of the mine form a natural cycle. The water used and discharged circulates in the same water catchment area and changes the chemical composition of the natural water resources.

The ecological quality of the environment may be improved by connecting the enterprises into one technological water cycle. The TPP water supply system should be connected directly to the mine water discharge outlet and all the raw water needed will be drawn from there.

The possible implementation of this idea is discussed below.

Present Water Management of the Mine

The mining field of the investigated mine is divided into five sections, which all have separate mine-water collection systems. Each section has also its own pumping station for bringing water into on-land channels that lead the water into two natural ponds situated on different sides of the mine.

The first pond collects water from two sections (capacities of pump stations 3,280 and 5,040 m^3 per hour, respectively) situated about 1 km from TPP (Fig. 4). Its area is 2 ha and depth 1.8 m.

The second, bigger pond is approximately 5 km from TPP and collects water from the other three sections (capacities of pump stations 10,000, 8,641 and 9,360 m^3 per hour, respectively). The parameters of this pond are: area 3.75 ha, depth 3.0 m.

The main water quality parameters of these ponds are presented in Fig. 5. During the last years oil products were not detected and the concentration of phenols was very low (0.001 mg/l in some samples) in both mine-water ponds according to the monitoring data from the oil shale company laboratory. With respect to other parameters such as total hardness, total alkalinity, sulfates and chlorides, the water quality of the second pond is better than that of the first one.

From here on the term mine water refers to the water with the quality of the second pond.

Present Water Management of TPP

TPP has used Lake Konsu as the raw water source since the early 1950s. The common pipeline that belongs to the oil shale chemical company *Viru Keemia Grupp Ltd.* supplies the technological water to the investigated TPP and several other enterprises in the Kohtla-Järve region. TPP is situated 20 km from the lake along the pipeline (see Fig. 4). The water supply and treatment systems of the plant have worked without considerable changes for more than 40 years.

The quality assurance laboratory of TPP has monitored the parameters of raw water such as total hardness and alkalinity since the 60s (Fig. 6,*a*). During this time the quality of the raw water source has degraded remarkably, and in the 1990s the need for monitoring other quality parameters, for example sulfate and chloride concentrations arose (Fig. 6,*b*). Total hardness and sulfate concentration have generally increased. These drastic changes may be caused by the fact that several enterprises, including mines, discharge their wastewater into Lake Konsu. It was noticed that water quality in Lake Konsu becomes closer to the average mine water quality with each year.

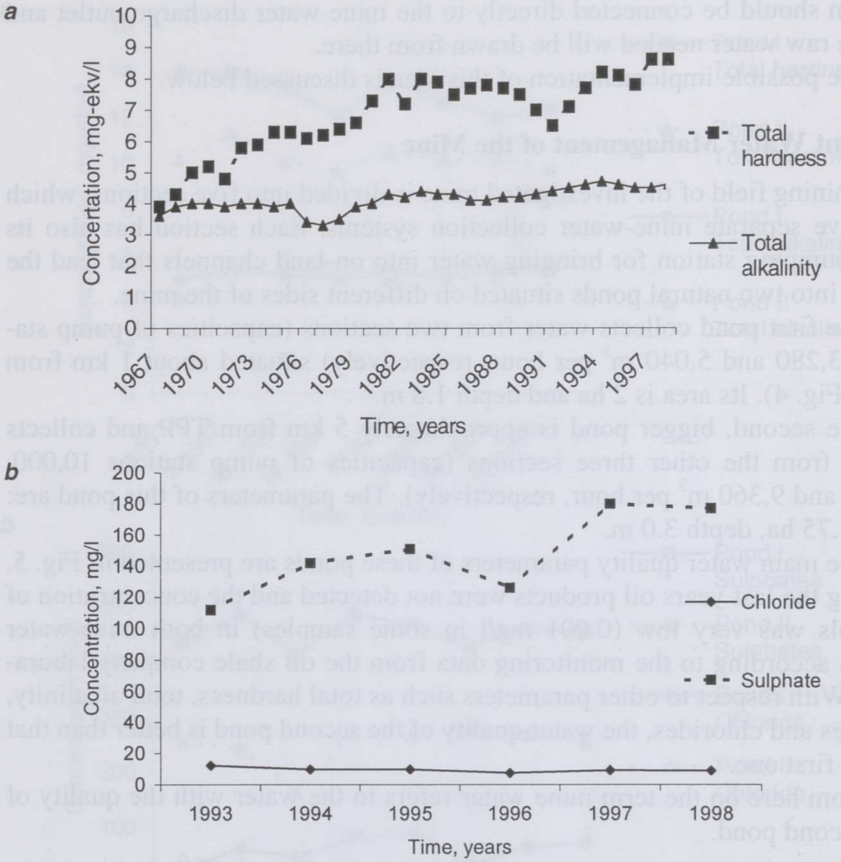

Fig. 6. Change of quality parameters of TPP raw water from Lake Konsu:: *a* – total hardness and total alkalinity; *b* – sulfate and chloride content

These trends have led to problems with raw water treatment at TPP. The present technological water treatment system consists of the following steps: screen, Na^+ cationic and $0H^-$ anionic filters, decarbonisator and finally one more Na^+ cationic filter. This system was designed for the water quality of Lake Konsu in the 1960s. With the water quality being lowered due to the pollution by mining and other local industries, the current system is hardly able to treat the water pumped from Lake Konsu today. As the reconstruction of the water treatment system is unavoidable in the near future, it is reasonable to discuss the mine water as an alternative raw water source.

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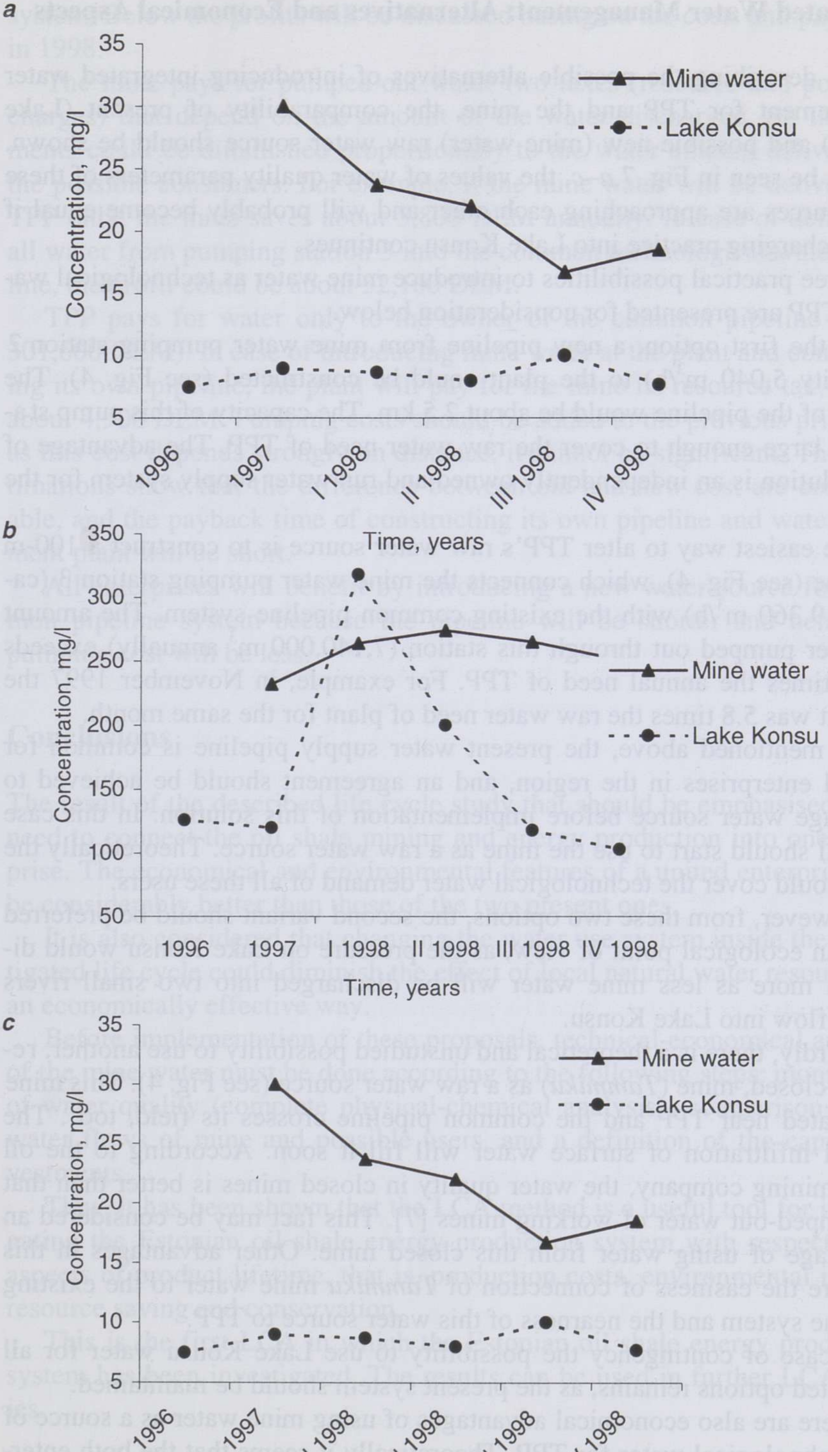
Fig. 7. Water quality parameters of the present and possible raw water source for TPP: *a* – total hardness and total alkalinity; *b* – sulfate content, *c* – chloride content


a
Concentration, mg/l
35
30
25
20
15
10
5
Mine water
Lake Konsu
1996
1997
I 1998
II 1998
III 1998
IV 1998
Time, years
b
Concentration, mg/l
350
300
250
200
150
100
50
Mine water
Lake Konsu
1996
1997
I 1998
II 1998
III 1998
IV 1998
Time, years
c
Concentration, mg/l
35
30
25
20
15
10
5
Mine water
Lake Konsu
1996
1997
I 1998
II 1998
III 1998
IV 1998
Time, years

Integrated Water Management: Alternatives and Economical Aspects

Before describing the possible alternatives of introducing integrated water management for TPP and the mine, the comparability of present (Lake Konsu) and possible new (mine water) raw water source should be shown. As can be seen in Fig. 7,*a–c*, the values of water quality parameters of these two sources are approaching each other and will probably become equal if the discharging practice into Lake Konsu continues.

Three practical possibilities to introduce mine water as technological water at TPP are presented for consideration below.

As the first option, a new pipeline from mine water pumping station 2 (capacity 5,040 m^3/h) to the plant could be constructed (see Fig. 4). The length of the pipeline would be about 2.5 km. The capacity of this pump station is large enough to cover the raw water need of TPP. The advantage of this solution is an independently owned and run water supply system for the plant.

The easiest way to alter TPP's raw water source is to construct a 100-m pipeline (see Fig. 4), which connects the mine water pumping station 3 (capacity 9,360 m^3/h) with the existing common pipeline system. The amount of water pumped out through this station (7,140,000 m^3 annually) exceeds many times the annual need of TPP. For example, in November 1997 the amount was 5.8 times the raw water need of plant for the same month.

As mentioned above, the present water supply pipeline is common for several enterprises in the region, and an agreement should be achieved to exchange water source before implementation of this solution. In this case they all should start to use the mine as a raw water source. Theoretically the mine could cover the technological water demand of all these users.

However, from these two options, the second variant should be preferred from an ecological point of view, as the pressure on Lake Konsu would diminish more as less mine water will be discharged into two small rivers which flow into Lake Konsu.

Thirdly, there is a theoretical and unstudied possibility to use another, recently closed, mine (*Tammiku*) as a raw water source (see Fig. 4). This mine is situated near TPP and the common pipeline crosses its field, too . The natural infiltration of surface water will fill it soon. According to the oil shale mining company, the water quality in closed mines is better than that of pumped-out water of working mines [7]. This fact may be considered an advantage of using water from this closed mine. Other advantages in this case are the easiness of connection of *Tammiku* mine water to the existing pipeline system and the nearness of this water source to TPP.

In case of contingency the possibility to use Lake Konsu water for all presented options remains, as the present system should be maintained.

There are also economical advantages of using mine water as a source of raw technological water for TPP. Theoretically it seems that the both enterprises – TPP and the mine - will benefit from changing the existing water system. Below the profits will be discussed basing on the costs and payments in 1998.

The mine pays for pumped-out water two taxes (resource and pollution charges) that depend on the amount of the water discharged. So the payments could be diminished proportionally to the water amount delivered to the possible consumers. For example, if the mine water will be delivered to TPP only, the mine saves about 5,800 DEM annually. In case of delivering all water from pumping station 3 into the common technological water pipeline, the profit could be about 32,100 DEM.

TPP pays for water only to the owner of the common pipeline (about 301,600 DEM). In case of introducing mine water at the plant and constructing its own pipeline, the plant will pay for the mine its resource tax, that is about 4,900 DEM. Pumping costs should be added to the previous price, but as this cost depends strongly on distance, it cannot be significant. These estimations show that the difference between old and new cost are considerable, and the payback time of constructing its own pipeline and water treatment plant will be short.

All enterprises will benefit by introducing a new water source for common pipeline system because the pipeline will be shorter and hence the pumping cost will be less.

Conclusions

The result of the described life cycle study that should be emphasised is the need to connect the oil shale mining and energy production into one enterprise. The economical and environmental features of a united enterprise will be considerably better than those of the two present ones.

It is also considered that changing the water use system inside the investigated life cycle could diminish the effect of local natural water resources in an economically effective way.

Before implementation of these proposals, technical-economical analysis of the mine water must be done according to the following steps: monitoring of water quality (complete physical-chemical analysis); comparison of the water flows of mine and possible users, and a definition of the capital investments.

Thus, it has been shown that the LCA method is a useful tool for investigating the Estonian oil shale energy production system with respect to all aspects of product lifetime, that is, production costs, environmental impact, resource saving and conservation.

This is the first LCA in which the Estonian oil shale energy production system has been investigated. The results can be used in further LCA studies.

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