LISA 11
ENVIRONMENTAL RISK IDENTIFICATION. MUUGA PUMPED HYDRO POWER PLANT

FACULTY OF ENGINEERING AND SUSTAINABLE DEVELOPMENT

Environmental Risk Identification
Muuga Pumped Hydro Power Plant

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Glossary

EIA – Environmental Impact Assessment

LPG – Liquid Petroleum Gas

PHPP – Pumped Hydro Power Plant

PHES – Pumped Hydro Energy Storage

SEA – Strategically Environmental Assessment

Introduction

Background

Estonia is increasing its wind turbine capacity in order to increase the share of electricity production based on renewable sources (target 900MW by 2018). In order for Estonia to ensure grid stability in case of significant electricity production based on wind turbines, the need for balancing and backup capacity in the electricity grid increases.

Estonian company Energiasalv Ltd has initiated a project focusing on making a Pumped Hydro Power Plant (PHPP) using seawater at the location Muuga (17km north east of the capital Tallinn). Ramboll Eesti AS is in the process of composing a SEA for the Muuga PHPP project, as this will be necessary to continue the project. This SEA will be a part of the decision making process for investing in the power plant.

Perspective

The author's background is Mechanical engineering (BSc) and Sustainable Energy engineering (MSc). Based hereon, the analysis made in this report will be based on these two fields to the environmental aspects discussed in the report. The project is therefore not to be considered as a project in environmental engineering, but as Mechanical/Energy engineering with an environmental perspective.

Boundary of the Project and Expected Outcome of the Report

The task of completing a SEA for the Muuga PHPP is beyond the limitations of this project (single person; 15ECTS). A SEA involves a series of different analyses and investigations and should be carried out in different project stages, e.g.: Early in the plan-making process; during project evolvement; and after project completion (monitoring). Moreover, a SEA must consider Politics, Plan, and Project levels [11]. The timeline for a full SEA is too excessive for the content and timeline of this report.

Rather, this report will focus on potential environmental risks for the Muuga PHPP project. Specifically the environmental risks identified through this project can be used as input for future environmental assessment of the said project. Through studies of environmental investigations for other PHPPs and other relevant aspects, it is investigated if the construction and operation of Muuga PHPP will lead to significant environmental risks in the Muuga area .

Description of the Work Method

In the first section of the report "*Introduction",* specific technical knowledge of the Muuga PHPP project will be collected based on studying available project material. Also, the project will be compared to other Pumped Hydro Power Plants in order to establish the relative size of the project. EU regulations on environmental assessments will be identified and studied in order to clarify the background and requirement of performing environmental assessments of projects of this nature (e.g. PHPP).

In the second section of the report "*Research on Potential Environmental Risk for Muuga PHPP*", relevant environmental risks to be considered in the geographical area of the project site and Environmental Assessments from other projects in the area will be identified and studied. Through this, it will be possible to identify which aspects that previously have been taken into consideration as well as to identify possible concerns citizens living in the area have had for other similar projects. Potential environmental risks for the construction and operation of Muuga PHPP will also be identified based on studying:

- Environmental assessments of other PHPPs;
- Environmental assessments of relevant construction in coastal areas (since most PHPPs are not constructed in coastal area, but in rivers/mountains).

Finally for the risk identification, Ramboll Eesti AS has addressed specific environmental risks relevant to consider and investigate based on local public concerns and the local municipality (the local authority).

Upon the identification of potential environmental risks, a summary will be listed of these identified risks. A selection of the identified risks, which are considered by the author to be most relevant for the purpose of this project, will be selected for further analysis in the following section "*Relevance and Experience of Potential Environmental Risks*". In this section, a literature review will study relevance and experience for the selection of environmental risks. Through this analysis, experience from other constructions and similar cases will be used to verify or argue against the identified environmental risks. This is done to gain information about the specific risks and will be used as input to the analysis of relevance of the identified environmental risks in the next part of the report *"Evaluation of Identified Potential Environmental Risks"*. In this part of the report, an evaluation of which environmental risks are most likely to be considered relevant will be made based on the collected information, including:

- Which are the environmental risks, consequences and probability
    - during construction period;
    - during operation period.

The final part of the report is an epilogue in which the conclusion, discussion and suggestions for future work of the project is stated.

Introductory Comments on Muuga PHPP and Environmental Assessment

Location[1]

Muuga PHPP is planned to be located at Muuga harbour. The nearest residential areas are Saviranna and Kallavera which are shown in the map below. The harbour in which the construction of Muuga PHPP is planned is visible in the top-middle of the map below. The distance to the mentioned residential areas is approximately 1000m.

[1] Map is copied from maps.google.com

The location is 17km northeast of Tallinn, which is the capital of Estonia. Location is marked with arrow in the map below. The seawater used in the PHPP is brought in from the Baltic Sea and more specifically the Gulf of Finland.

On a regional map it is visualized that Tallinn is located in the Baltic Sea. The Baltic Sea is connected to the North Sea (and the rest of the ocean) only through the waters along Denmark. Therefore, the Baltic Sea is an isolated sea.

Technical details

The sea is the upper reservoir of the PHPP and the lower reservoir will be located 500m below the surface. An existing granite mine has been suggested as reservoir, but currently the status of the project is that a new reservoir will be constructed for the purpose.

Water at sea level is in possession of higher level of potential energy compared to when the water is located in the reservoir 500m below sea level. The energy of the seawater is released and converted into mechanical energy (and in the end, electricity through the turbine(s)/generator(s)) when the seawater flows into the granite reservoir (with a loss in gravitation height of 500m). This operation takes place when the PHPP is producing power to the grid (when electricity consumption and/or price is high).
At times when electricity prices are low due to excess electricity production e.g. from wind turbines, water is pumped from the reservoir back into the sea. In this operation mode, the PHPP is consuming electricity from the grid. In general, for PHPPs the cycle (water in and out of reservoir) usually takes place on a daily cycle, but longer time intervals can also occur (weekly or even seasonal) [10].

The head for the water used in the power plant is given as the difference in height between the lower reservoir and the upper basin (sea level) and is specified as 500m. Hydro Power Plants with effective heads above 100m can be classified as High-Head Hydro Power plants [3]. In order to make a PHPP project economical feasible and viable, it is important that there is access to the electricity grid, access to water for storage and a high head (big difference in elevation between the two reservoirs) is present [10] – these demands are met at the proposed Muuga PHPP project.

The turbines selected for the plant are three vertical-shaft reversible Francis turbines. The configuration is: 1x100MW, 2x175MW. In addition, one 50MW vertical-shaft Francis turbine is specified (non-reversible) [2].

Seawater for Pumped Storage

The use of seawater is until now only used in one other PHPP worldwide – Okinawa in Japan which has been in operation since 1999. The use of seawater is, from a technical perspective, challenging because of the aggressive corrosive environment due to the salty water. The use of seawater is, however, considered to be one of the future developments in the field of PHPP since it may have several advantages over conventional PHPP. The advantages are e.g. lower civil construction cost and more potential sites [10].

Size of the Plant (compared to other PHPPs)

In order to compare the proposed project Muuga PHPP with other Pumped Hydro Power Plants world wide, the capacity for PHPP for other projects is investigated.

Pumped Hydro Energy Storage (PHES) is the only useable technology for large-scale energy storage (>100MW) which has proved to be viable as a commercial solution [10]. Over 300 plants are installed worldwide with a total capacity of over 95GW – the average size of each plant is approximately 300MW based on these numbers.

USA and Japan has the largest installed capacities of PHPP worldwide. USA has an installed capacity of 21.886MW based on 39 PHPPs ranging from 8MW to 2000MW. The highest head is 543m (Helms pumped storage, Fresno County, California). Japan has 34 PHPPs with a total capacity of 24.575MW ranging from 200MW to 1932MW. In Europe, some of the larger projects constructed over the recent years are Goldisthal in Germamy (1060MW) and Kopswerk in Austria (450MW) [10].

Compared to other projects, it can be concluded that Muuga PHPP is not one of the largest PHPPs in the world but it is above medium size. Furthermore, it should be noted that the only other seawater based PHPP is Okinawa in Japan with a capacity of 30MW [10]. Finally, the construction with a sub-surface lower reservoir (made from excavated granite) is uncommon. Based on these observations, it is concluded that Muuga PHPP is an ambitious and large project.

Background for Environmental Assessments

Environmental Assessments for projects of applicable nature are mandatory according to EU regulations. EU directive 85/337/EEC specifies that an Environmental Impact Assessment (EIA) must be performed for specific types of projects (i.e. dam; motorway; airport; or factory). Directive 2001/42/EC specifies that Strategic Environmental Assessment must be performed for public plans and programmes (e.g. increasing the share of electricity production based on wind turbines). The aim of both directives is to ensure that projects, programmes and plans, which potentially have a significant effect on the environment, are subject to environmental investigation prior to being authorized form the legal authorizations.

Both of the described Environmental Assessments aim to provide a high level of environmental protection in general. Moreover, the aim is to include these environmental considerations in plans, programmes and projects. Public participation is a key element in both directives and this is important in order to improve the quality of the assessments. Projects and programmes financed based on EU funds have to comply with EU Directives on Environmental Assessment in order to obtain approval for financing. [6]

Environmental Impact Assessment, EIA

A list of projects that require an EIA is supplied in EU Directive 85/337/EEC [8]. Different annexes are amended to the EU directive. The projects described in Annex I always require an EIA. The projects described in Annex II are subject to EIA upon screening performed by the authorities. The project of constructing Muuga PHPP is covered by Annex II, Section, items (a) and (j). The wording used for these items is inserted below:

Annex II, Section 3. Energy Industry,

(a) Industrial installations for the production of electricity, steam, and hot water (unless included in Annex I)

(j) Installations for hydroelectric energy production

By studying Environmental Assessments for other projects, this project aims to collect relevant information regarding environmental risk for the Muuga PHPP project.

Strategical Environmental Assessment, SEA

Ramboll Eesti AS is currently working on a SEA for the mentioned project. Several details for the project have not been finalized yet – e.g. considerations about construction of an artificial island for the water intake are being analysed. Based on the outcome of the SEA and the decision making process after the assessment, the solution with the most beneficial environmental impact will be determined.

As mentioned earlier, the scope of an SEA is upon the limitations of this report. A SEA does, however, depend on input from other sources, as the SEA is a broad analysis [11]. Therefore, the work with this report aims to be used as an input document for the ongoing SEA.

Elements in Environmental Assessments

An Environmental Assessment in general considers a range of different environmental elements. The types of impact that are considered are: Biophysical, Social, Health and Economic [12]. The environmental risks identified and considered are meant to cover all of these areas.

Research on Potential Environmental Risks for Muuga PHPP

As stated in the section "*Description of the Work Method*", four subsections have been chosen to identify potential risks to be considered. The four subsections have been chosen to obtain inputs both form the local area and from the constructions from the rest of the world with relevant construction and operation inputs. Identified potential environmental risks are given ID numbers in each section (1st group named A1, A2, etc; 2nd group named B1, B2, etc) for future identification and reference.

From the studied input documents (e.g. EIA from other projects), only the items that are considered potentially relevant for Muuga PHPP are commented and noted in the following. This selection is made in order to merely consider relevant aspects for Muuga PHPP (e.g. it is not relevant to consider influence on agricultural land since the construction area of Muuga PHPP will not influence agricultural areas since the construction is a underground structure – nor during the construction phase or during operation). For each potential environmental risk identified in this section, comments are made about how these potentially relevant risks are considered for Muuga PHPP. No further research is available in this section, but some comments about potentially relevant risk factors are considered for further investigation later in the report.

In the final part of this section, a summary of the identified potential risks will be grouped based on the given ID numbers and type of environmental risk. As described in the section "*Description of the Work Method*", the individual groups will further be analysed and investigated.

Identification of Environmental Risks in Muuga Harbour from Other Projects in the Area

Other projects proposed at Muuga Harbour have required environmental investigations. In order to determine relevance of the environmental sensibility in the area, EIA reports for extension of Muuga Harbour [9] and Muuga Breakwaters [7] have been used as background material. The reports have been studied and sections that are considered to be relevant for the purpose of constructing Muuga PHPP have been summarized and commented in the following section.

ID. No.	***Environmental risk, Muuga area***	***Construc-tion impact***	***Opera-tion impact***
A1	Coastal processes influence the shape of the sea bottom in the area outside Muuga Harbour ([9] section 2.1.4). Erosion on the sea bottom has been affected by human activity (filling) and this has resulted in a shallower sea due to sand dumps near the current coal terminal that have been carried out to the sea. It is also noted that problems with coastal processes in the nearby area Saviranna have been an item in the public discussions about the extension of Muuga Harbour ([9] Section 2.1.5). Marine Environmental Monitoring Report (2004) of Muuga Harbour has recommended that yearly motoring of coastal changes should be continued at least six years after completion of the construction of harbour extension in order to monitor changes.		X
A2	Winters in Estonia can be relatively cold. For the functionality and the operating conditions of Muuga PHPP it is relevant to take the ice conditions in the area in to consideration. The harbour can be considered as an ice-free harbour, which is important for the all-year functionality of the PHPP as ice does occur during the winters. Based on observations in the period from 1920 to 1990, the average ice thickness has been 35cm and the maximum thickness has been 73cm ([9] section 2.3.4). Underneath the ice layer, liquid water exists (which can be used for the PHPP). Water will flow in and out of the underground reservoir located at 500m below sea level. Based on the flow, mixing of water, efficiency of turbines (heat produced) and geothermal heat the tendency to experience ice in the harbour is likely to		X

	decrease. This can influence the eco-system (positive/negative) and lead to a more accessible harbour in the winters due to less ice.		
A3	Noise from the current railroad has been registered to disturb in the area. ([9] section 2.10). Intensification of harbour transportation is expected to increase the noise level. The noise level of the PHPP is therefore also relevant to consider – both during construction and operation.	X	X
A4	Ambient air can be affected by dust from the building phase and from coal-dust from the coal terminal ([9] section 4.1). Excavation of granite from Muuga PHPP will potentially also affect the local area. During operation, air will be pushed in and out of the reservoir at the same rate as water enters the reservoir. Thereby underground material (and radon) will be emitted to the local area.	X	X
A5	Impact on fish fauna (saltwater fish like Baltic herring, sprat, flounder, smelt and stickleback) based on the construction and dumping site from harbour extension ([9] section 4.5). For the extension of the harbour, this impact is considered mainly form a construction point of view. Hydro Power plants in general can be harmful to fish life - e.g. dragged in to turbines ([3] section 5.2). Therefore, it is relevant to consider if Muuga PHPP will also have an influence on fish fauna around Muuga harbour.	X	X
A6	Impact on landscape. The extension of Muuga Harbour will irreversibly affect the landscape around the construction site. The area is however not classified as natural protection site ([9] section 4.8.1). Most of the construction of Muuga PHPP will be below the surface, so only the part of the construction which is visible from the ground, will be considered as impact to the landscape.	x	

A7	Impact on Human Health, Welfare and Property. The extension of Muuga harbour is expected to influence the surroundings and countermeasures must be made for the different areas ([9] section 4.13.1). Could also be relevant to consider, but it is a result of the other effects/risks.	x	x
A8	The negative impacts of extension of the eastern part of Muuga Port for local habitants can be summarized as noise (industrial, transport and based on technical equipment), Pollution of Ambient Air (Fertilizers, Coal dust and Gaseous Pollutants) and Potential pollution by oil products ([7] section 5.7). Noise and ambient air (radon and dust) are relevant to consider.	x	x

Environmental Risks Raised by Local Citizens and Municipality

Ramboll Eesti AS has raised the following items as relevant to consider in the report during the meeting 19 August 2011. Local citizens and municipality have also raised other items, however, the stated items are selected as the main relevant aspects for this specific project.

ID. No.	***Environmental items, raised by local citizens and municipality***	***Construc-tion impact***	***Opera-tion impact***
B1	Radon is present in the underground all over the earth. In granite (material in the ground around Muuga) the level of radon is high, and therefore there is a potential risk of increasing the intensity of radon radiation when introducing a new construction in the ground. It is considered that the increased radiation is a risk both during the construction period when granite is excavated, but potentially also during operation when water and air is flowing in and out of the underground reservoir.	X	X
B2	Mixing of ground water and seawater. Ground water level is	X	X

	approximately at 80m. The reservoir is planned at a depth of 500m. This means that the construction and water flow during operation will go through the ground water level. This implies the risk of mixing of fresh water (ground water) and seawater.		
B3	The noise level is potentially going to increase during: - Construction – traffic will increase during the 5-6year-construction period. - Operation – potential noise from the operation of the PHPP should be considered	X	X
B4	Risks of accidents - Oil, coal and LPG in the area – The local citizens are concerned if the construction and operation of a power plant in the harbour area will increase the risk of explosions in the highly energy intensive storage facilities (Oil, Coal and LPG).	X	X

Environmental Assessments for other PHPPs

In most cases, PHPPs are located in rivers and with reservoirs at an elevated position in mountains or other natural landscape with elevation variations. Based on the alternative design nature of Muuga PHPP, it is not an easy task to directly find comparable PHPP projects, which can be used as reference for Muuga PHPP. However, in order to identify typical environmental risks for PHPPs, environmental assessments for a typical design PHPP and previously mentioned Okinawa PHPP have been studied, and aspects that potentially are evaluated to be relevant for Muuga PHPP will be mentioned in the following.

AVEC - Slovenia

In Slovenia, the AVEC Pumped-storage hydroelectric power plant is operational. The construction started in 2006 and trail operation started in 2010. The power plant has a capacity of 185MW.

The construction is located around the Soca River, and existing reservoirs along the river at different elevations are used as basins to store water. By constructing dams and turbine/pumping arrangements it is possible to use the existing landscape for the main construction of the PHPP.

Following items, which can be relevant for Muuga PHPP, were considered as environmental risks in the EIA for AVEC PHPP [1].

ID. No.	***Environmental items, AVEC***	***Construc-tion impact***	***Opera-tion impact***
C1	Geomorphology. Geomorphology is the scientific study of landforms and the processes that shape them. The bottom of the sea could possibly be influenced by the in and outflow of water form Muuga PHPP.	X	X
C2	Geosphere and ground. Geosphere refers to the solid part of the earths (the earths crust). The suggested granite excavation may be considered to influence the Geosphere. Also changing in gravitational load (water in mine / empty mine) could possibly influence the Geosphere.	X	X
C3	Hydrosphere – groundwater. E.g. if the mine is influenced by ground water there is a risk of mixing of seawater and ground water and this could influence the groundwater quality.	X	X
C4	Water ecosystems. Eco-system of the sea could be influenced. Both by the flow from the operation. Furthermore, temperature level of the sea (locally) may change (e.g. less ice in the water during winter).	X	X
C5	Fish - Fish living in the sea could be influenced by the construction and operation.	X	X

C6	Noise. Relevant – both to evaluate noise during construction and operation. It should be considered if noise will influence surroundings, quality of life, etc..	X	X
C7	Dust is relevant to consider – especially from the construction phase.	X	X
C8	Radiation. Granite is a source of radon radiation and changing the access to granite layers can lead to changed levels of radiation in the local area.	X	X
C9	Visible environment. The construction period will last several years. During this phase, it is also relevant to consider if appearance after completed construction will have a positive or negative impact.	X	X
C10	Dam security/safety. It is important that the PHPP does not endanger e.g. swimming in the ocean or other relevant aspects.	X	X
C11	Quality of life. Will the construction and operation influence the area (noise, other?)	X	X
C12	Hydrology. Hydrology is the study of movement, distribution and quality of water on earth. The subject is relevant locally - and possibly regionally - as the construction and operation potentially can influence water in the Gulf of Finland and/or the Baltic sea.		X

Okinawa (seawater)

The Okinawa Seawater Pumped Storage Power Plant in Japan was build as a demonstration plant for seawater pumped storage. From the demonstration project, it was intended to find solutions for technical problems of using seawater and also to identify and find solutions for the environmental problems originated from the construction and operation. The environmental surveys and research was carried out over a six-year period staring in 1981. The construction was performed in 1991-1999 [4].

The area around Okinawa Seawater Pumped Storage is a delicate environment with special type of soil, rich landscape and plant and species. The special soil has a high specific gravity and is easily washed out to the open sea with the danger of affecting the coral reef. The main concern for the construction and operation was salt spray from the forced motion of seawater. Wind tunnel tests were performed together with simulations using numerical models to evaluate this effect. This, however, resulted in little difference from the natural spray from the sea surrounding the island. The plant and animal life was also a concern.

The main items of concern after the environmental investigation were concentrated on the sensible plant and wildlife at the island Okinawa (outflow of muddy water to the sea; reduction of habitant area on the island; damage to animals from construction vehicles). These items are however not relevant for Muuga PHPP as the nature is not comparable to Okinawa. However, as in the former table, a selection of mentioned environmental risks in the Okinawa report has been listed and commented for relevance in the Muuga PHPP case. (ID. Numbers continued from previous section, as both tables are same category – experiences from other PHPPs):

ID. No.	***Environmental items, Okinawa***	***Construction impact***	***Operation impact***
C13	Air quality – Air in the surroundings can be affected by dust from the construction phase. In the Okinawa case, also by salt-mist from the seawater.	X	
C14	Water quality – Risk of mixing seawater and ground water. Risk of disturbing the seawater with new currents and heavy in- and out-flow of water.	X	X
C15	Noise – During construction phase (based on heavy machinery). During operation from the Power Plant.	X	X
C16	Ground settlement – Risk based on vibrations from heavy machinery. Permanent changes may like cracks in the ground or collapsed areas.	X	

C17	Sea Current – The heavy in- and out-flow of water from the PHPP may influence the sea-currents in the area.		X
C18	Fish – fish life may be affected based on currents from in- and out-flow of water from the reservoir to the sea and based on the function of the PHPP (turbines).	X	X

EIAs for Structures (other than PHPPs) Near Coastal Lines

As mentioned, only one other PHPP based on seawater is operational worldwide (Okinawa). Therefore, limited information is available of environmental risk from similar constructions.

Examples of another construction taking water in from the sea, and to some extend extracts water to the sea again, is water desalination plants used to produce fresh water from salty water. The desalination plants are especially used in dry regions where a shortage of drinking water exists.

An environmental impact study of seawater desalination plants gives the following relevant items to consider [5] (which are also found relevant to considered for Muuga PHPP):

ID. No.	***Environmental items, Water desalination plant***	***Construc-tion impact***	***Opera-tion impact***
D1	Source water intake - Loss of Aquatic organisms when these collide with water intake. Relevant for Muuga PHPP as organisms (fish and other) could be dragged into the plant.	-	x
D2	Reject streams. In the case of water desalination plants a large proportion of the problem is related to chemicals used in the process, but also the temperature difference of the water that is rejected to the sea. For PHPP, the stream itself is relevant and potentially a temperature difference based on heat produced when water passes the turbines, and geothermal heat from the reservoir.	-	x

D3	Air pollution. For water desalination plants mainly based on the large energy requirement for the process – for Muuga PHPP it is relevant to consider in general is the air quality will be affected by the construction and the operation of the plant.		

It is noted that the main environmental risks for water desalination plants studied in reference [5] deals with the chemicals used in the water desalination process. These effects are not valid for Muuga PHPP, and therefore they are not mentioned in the table above. As for the previous sections, only inputs that are considered by the author of this report to be relevant to consider, for Muuga PHPP are referred in this report.

Summary of Potential Environmental Risks

In the former sections, a number of potential environmental risks have been identified based on other projects, and the environmental risks investigated in these projects.

In this section, the identified potential environmental risks have been collected in seven groups. Each group has an indication of which ID. numbers from the former sections that has been used as input to each group. The groups will be used to sort the identified potential risks in main subjects and to determine if further investigation and research will be made in this report (based on relevance and available resources).

Table of potential environmental impacts		
Group	*ID. numbers*	*Description*
Physical Surroundings	A1, A2, A6, C1, C2, C9, C12, C16, C17	Risk of physical changes in the surroundings of Muuga Harbour should be considered (e.g. changes to the sea bottom based on flow from the PHPP; visible changes to the surroundings/landscape) and potentially the formations of the underground (geomorphology) can be relevant to consider.) In terms of the seawater, it can be relevant to consider if ice formation in winters will be different based on the PHPP

		operation. Also, it would be relevant to consider if flow and distribution of water will be different in the sea region. This analysis could be made similar to the analysis made in [5] for the changed sea formation in the case of Muuga Harbour extension. Items in this section will not be evaluated further in this report, as it will require specialist knowledge in the specific fields. It is, however, evaluated as relevant subjects to consider based on available resources later in the EIA/SEA phases.
Noise	A3, A8, B3, C6, C15	Noise both from the construction and operation phases is an environmental risk that is covered in different aspects from the studied material. Noise will be investigated later in the report. It will be analysed how much transportation should be expected in the construction phase. During operation, expected noise from air release will be evaluated.
Ambient Air and Radiation	A4, B1, C7, C8, C13, D3	The construction phase can be expected to increase the level of dust in the local area. This is a consequence of the construction, and can be seen more as an environmental impact that as a risk – there is not much doubt that this will actually happen. Therefore, this issue is not investigated further in the report. During the construction and operations phases, potential environmental risks are identified for increased level of radon radiation. It will be investigated in this report if the level of radon radiation can be expected to increase, and thereby if this is a relevant concern as environmental risk.

Ground Water	B2, C3, C14	The reservoir will be placed below the ground water level. As a consequence both during construction and operation, the ground water level will be crossed. The main concern is the risk of pollution of ground water. This concern will be investigated later in the report. Experiences from other constructions will be studied, and based on these, it will be evaluated if it will be possible to ensure that ground water pollution can be avoided based on appropriate construction.
Risk of Accidents	B4, C10	The local citizens and the municipality have raised the concern that the construction and operation might increase the danger of accidents in the area. This risk is based on the fact that storage of carbon based fuels (Oil, Coal, LPG) are present in the harbour. If the construction or operation of Muuga PHPP could lead to increased risk of accidents, it will be important for the considerations about the project. It will be investigate later in the report if PHPP constructions can be considered as safe or unsafe structures in terms of danger of ignitions of surrounding elements (e.g. in case of turbine failure).
Eco-systems (fish, plants, etc)	A5, C4, C5, C18, D1, D2	Based on different sources, there is a probability that the Eco-system in the sea around Muuga Harbour will be affected by the construction and operation of the PHPP. This item will not be investigated further based on lack of resources and specific knowledge. It is, however, considered as a relevant subject to consider later in EIA/SEA investigations based on relevant available resources.
Economy and	A7, C11	Welfare of the local people and economical consequences for

human welfare		individual citizens should be considered (e.g. will it become less attractive to live in the area based on the construction and operation of the suggested PHPP). This item will not be investigated further based on lack of resources and specific knowledge. It is however considered as a relevant subject to consider later in EIA/SEA investigations based on relevant available resources. Also, when relevant it will be commented if the other investigated items are expected to influence economy and human welfare.

Relevance and Experience of Potential Environmental Risks

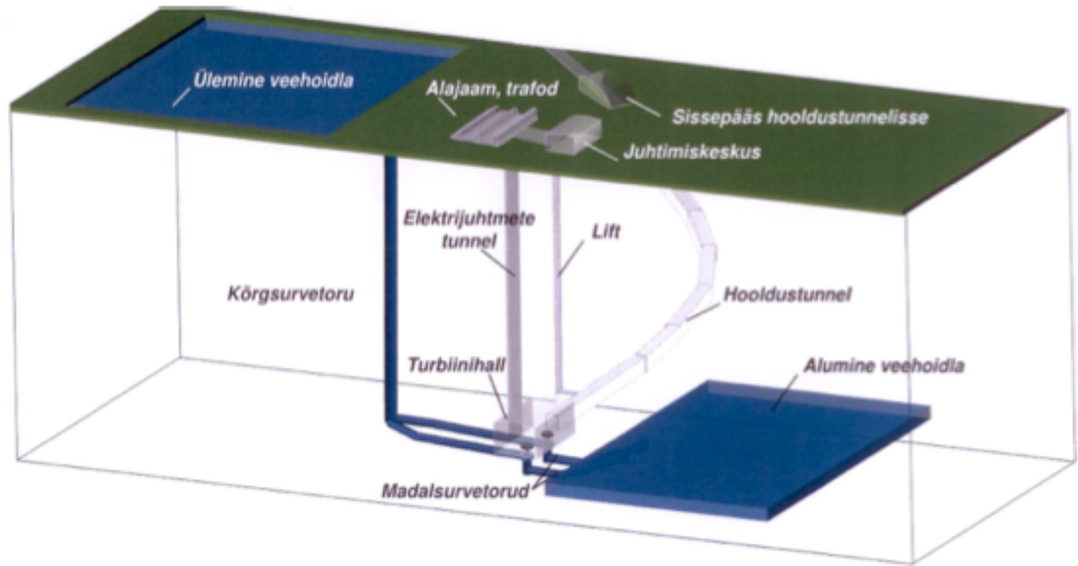
In the following section, the potential environmental risks identified and selected for further investigation in section "*Summary of Potential Environmental Risks*" will be studied. The study will be based on analysis of the different aspects and on relevant scientific articles on similar subjects where applicable.

Noise

Noise is considered a potential environmental risk, both during construction phase and during operation phase. Issues related to the two phases will be discussed separately in the below sections.

Noise during Construction phase

During the construction phase, excavated granite will be removed from the excavation site. In the picture below (copied from [14]) it is visible that a maintenance tunnel (Hooldustunnel) will be made. This tunnel will be needed for both the construction phase and for later maintenance. The tunnel is made for truck transport. To remove the excavated granite from the reservoir to ground level, trucks are necessary. The suggested construction site is located in the harbour area of Muuga and this enables the option to remove the excavated material both by sea transport and by train.



However, to transport the material from the entrance of the maintenance tunnel to the train-station or harbour, trucks are needed. Based on these observations, it is concluded that trucks will be used for the transport in the local area in which noise is also going to be a concern. Noise from trucks is therefore going to be investigated in the following:

Frequency of Truck Transport and Noise level from Trucks

Based on the reservoir volume, density of granite, load capacity of trucks and construction period, it is possible to estimate the frequency of trucks going in and out of the Maintenance tunnel. Based on the frequency, it will be possible to evaluate if noise from trucks going in and out of the tunnel will be a significant source of noise in the local area.

Input data for calculation of frequency of transport:

1. Density of Granite: 2691kg/m^3 for solid granite[2]. The granite is assumed to be solid before the excavation from the reservoir.
2. Volume of excavated granite (same as volume of reservoir): 4,75E6 m^3 [2]
3. Mass of excavated granite: (Density x Volume =) 1,28E10 kg
4. Construction period: 5 years. Based on a targeted commencement of Muuga PHPP in June 2017 [2].
5. Working days (assumption): 365 days/year
6. 10 hours work per day (assumption)
7. Maximum load carrying capacity of dump truck in EU[3]: 32 ton

Frequency of truck transport calculation

8. Granite excavated per hour daytime: 1,28E10kg/(5 y x 365 days/y x 10 h/day) = 700ton/h
9. Trucks going in and out of the maintenance tunnel per hour (10 hours per day): 700ton/h / 32 ton = 22 trucks per hour (both in and out of the tunnel).

Based on the above calculation, trucks will be present in the area 2 x 22 times per hour during daytime. 22 times running with full load going out of the tunnel. 22 times without cargo going back into the reservoir to pick up a new load. This means that trucks will operate in the local

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[2] http://www.simetric.co.uk/si_materials.htm
[3] http://en.wikipedia.org/wiki/Dump_truck

area with an average time interval of 1,36 minutes. In reality, this mean that a truck will be in operation at all times.

From available literature, the typical noise level for a heavy truck is estimated to be 84 to 86 dbA[4] where the truck is operating. In a specific case study for trucks [28] a noise level of 88dbA is evaluated for dump trucks at a distance of 20ft (6m) and a height of 3m based on measurements in several frequency bands. A noise level of approximately 85dbA is therefore used for the further evaluation.

Noise during Operation phase

During the operation phase, the raised concern for noise has been if the release of air from the reservoir during filling of water will result in disturbing noise. In order to evaluate this, the speed of air going out from the reservoir when water enters the reservoir is evaluated and compared to noise guidelines for fluid speed in ventilation and gas-pipes:

Input data for the calculation of air speed in release-tube:

1. Air flow = Maximum water flow into reservoir Q(max) = 110m3/s [2]
2. Diameters of shafts (based on e-mail from Ramboll Eesti AS dated 2 November 2011), it has not been decided which channel would be used for the air release. The options are:
    a. Main tube – diameter 8m → cross-section area = 50,3m2
    b. Additional tube – diameter 4m → cross-section area = 12,6m2
    c. Water tube – diameter 7m → cross-section area = 38,5m2

Calculation for air speed in release-tube:

3. The air speed is calculated as the ratio between airflow and cross-section area of the tube. The results for air speed is:
    a. Main tube – 2,18m/s
    b. Additional tube – 8,75m/s
    c. Water tube – 2,85m/s

[4] http://www.drnoise.com/PDF_files/Traffic%20Noise%20Primer.pdf

In order to evaluate if the airflow itself will result in noise, the flow through the release tube is considered and compared with similar applications. For this purpose, relevant references from general engineering applications and gas flow designs are made below.

Based on guidelines for noise in engineering applications [29], it is observed that reduction of fluid flow speed is a key parameter to reduce noise from fluid flow. Based on this observation, the largest possible flow channel should be used for the air release flow (the 7m diameter tube is the preferred tube in terms of noise reduction).

A standard for gas flow design [30] provides a formula for evaluating of maximum acceptable flow in tubes in order to avoid vibration or noise problems. The formula is:

$V = 175\left(\frac{1}{\rho}\right)^{0,43}$ or 60m/s, whichever is lowest

In the formula the following values are used:

- V = max. velocity of gas to avoid noise (m/s)
- ρ = density of gas (kg/m^3)
  - Density of air at 10°C is 1,249kg/m^3.[5]

The maximum speed to avoid noise problems is calculated:

$$V = 175\left(\frac{1}{1{,}249}\right)^{0,43} = 159\,m/s \quad \rightarrow \underline{V_{max\_air} = 60\,m/s}$$

The calculated value is significantly lower than values for all of the suggested tube diameters. Maximum air speed for the suggested diameters is 8,75m/s. Based on this, it is concluded that the airflow will not be a source of noise in the area.

In order to achieve additional safety against other sources of noise from the reservoir (e.g. noise from water through the turbines) an additional measure to reduce noise could be

[5] http://www.engineeringtoolbox.com/air-properties-d_156.html

relevant to consider. For this purpose, a quiet nozzle (or sound damper) could be installed in the air relief tube in order to lower the emitted sound level from the reservoir. A quiet nozzle is a component used in several applications – one of the best known is to reduce noise from the exhaust on combustion engines (cars) but the quiet nozzle is also used in e.g. ventilation systems. The quiet nozzle design is made to diffuse and absorb the sound by means of diffuser, absorbent material and redirection of the gas through a number of perforated plates and small holes [29].

Noise Reduction

The noise level at the residential areas located approximately 1000m from Muuga PHPP will be significantly lower that the sound levels experienced near the construction site. As a general design rule, it can be expected that the sound level will be reduced by 6dB when the distance to the sound source is doubled. This phenomenon is known as *the rule of 6*. Below a table of noise reduction based on distance is given[6]:

Distance from source [ft]	20	40	80	160	320	640	1280	2560
Distance from source [m]	6	12	24	48	96	192	384	768
Noise reduction [dB]	-0	-6	-12	-18	-24	-30	-36	-42

Based on the above table, a noise reduction of approximately 42dB can be expected when the noise is registered in the nearby residential areas (1000m away) compared to the noise registered at Muuga PHPP. This means that a sound level of 85dba registered outside near Muuga PHPP will be reduced to approximately 43dbA in the outside areas of the nearby residential areas.

Besides reduction of noise over distance, it is also possible to reduce the noise by means of installation of Noise Control Fixtures [30]. An example of this is e.g. sound walls, which are present along some motorways and railroads in city environments.

[6] http://www.generatornoise.com/

Acceptable Noise levels

The perception of noise is an individually matter for the receiver. Low levels of noise disturb some people, and others can accept higher levels of noise without discomfort. Furthermore, the disturbance can be different for different frequency levels and combinations of sound (e.g. in general noise from industry or traffic will be more disturbing than music if they are registered at the same sound level). In scientific articles on this matter [27], studies are made on a number of persons who is subjected to the same level of noise. It is then registered how big a fraction are experiencing discomfort for a specific level of noise.

For the purpose of this report, acceptable levels of noise will be considered in more general terms, as it will require detailed knowledge and field measurements to conclude on a more detailed level. The following guidelines for acceptable noise levels have been obtained for the purpose of identifying noise levels:

Acceptable noise levels	
Residential areas (outside) (where people are relaxing – e.g. in a garden)	55dbA[7]
Industrial areas (8 hours work per day)	85dbA[8]

Conclusion on Noise

As stated previously in this section, individuals are disturbed by noise differently. Based on this and on the theoretical approach used in this report, the conclusion for noise will be focused on the general guidelines for noise also mentioned previously.

In the construction phase, noise at the construction site is expected at levels that are considered as an environmental consequence (around or above 85db). The constant level of noise from dump trucks operating in the harbour area removing excavated granite will be a

[7] http://www.engineeringtoolbox.com/epa-protective-noise-level-d_720.html
[8] http://www.hse.gov.uk/noise/regulations.htm

environmental issue – it should not be considered as a environmental risk, but as a consequence. Precautions must be made to ensure that workers in the area are not subject to higher levels of noise than acceptable (85dba for 8 hours per day). The area is already an industrial area (harbour), so the increased level of noise will not cause problems for the general public in the harbour area, as noise is already present and the area in neither a living or a recreational area.

In the nearby residential areas, it is expected that the outdoor noise level will be reduced to a value within the acceptable (below 55dbA) based on the distance to the construction site. However, the level of noise is expected be increased compared to the current level, and this can lead to lower levels of satisfaction in the areas, and potentially also lead to lower real estate prices and other effects concerning the human well-being in the area. It should be noted that the construction period is expected to be 5 years during which the noise level will be increased.

In the operation phase, noise from the air relief tube is not considered to be an environmental risk. In case noise e.g. originated from water running through the turbines is a source for noise, a migration method will be possible to design the air relief tube in a way that makes it possible to install a quiet nozzle (sound damper). The implementation of a quiet nozzle is, however, to be considered a restriction and will slightly lower the efficiency of the PHPP and also add an additional cost to the project.

Radiation

Increased level of radon radiation is a potential environmental risk raised previously in the report and selected for further investigation. In the following section, it will be studied if the risk is relevant for the construction and operation of Muuga PHPP.

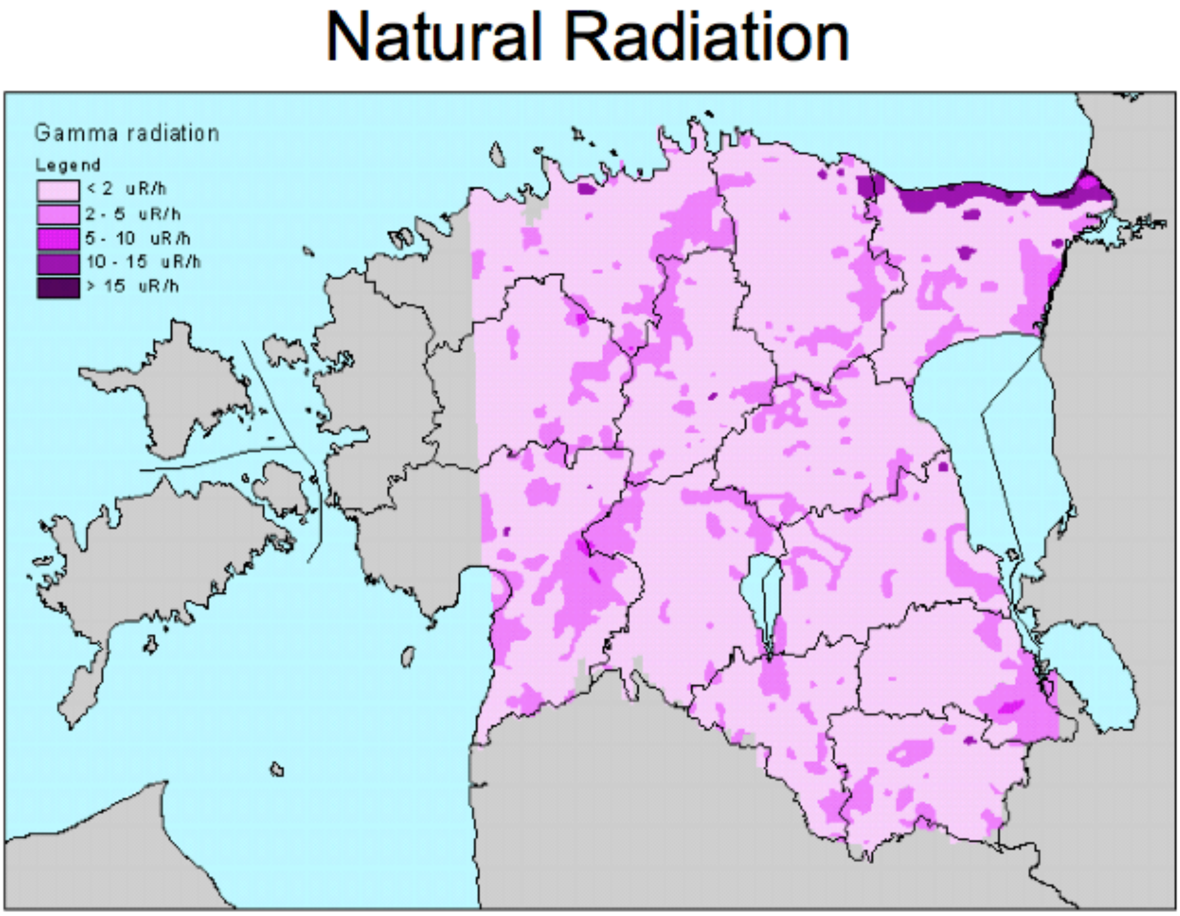
Consequence of Radon Exposure

Radon radiation inside buildings and other structures is the largest form of radiation humans are exposed to [15]. The main danger of radon exposure is the risk of lung cancer when inhaled to the lungs [16]. It must, however, be noted that radon is a natural occurring substance from earth. The level of radiation is varying between locations on earth depending on the content of the underground and other factors (e.g. the path of radiation to the crust of the earth). But radon radiation is a part of the environment on the planet. The relevant question in this analysis is therefore if the concentration of radon radiation will increase based on the construction of Muuga PHPP. The increase of radon radiation is relevant to consider, both at the construction site (the reservoir) and in the surrounding area.
Radon radiation is especially relevant indoors as the radiation level builds up in case of insufficient ventilation in modern type well-insulated houses [18].

Background for Radon Exposure

In a natural environment, radon is present as decay from the radioactive processes of especially Uranium and Thorium that occur as natural substances in the underground all over the planet. Increased levels of Uranium occur in Granite [18] and that is the material excavated from Muuga PHPP reservoir. The level of natural radon radiation, also called background radiation, is stated in natural radiation maps. A natural radiation map for Estonia is given below[9]:

[9] Source of background radiation map:
http://www.nucleonica.net/wiki/images/8/86/NuTRoNS1-Pesur.pdf



Acceptable Levels of Radiation

EU regulative 96/29/EURATOM defines limits for acceptable radiation both for workers and for the public in general [19]. The directive defines acceptable limits for radiation for people affected by radiation – both from natural sources (e.g. radon radiation in a excavation mine) and from man-made sources (e.g. nuclear plants, nuclear waster, etc).

To evaluate the amount of radiation received by an individual, the unit *Sievert* (Sv) is used. One Sv is equivalent to 1 Joule per kg mass and thereby refers to the energy absorbed from the radioactive source.

For workers (earning salary while working a radioactive environment) the limits are defined in article 9 of the directive. Over a 5-year period, an individual worker must not receive more than an effective dose of 100mSv, and maximum 50mSv in one year. Under special circumstances, the boundaries can be increased, but it will require special permission for specific cases from the authorities and it must be granted upon evaluating the specific case. Furthermore, workers must be informed about the increased radiation and potential consequences, and accept the risk individually.

For the public in general, it is the individual member states (of the European Union) that determine a target limit of 1mSv per year.

To summarize the above, specific rules for the amount of radiation individuals may absorb exist in the EU regulative 96/29/EURATOM. For the construction and operation of Muuga PHPP, the rules and regulations mentioned in the EU directive must be fulfilled.

Concentration of Radon Radiation

Unventilated chambers below the surface contains increased levels of radon radiation [15]. A measurement study in China [13] reveals that radon can be carried from the subsurface to the surroundings by the presence of a carrier. The study was performed to identify if geological faults (geological fault is a crack in the underground material enabling passage of material from the underground to the surface) would influence the concentration of different substances – one of them was radon. The study mentions that radon can be transported by means of a carrier to the surface – one possible carrier is water vapour. Based hereon the possibility that the PHPP during operation could carry radon gas to the surface is present, and thereby potentially leading to increased concentrations.

Based on the above, it must be taken into consideration that possible concentration of radon inside the reservoir could be carried to the surface when water enters the reservoir, as water vapour exists in the ambient air equivalent to the saturation pressure at a given temperature.

Radon level in Underground Work Places

Radon radiation levels in a number of underground workplaces have been examined in Catalonia, Spain [15]. The radiation levels were examined in order to consider if the previously mentioned EU regulative 96/29/EURATOM was met for underground workplaces.

Thirteen underground workplaces were examined. The workplaces include mines, former mines turned into museums, tourist caves and the subway of Barcelona. Based on the 13 workplaces, two sites were identified to have higher radiation level than the maximum recommended level (1500 Bq m^{-3}) (1 Bq equals 1 decay per second [19]). Maximum recommended level means maximum level before taking action to the radiation problem by means of design changes (ventilation or other).

In one of the underground work places, the ventilation system had been taken out of operation before the measurements. It had only been turned on 10 minutes before the measurements were started, and this resulted in an initial measurement of 3600 Bq m^{-3}. After 1 hour with forced ventilation in operation the measurement was reduced to 400 Bq m^{-3}. This clearly visualizes the importance of forced ventilation systems in underground work places.

Surrounding Environment

Radon radiation is already present in the local area, which is also possible to identify by the supplied natural radiation map. Despite the presence of ventilation form the reservoir to the environment, radon concentration in ambient air in the surrounding environment will not occur. It can therefore be concluded that radon levels in residential areas near Muuga PHPP will not increase based on the ventilation. The ventilation air from the mine will diffuse in the air, and at the distance of residential buildings (500m), an increased level of radon radiation is not to be expected.

Another approach to conclude the above is to consider that the granite (and thereby Uranium) is present in the underground – with or without the excavation. The presence of geological faults (cracks in the ground and potential carries of radon) will enable radon to reach the surface [17] also without the excavation.

Conclusion on Radiation

Regulations for the acceptable radiation is presented both for workers in the excavation site and for the local citizens. It is not expected that local citizens will be affected by radiation from the excavation site – nor during construction or operation period. For the workers in the excavation site, it is necessary to ensure that appropriate forced ventilation systems are installed and operating, in order to meet the acceptable radiation levels from EU regulative 96/29/EURATOM.

Ground Water

Possible pollution of groundwater has been raised as a potential environmental risk for the project earlier in the report. The reason for the concern is that the construction of Muuga PHPP will go through the groundwater level. Groundwater is located approximately 80m below sea level at the location. The reservoir, turbine, etc, will be located at approximately 500m below sea level. The risk of seawater mixing with ground water (and thereby polluting the groundwater) is the main concern.

The following vertical tubes of the construction are passing the ground water level (see sketch of the construction in section Noise During Construction phase, page 27):

- Water inlet/outlet for the turbines
- Maintenance tunnel
- Lift
- Air relief tube (air can escape when water is entering the reservoir)

It is assumed that the lift and maintenance tunnel will be sealed from the reservoir, and therefore seawater will not be able to enter the groundwater through these channels/tunnels. On this basis, it is mainly interesting to investigate the Water Inlet/Outlet and Air Relief Tube. Both of these are assumed to be cylindrical tubes (based on the previously mentioned sketch).

The construction of the channels/tunnels will be based on Rock Grouting (information from Ramboll Eesti AS). Rock Grouting is a technique where a sealing material (usually cement) is forced into the surrounding material at high pressure. The sealing material will flow into cracks and holes in the granite/rock. The sealing material will cure after a period of time then it reaches solid stage and thereby act as a seal. Rock Grouting is a known technique, and it is e.g. planned used for sealing of groundwater around a planned nuclear waste deposit in Sweden [22], and also for other sealing applications. Examples of this will be discussed later in this chapter.

Background – Risk of Mixing Seawater and Ground Water

Mixing of seawater into groundwater, also called Groundwater intrusion, is a known problem in coastal regions. Usually the problem occurs due to pressure difference between the seawater and the groundwater – both from a possible height difference and different density based on the salt content of the seawater. In case excessive volume of groundwater is extracted, a pressure difference between the sea and the ground water will occur (low pressure in ground water reservoir based on excessive extraction). This will enable seawater to travel through the solid material (e.g. sand or perforated underground) and thereby enter the ground water[10]. In case of seawater pollution of groundwater, the groundwater becomes unusable for drinking[11].

Experience from Other Constructions going through Ground Water Levels

Different constructions go through the groundwater level. Examples of these are Oil and Gas drillings, Geothermal Heat Power Plants, Subways/Tunnels and Mines. In general, it is important to seal all connections made from the surface to the groundwater, as different sources of pollution are present for groundwater contamination [23]. Examples of contaminants are surface water runoff, waste from agriculture and seawater (as discussed in this specific project).

In order to construct a permanent and long-term stable seal for any drilling application in connection with groundwater, a round seal is beneficial. The round shape will stabilize the earth surface and prevent unintended water or substances to migrating into the groundwater [23]. Furthermore, the sealing material and technique must be suitable for the individual application. Grouting is mentioned and discussed in [23] and the method is argued to have several advantages (cement is an available resource; creates extremely rigid columns and the weight of the cement easily displaces all other fluids in the sealed hole). However, disadvantages are also mentioned. These are shrinkage during the curing process and the

[10] http://en.wikipedia.org/wiki/Saltwater_intrusion
[11] http://www.mnn.com/earth-matters/translating-uncle-sam/stories/how-does-groundwater-pollution-occur

heat generated from the cement during the curing process. The heat is mainly a problem if plastic materials (e.g. PVC) are present in the tunnel/excavated area.

Geothermal Heat Pumps

A specific installation that requires drilling/construction and sealing through the groundwater level is Geothermal Heat Pumps. Guidelines for installation of Geothermal Heat Pumps (from the National Ground Water Association in U.S.A.) reveal that also for this type of application, grouting based on cement is used as sealing technique to protect the groundwater [21]. In this specific application, grout furthermore has the function to increase the surface contact to the surrounding material in order to optimize the thermal contact, and thereby increases the efficiency of the Geothermal Heat Pump installation. It is noted in the referenced guidelines that grout is an economical and efficient method for obtaining both function (sealing and increasing thermal contact). Geothermal Heat Pumps are based on a refrigerants that has the with lower freezing and boiling point that water – a chemical that is not desired to have mixed into the groundwater. Based on the guidelines, and the nature of refrigerants, it is noted that Grouting must be considered as a safe and reliable sealing method from the National Ground Water Association in U.S.A.

Road Tunnels with Ground Water Ingression

Another application for which Rock Grouting is referenced is in road tunnels affected by sudden groundwater ingression. An example of this application is found in Taiwan [20] from which the following information is obtained. The geology of Taiwan with high frequency of mountains results in tunnels being used for many road applications. One of the major obstacles for the tunnel projects is the risk of sudden ground water ingression (ground water finds way to the tunnel and flow of water can harm the construction). Examples of water-flows at the volume-range 750-1000L/s are presented in the article. The tunnels are large highway projects with a construction diameter of 10,8m and length of the tunnels of up to 12,7km. During the construction, the drilling equipment was flooded, based on sudden water ingression when the drill hit fragile rock material. This leads to increased risk – both financial and for workers. To improve the stability of the rock/mountain, and to seal against incoming water to the tunnel, the technique of Grouting was uses with success for the remaining part of the tunnel construction.

Conclusion on Ground Water Pollution

Based on the above applications of Rock Grouting with practical experience for sealing of groundwater, and based on the planning of a nuclear waste deposit with sealing of groundwater by means of Grouting [22], it is concluded that the technique is well proven and safe for groundwater sealing. It can be concluded that a low risk for contaminating the ground water is present based on the known applications and guidelines. From the articles studied, it is however observed that the grouting is a specific and specialised task, and the grouting must be handled and designed by experienced actors with relevant experience in order to ensure a low risk of installation of design error. If proper care is taken, the technique is seen as safe for the groundwater environment.

In case of Groundwater pollution, the severity for the surrounding environment is high. Quality of drinking water will decrease – some wells/aquifers may be completely useless. Also, it will be extremely costly to clean up contaminated groundwater[12].

As a safety measure it could be suggested to implement surveillance of the groundwater quality in connection with the construction of Muuga PHPP – both to monitor if a leakage should occur, but also to monitor groundwater intrusion in traditional sense (based on excessive groundwater extraction) since this is also a coastal region. Thereby, the local community could get better safety for their drinking water quality as the risk from groundwater intrusion - both from contamination form Muuga PHPP, but also from traditional seawater intrusion based on excessive extraction of groundwater - could be observed at an early stage.

[12] http://www.lenntech.com/groundwater/reducing-contamination.htm (commercial site)

Risks of Accidents

The potential risk from accidents in the harbour area has been selected for further investigation previously in the report in the section "*Summary of Potential Environmental Risk*". The potential risk is based on concerns from the local citizens and the municipality presented by Ramboll Eesti AS. The concern for potential risk is more specifically if the location of a PHPP facility in the Muuga harbour area will increase the risk of fire or explosion in the storage facilities (Oil, Coal, LPG) at Muuga Harbour. It will be investigated if PHPP constructions can be considered as safe or unsafe structures in terms of danger of ignitions of the surrounding storage facilities.

Known Accidents with Hydro Power Plants

When searching for accidents and risks for Hydro Power plants, the main considered risk is dam failure with the consequence of flooding large land areas [24]. The risk of dam failure is, however, not relevant in this specific case since the reservoir is located below the surface, and a potential dam failure will not result in flooding of living areas as in the case of traditional Hydro Power plants.

Fire and explosion are not a risk that is being considered in general. Based on the technology of a Hydropower facility (water running through turbines) there is neither a direct reason to consider fire nor explosions a risk. However, the risk is considered in the following based on the raised concern from the local citizens.

Possible Sources for Accidents

In order to evaluate if the presence of a PHPP facility will present a risk for fire or explosion in the area, different sub-systems of the installation are analysed individually in the following. Based on the evaluation of risk for the individual subsystems it will be concluded if the installation of a PHPP can be considered a risk for starting fires or explosions in the final part of this section.

Mechanical Components of Power Plant (Turbines, Shafts, Bearings, other)

The central part of a Hydro Power Plant, which converts energy from elevated water into electricity, is a mechanical structure. Potential energy from the seawater is released through the turbines and converts this into mechanical energy in the shaft of the turbine. The shaft is connected to a turbine, which converts the mechanical energy into electrical energy [3].

Mechanical structures (machines) are based on components that potentially can fail. As a final consequence a mechanical failure can lead to fire based on heat from excessive friction. An example of a component of this nature is bearings used to support the turbine shaft. Frequency of accidents for industrial components of the type used e.g. at Power Plants is low – components of this type are designed to be running continually for several years. As an example from a specific application, a thrust bearing for hydropower plant has been reported to run for more that 30 years before unexpected failure [26].

As a general safety precaution for large mechanical installations in order to avoid accidents, it is common to install surveillance equipment that can monitor the condition of the components to ensure stability of the machine and to minimize maintenance cost. Monitoring could include vibration analysis, temperature monitoring of components and lubrication oil, and other aspects. An example of monitoring of this type is also used in the mentioned case with a specific application running for 30 years [26]. The detection of bearing temperature was the reason the bearing failure was detected at an early stage, thereby avoiding further damage.

Besides the above-argued low probability for an accident for the specific application, the consequence of an accident is considered low. Even in case a fire should ignite in the turbine (or related components), no combustible medium (oil, gas or biomass) is present in the reservoir. The distance to the surface is 500m wherefore it is unlikely that a fire should be able to reach the storage facilities at the harbour.

Electrical Installations

In the mechanical part of the installation of a Hydro Power plant, energy is converted into electricity. The generated electricity has to be transmitted into the national electricity grid. The planned capacity of the power plant is 500MW and the cabling between the power plant and the grid will be dimensioned for this – with the 500MW capacity the installation can be argued to be a high-energy installation.

Two types of electrical hazards for human are relevant for high-energy electrical installations – Electrical Chock and Electrical Arc/Flash burn [25]. Electrical Chock requires a person to be in contact with the conductor. Electrical Arc is transmitted over a distance from the conductor to the person being exposed – it can be consider as a lightning between the electrical conductor and the person being affected by the arc. For this phenomenon safety distances to high-energy conductors are defined.

Based on the above, it can be observed that fire/ignition theoretically can be started based on electrical installations. If an Arc/Flash is present in a high-combustible environment (e.g. chamber filled with LPG), there is a potential risk of ignition. However, as discussed in the referenced document [25] there are well-defined rules and regulations to be followed for installations of this nature. The electrical installations for Muuga PHPP must (naturally) follow installation requirements for high-energy/voltage electrical installations. With this in mind, there is no specific risk for fires or explosions based on the electrical installations.

As a final safety precaution, it should be considered that electrical installations could be designed in locations away from combustible material. That means that the design of the electrical installations should be made to ensure that high-energy/voltage installations are not be present near storage facilities of Oil, Coal and LPG.

Transformation Station and Power lines

Power produced at the power plant will be integrated in the grid. Before connection to the grid, the voltage of the grid must be obtained and for this purpose a transformation station will be constructed. It has been informed that a transformation station will be positioned above ground near the PHPP for this purpose.

The presence of transformation station and high-voltage power lines implies the risk of electrocution of e.g. birds in case they come in contact with connections at the transformation station or short circuit power lines. The risk of birds being electrocuted in collision with power lines is a separate subject. Discussions on preventive measures are included in referenced document [26]. In case electrocution is occurring, a flash (or lightening) will be present which could potentially lead to ignition of combustible mediums (e.g. LPG).

As in the case with electrical installations in general, precaution should be made in the construction phase to ensure that neither transformation station nor high-energy power lines are present in the harbour storage area. This is a design matter that can be taken into consideration during the design phase and in case proper safety distances are kept, there is no risk of igniting fires in the storage facilities based on power lines or transformation station.

Conclusion on Risk of Accidents

The PHPP itself does not contain a risk for fire or explosions. Mechanical components could fail and develop heat and as a final consequence ignite fire. However, the location 500m below sea level, water in the reservoir and no presence of combustible material in the reservoir makes it highly unlikely that a fire or explosion should develop into the storage area of the harbour facility.

For the electrical installations including the transformation station, proper care (standards for high-energy electrical installations should be followed) in order to ensure that a potential fire or flash will not in any way be able to reach the storage facility. However, this is an unreasonable concern as long as the concern is included in the design phase.

It is not expected that the presence of a PHPP will increase the risk for fires or explosion in the harbour or storage area.

Evaluation of Identified Potential Environmental Risks

In this section, the identified environmental risks from the former sections will be evaluated. Based on the gathered information, individual risks will be shown in two matrixes to visualize the consequence and probability of each identified environmental risk both for the construction and operation phase. In these matrixes, it is also shown how the suggested migration suggestions are expected to influence the evaluation of consequence and probability in each matrix. The identified risks for both construction impacts and operation impacts are shown separately (hence two matrixes).

Consequence and probabilities for identified environmental risks during the constructions phase are given in the matrixes below. Each colour presents a pair of environmental risk – the notation with an "m" in the end of the name states that migration suggestion is introduced. It can thereby be observed how the suggested migration will influence the position in the consequence/probability matrix. Before each matrix a table with explanation for letter code and migration and expected consequence is presented.

Construction Impacts

Abbre-viation	*Name*	*Explanation for position in matrix (before migration)*	*Migration suggestion*	*Explanation for position in matrix (after migration)*
CA CAm	Construction, risk of accidents	Consequence of a fire or explosion in the harbour-area is high based on the presence of oil, coal and LPG. The probability for an accident is however low. Nonetheless, if electrical installations are present in the harbour area there could be a potential risk.	In the design process, ensure that electrical high-energy installations are not present in the harbour storage area.	Consequence of a fire will decrease if the fire cannot reach the harbour area. Moreover, the probability is lower than before migration, as electrical installations are designed not to be able to reach the storage facilities.
CW CWm	Construction, groundwater pollution	The consequence of groundwater pollution is high as the groundwater becomes unusable for drinking. The probability is low, as seawater has not yet entered the reservoir during the construction phase.	Installation of a monitoring system for groundwater quality that can be used to monitor if leakage occurs from the PHPP, but also for groundwater intrusion in traditional sense.	The consequence is the same as without migration – if the groundwater is polluted, it becomes unusable for drinking. The probability will become lower based on faster detection of pollution, which will make it possible to stop a leakage or empty the reservoir (for any fluid that may be present at the time of leakage).
CR CRm	Construction, radiation	The probability of exposure is high based on the presence of granite (with a natural content of uranium which radon is a decay from) and at the same time, workers are in the area during the construction phase. The consequence is high as the	Installation of forced ventilation system in the reservoir.	The consequence remains high – the risk for humans to radon exposure remains to be lung cancer. The probability will become lower based on the migration suggestion as the concentration of radon becomes lower based on

		risk for humans exposed to radon exposure consists of increased risk of lung cancer.		the forced ventilation system.
CN CNm	Construction, noise	For the workers in the construction area, the risk is high – e.g. risk of reduced hearing based on high load of noise. For residents in the nearby villages, the risk is related to personal well being and value of their properties. Based on this, the consequence is set to medium. The probability is defined as high, as noise is expected to be an unavoidable environmental consequence during the construction phase.	Hearing protection can be used for workers to reduce noise intensity. Potentially, a sound wall could be constructed to reduce noise in residential areas.	In both cases, the consequence is the same as before migration, but the probability is lower for disturbance from noise if the migration measures are introduced.

The above stated probabilities and consequences are illustration in the table below:

Construction - Environmental risk evaluation

Probability \ Consequence	Low				High
Low					
				CWm	
		CAm		CW	
					CRm
				CA	
			CNm		
			CN		CR
High					

CA	Construction, risk of accidents
CAm	Construction, risk of accidents (with migration)
CW	Construction, groundwater pollution
CWm	Construction, groundwater pollution (with migration)
CR	Construction, radiation
CRm	Construction, radiation (with migration)
CN	Construction, noise
CNm	Construction, noise (with migration)

Operation impacts

Abbre-viation	*Name*	*Explanation for position in matrix (before migration)*	*Migration suggestion*	*Explanation for position in matrix (after migration)*
OA OAm	Operation, risk of accidents	Same as for the construction aspect. The consequence of a fire or explosion in the harbour-area is high based on the presence of oil, coal and LPG. The probability for an accident is however low. If electrical installations are present in the harbour area there could be a potential risk.	Ensure in design phase that electrical installations are not present in harbour storage area.	Both probability and consequence will decrease based on migration, as a fire will not be able to reach storage facilities even if it ignites.
OW OWm	Operation, groundwater pollution	The consequence of groundwater pollution is high as the groundwater becomes unusable for drinking. The probability is low based on the existing experience with grouting described in the report.	The same as in the construction phase. Installation of a monitoring system for groundwater quality that can be used to monitor if leakage occurs from the PHPP, but also for groundwater intrusion in traditional sense.	The consequence is the same as without migration – if the groundwater is polluted, it becomes unusable for drinking. Probability will become lower based on faster detection of pollution, which will make it possible to stop a leakage or empty the reservoir.
OR ORm	Operation, radiation	As in the case of the construction phase, radon exposure is a consequence inside the reservoir. The probability is set lower than in the construction phase as fewer people are present in the reservoir during the operation phase (the PHPP	The same as in the construction phase – a forced ventilation system is suggested as migration.	Probability will decrease as the concentration of radon in the reservoir will decrease based on the forced ventilation system.

		will be fully automated, so people will only be present for maintenance and similar purposes).		
ON ONm	Operation, noise	The consequence and the probability of noise in operation phase is considered to be low as the investigations made in the report showed that noise is not expected to be an environmental risk based on air release from the reservoir.	Quiet nozzle (sound damper) could be installed.	The probability of noise as an environmental risk is lower as the noise level is lowered by use of a quiet nozzle. The consequence of noise remains constant compared to before migration.

The above stated probabilities and consequences are illustration in the table below:

Operation - Environmental risk evaluation / Probability ↓ · Consequence →	Low				High
Low					
	ONm	OAm		OWm	ORm
	ON			OA	
				OW	
					OR
High					

OA	Operation, risk of accidents
OAm	Operation, risk of accidents (with migration)
OW	Operation, groundwater pollution
OWm	Operation, groundwater pollution (with migration)
OR	Operation, radiation
ORm	Operation, radiation (with migration)
ON	Operation, noise
ONm	Operation, noise (with migration)

Cumulative effects

Cumulative (domino) effects are considered – is it possible to identify risks that will be initiated by other risks. An example to determine cumulative effects is given in the EIA for Muuga Harbour Extension [9]. In the referenced case, several different environmental aspects are found and based on this, a specific matrix is set up to determine if cumulative effects will occur from impacts influencing each other.

For the purpose of this report, the amount of environmental risks identified is not extensive. Therefore, it is not relevant to consider a cumulative impact matrix. Instead the author has evaluated if any impacts will be able to influence each other, and thereby result in cumulative effects between different identified (or related) environmental risks.

Two potential cumulative effects have been considered:

The first identified cumulative effect is the potential risk of radon contamination of groundwater. Potentially, if the groundwater seal (tube sealed by rock grouting) is damaged, radon levels in groundwater could increase and this could further decrease the quality of groundwater. In one source [16], it is mentioned that there is a high partition coefficient (gas to water) for radon. This means that radon gas can be absorbed or carried by water.

The second identified cumulative effect is the fact that radon concentration could increase in the reservoir if forced ventilation system, which is suggested, as migration measure is not operating. This would imply that if the project is abandoned during the construction period (e.g. due to insufficient funding or other problems), it is potentially harmful if somebody begins using the reservoir for other purposes (shelter etc).

Other cumulative effects may be present and the above should be considered as examples of cumulative effects for the specific project based on the information gathered through this project.

Epilogue

In this final part of the report, the experience and knowledge gained during the report will be concluded. Also, during the sections "*Discussion and Future Work*", the relevance and possible future work based on the project will be mentioned.

Conclusion

The outcome of the report is an identification and initial evaluation of relevant environmental risks for the project. As stated in the section "*Description of the Work Method*", the original intention of the report was to serve as an input document amongst others for the ongoing SEA for Muuga PHPP that is being performed by Ramboll Eesti AS. This purpose is fulfilled by the identifications and evaluations made in the report.

Based on an array of sources, the potential environmental risks for the construction and operation of Muuga PHPP have been investigated. This foundation of inputs for potential environmental risks serves to ensure that as many aspects as possible are considered for potential environmental risks for the specific project.

For the topics selected for further investigation in the report, relevant experience from other applications have been gathered, and based on this theoretical approach, it is evaluated if the identified environmental risks are likely to occur and also if the consequences of each risk are substantial.

In the section "*Evaluation"*, risk matrixes based on non-quantified values are presented, and based on these matrixes it is visualized to the reader how suggested migration measures for the identified potential environmental risks will influence each risk. As stated in the later section "*Future Work*", it would be relevant to establish quantified (calculated) probabilities and consequences of each identified risk in order to upgrade this section with quantifiable scales. It has, however, not been possible to include this in the project based on available data, timeframe for the project and resources for research.

Based on the analysis made in the report, it is concluded that the main environmental risks identified through this project is noise during the constructions phase and radon radiation inside the reservoir.

- Noise based on transport of excavated material is expected to be an environmental consequence during the construction phase. Precautions (e.g. sound-walls) could potentially be constructed to lower the environmental consequences for the surrounding residential areas, but this is evaluated to an expensive additional construction project. It is therefore concluded that noise from the construction phase potentially can be harmful (e.g. in the form of less satisfied people and negative effect on e.g. real-estate prices) for the nearby residential areas during the approximately 5-year construction period. This can is also described in a general term as the NIMB (not in my backyard) syndrome. This expression is commonly used to describe how people are in favour of clean energy production, as long as they are not located close to their own residential area. During the operations phase, it is not expected that noise will be an environmental risk.
- Radiation inside the reservoir will only be of be of danger to the workers inside the reservoir. It is not expected that the radon radiation will influence the nearby residential areas. Based on a forced ventilation system in the reservoir, it is expected that radon concentration can be brought to an acceptable level, which fulfils the requirements from EU regulative 96/29/EURATOM. Thereby, it is concluded that the risk can be eliminated based on this suggested migration method.

It is furthermore concluded that the presence of Muuga PHPP will not have a severe influence on the probability of fire or explosions in the storage facilities in the harbour area. It is, however, recommended to ensure in the design phase that electrical high-energy installations are not present close to the storage facilities in order to eliminate potential risks of fire. Groundwater pollution from the seawater entering the reservoir is not seen as a likely consequence of the construction or operation of Muuga PHPP. This is concluded based on the available experience with Rock Grouting - the technique that will be used to seal the reservoir tubes.

As a final conclusion on the report, the above stated environmental risks have been identified. For the mentioned risks migration measures have been suggested to lower the probability and/or consequences of each identified risk.

Discussion

As stated in the section "*Perspective",* this report is performed based on the author's education in Mechanical and Sustainable Energy Engineering. The author believes that the work performed in this report potentially can bring other aspects in the environmental assessment that a traditionally assessment made by environmental engineers. The work performed does not cover all aspects of environmental risks for the suggested construction, but assessments of this nature requires input from several sources, and considered in this light, the report is considered as a valid input.

Future Work

In the section "*Summary of Identified Environmental Risks*", a selection of topics is made which will be investigated further in the report. Going beyond the scope of this report/project, it would be relevant to investigate the subjects that are sorted out from further analysis in this section. The selection was made based on available data, knowledge and resources. As an example, it could be a separate project to make an analysis of the effects in the sea-bottom of the water flow from the PHPP operation.

In the section "*Evaluation of Identified Environmental Risks*", it would be relevant to quantify evaluations of both probabilities and consequences for the identified environmental risks. This would serve to give a better tool for evaluating each risk and also to evaluate the effects of the suggested migration suggestions.

Finally, it could be relevant to consider how environmentally friendly the project is. If all the granite is removed by means of trucks, and energy demanding excavation machines. In this context it is could be relevant to consider a term, which can be described as ”carbon pay back time”. How long will it take before the plant has preserved enough green electricity to ”pay” for the gasoline used on the excavation phase? This would be an interesting project in itself.

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