Eirik Holand

Floating Hatchery for Growth of Post-Smolt Salmon by using Recirculating Aquaculture System

Master's thesis in Marine Technology
Supervisor: Pål Lader
June 2020

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Summary

Norway is currently the world's largest producer of Atlantic salmon. This is the case even before the government's goal of increasing the total production volume a fivefold is taken into consideration. However, this is a goal that is due in 2050, and several problems and challenges must be solved for this to be achieved. Some of the problems include sea lice, diseases, escape, and pollution. These problems may be reduced by growing the fish to a larger size after smoltification, for example to 1000 grams, before transiting out to the traditional on-growing sites at sea. Hence, the fish is not prone to the problems mentioned as it is not located in the sea. Additionally, salmon grown in post-smolt facilities are more robust than salmon transferred to cages after the smoltification. This makes the salmon less prone to mortality during the first encounter with pumping and the sea and may handle operations as delousing in a better manner. Lastly, control of what affects the fish is increased, as it is kept in closed containment systems and provided water through recirculating aquaculture system (RAS). The overall goal of this thesis is to use this information and come up with a new sort of concept of hatchery that may benefit companies and make the production of post-smolt more available and common. For this to be achieved, a threefold approach concerning technology, biology, and system design is used.

Initially, a literature review was necessary to create insight regarding current aspects of salmon production, primarily on RAS and production of salmon smolt. Additionally, a thorough understanding of design theory is important for the fulfillment of the thesis. The design theory included information on how to design the system through the *needs*, *function*, *form* mapping model. The method relies on the initial needs and requirements of a system, and how these are made into function and sub-functions the system ought to perform, which again determine the physical form and arrangement. The needs and requirements, as well as the functions, were based on information collected from the literature reviews on RAS and production of salmon smolt. Due to already existing hatcheries taking up large areas on land, the hatchery is required to be a floating structure. This characteristic makes the hatchery relocatable, making it possible for each company to use at locations that previously would not have been possible. For example as a secondary unit, in close combination with an original hatchery, or at a separate site with freshwater resources that previously have been unavailable.

The hatchery will be able to grow 2.5 million individual salmon from 100 - 1000 grams during a calendar year, performed during two production cycles. This is done in ten equal tanks with a volume of 1'667 m^3 each. This water amount is supplied and cleaned by two separate RAS sections placed as the tanks surround the RAS units. Hence, short travel paths of the water are acquired, aiding a compact layout of the hatchery. The hatchery will be shaped like a stretched hexagonal figure with a total length of 151 meters, and a width of 76 meters. It will have a draught of over 3 meters, which further indicates a freeboard of almost 3.5 meters.

Sammendrag

Norge er per dags dato verdens største produsent av atlantisk laks, noe som gjelder allerede før Regjeringens planer om å femdoble produksjonen er tatt i betraktning. Denne målsetningen gjelder dog innen 2050, og for at det skal være mulig må problemer og utfordringer først løses. Noen av disse problemene inkluderer lakselus, rømning, sykdommer og utslipp. Disse problemene kan reduseres ved å vokse fisken til en større vekt, for eksempel 1000 gram, før den blir transportert ut til et tradisjonelt påvekstanlegg på sjøen. Dermed blir ikke fisken påvirket av de nevnte problemene siden den ikke er plassert i sjøen. I tillegg, laks som er vokst i postsmoltanlegg er mer robust enn laksen som er flyttet til merder etter smoltifiseringen. Den er dermed mindre utsatt for dødelighet under første møtet med pumping og sjøen, og kan håndtere operasjoner som avlusing på en bedre måte. Tilslutt får en bedre kontroll på hva som direkte påvirker fisken, siden den holdes i lukkede tanker og forsynes med vann fra *recirculating aquaculture system* (RAS). Det overordnede målet med oppgaven er å bruke denne informasjonen, og komme opp med et nytt settefiskkonsept som kan gi selskap fordeler og gjøre postsmolt produksjon mer tilgjengelig og vanlig. For at dette skal kunne gjøres må en tredelt tilnærming innen teknologi, biologi og systemdesign brukes.

Initialt ble et litteratursøk nødvendig for å skaffe innsyn angående aspekter som brukes i dagens produksjon av laks, og hovedsaklig om RAS og smoltproduksjon. I tillegg er en grundig forståelse for designteori nødvendig for utførelsen av oppgaven. Designteorien inkluderer informasjon om hvordan systemet designes ved bruk av kartleggingsmodellen *needs*, $function$, $form$. Modellen benytter de initielle brukerbehovene og kravene for systemet, og gjør disse om til funksjoner og underfunksjoner systemet skal utføre, som igjen bestemmer den fysiske utformingen og arrangementet. Brukerbehovene og kravene, samt funksjonene, er basert på informasjonen hentet fra litteratursøket om RAS og smoltproduksjon. På grunn av allerede eksisterende settefiskanlegg som opptar store arealer på land er det nødvendig at anlegget blir en flytende konstruksjon. Denne egenskapen gjør anlegget flyttbart, noe som muliggjør at selskap kan bruke det på plasser som tidligere ikke har vært mulige. Dette kan innebære som en sekundær enhet, i nær sammenheng ved det opprinnelige anlegget, eller på en separat lokalitet med ferskvannsressurser som tidligere har vært utilgjengelige.

Anlegget vil kunne vokse 2.5 millioner laks fra 100 - 1000 gram i løpet av et kalenderår, utført ved to produksjonsykluser. Dette gjøres i 10 like store tanker som rommer 1'667 m^3 hver. Vannmengden i tankene forsynes og renses av to separate RAS-seksjonene plassert slik at tankene omringer RAS-enhetene. Dermed oppnås korte reiseveier for vannet, som gir et kompakt layout av anlegget. Anlegget vil være formet som en strukket heksagonal figur med en total lengde på 151 meter og en bredde på 76 meter. Det vil oppnå en dypgang på snaue 3 meter som igjen tilsier et fribord på nesten 3.5 meter.

Preface

The report at hand is the master thesis performed in the 10th and final semester of my M.Sc.in Marine Technology. The thesis was written during the spring of 2020 as a mandatory part of the Masters of Science program at the Norwegian University of Technology and Science (NTNU). It is a continuation of the project thesis performed in the autumn of 2019. The project thesis function as a literature review of recirculating aquaculture system and the production of smolt currently used in the aquaculture industry. Hence, large parts of Section 4.1 and Section 4.2 is gathered from the project. The overall aim of the thesis is to utilize this information to create a concept design of a new sort of aquaculture facility.

I would like to thank my supervisor, Pål Lader, at the Norwegian University of Science and Technology, who provided guidance and support during the project thesis leading up to the master thesis in addition to this semester in its fullest. I would further like to thank Ole Jonny Nyhus at AKVA group Land Based AS for inviting me to their offices and provided information and figures on the recirculating aquaculture system.

Eirik Holand

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Nomenclature

$\ddot{\eta}_2$, $\dot{\eta}_2$	Acceleration and velocity in sway direction
η_1	Motions in surge
η_2	Motions in sway
η_3	Motions in heave
η_4	Motions in roll
η_5	Motions in pitch
η_6	Motions in yaw
λ	Wave length
ω	Wave frequency
ω_1, ω_2	Wave frequency of two different regular waves in sea state
ϕ	Velocity potential
ϕ_{01}	First order velocity potential of incident regular wave
ϕ_D	Velocity potential of diffraction waves
ρ	Density
ζ	Wave amplitude
ζ_1, ζ_2	Incident wave amplitude of two different waves in sea state
ζ_a	Incident wave amplitude
A	Projected area
A_{22}	Added mass in sway due to sway motion
A_R	Amplitude reflected wave
A_T	Amplitude transmitted wave

B_{22}	Damping in sway due to sway motion
C_{22}	Restoring in sway due to sway motion
E	Elastic modulus
F_2	Force in sway direction
$F_2, Diffraction$	Diffraction force in sway direction
$F_2, Excitation$	Excitation force in sway direction
$F_2, Froude - Kriloff$	Froude-Kriloff force in sway direction
$F_2, Radiation$	Radiation force in sway direction
F_b	Buoyancy force
F_D	Drag force from current
F_w	Weigth
g	Gravitational acceleration
H	Wave height
h	Water depth
k	Wave number
k_{22}	Mooring line stiffness in sway direction
l	Length
n	Normal vector
n_2	Normal vector in sway direction
P_{dyn}	Incident wave dynamic pressure
t	Time
T_{2n}	Natural period in sway
U	Current velocity
x, y, z	Coordinates

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Chapter 1

Introduction

This chapter introduces the background, state of the art, objectives, and the structure of the thesis.

1.1 Background

Norwegian aquaculture has rapidly been growing over the last 20-30 years and is currently the second-largest contributor of Norwegian export, where 1.1 million tonnes of salmon, worth NOK 67.8 billion, was exported in 2018 (Norwegian Seafood Council (2019)). This is a further 5 % increase compared to the previous year. The industry is an important provider of jobs and taxes for communities and cities along the entire coastline, from north to south. It employs thousands of people directly in the farming companies, but also indirectly in companies that support these. It has contributed to a greater economy and even migration to small places that else would have been prone to urbanization.

The aquaculture industry has experienced large economical growth and meanwhile produced sustainable food. This has, along with the mentioned reasons above, led the Norwegian Government to state a goal of increasing production volume a fivefold within 2050 (Norsk Industri (2016)). However, growth can not be prioritized at any costs, and may only be possible if the industry solves some of the problems it is currently facing. Many of these problems may be solved by the introduction and development of new technology. This technological development must be carried out thoughtfully, where the technological advance is done according to the biology of the fish (NTNU (2020)).

Some of the current problems the industry is facing include salmon lice, diseases, and escape. Salmon louse (*Lepeophtheirus salmonis*) is a natural ectoparasite that feeds off the mucus, skin, and blood of salmon. The lice cause skin lesions and infections to the host, that in some cases lead to death. To combat this, companies spend in total over NOK 5 billion to keep the concentration of lice in cages as low as possible (Iversen et al. (2019)). Salmon lice are the biggest challenge the industry currently faces, and the Norwegian Government has stopped handing out production licenses to salmon farmers before the concentration of lice has been taken down to acceptable levels. Additionally, the salmon is exposed to diseases as Infectious salmon anemia (ISA), Viral hemorrhagic septicemia (VHS), and Pancreas Disease (PD) which suppresses the salmon's appetite and may be fatal. The salmon is also prone to escape from the cages. Escaped salmon may migrate to rivers where wild salmon stocks spawn and may lead to the interchanging of genes between wild salmon and cultivated salmon. Cultivated salmon does not possess the genes of natural salmon, and genetic pollution might occur.

A possible solution to some of the problems may be to limit the overall period where the salmon is grown at sea. This will reduce the time where the fish is exposed to lice, diseases, and escape. However, for the growth phase at sea to be reduced, the previous phase must be extended. This phase is the production of salmon juvenile in hatcheries, and hence must be expanded to include biomass growth of smoltified salmon (post-smolt) for a longer time. This process is already used in the aquaculture industry, but not every company is utilizing this production method, or rather, not able to utilize it. If more companies would have the option, lice, and diseases could be reduced, while escape may be reduced if designed properly. Hence, the motivation is to come up with a concept design that makes post-smolt production more available. Production of juvenile salmon and post-smolt is explained in Section 4.2.

1.2 State of the Art

In the 1970s, the aquaculture industry started breeding programs of salmon based on competence from the agriculture. This is, along with sea cage technology, credited as one of the key reasons for the great expanse of the industry. In the early years, wild salmon was collected and stripped of eggs and sperm, before fertilizing happened in tanks. Nowadays, salmon is bred in separate locations to assure the best possible genes are used for each generation of salmon. The juvenile salmon is kept in the hatcheries until they have undergone a smoltification process and can be transported out to the sea. Currently, several new hatcheries are integrating post-smolt facilities on site, where smoltified salmon can be kept and grown for a longer period. However, this is only relevant for newer hatcheries, whereas older hatcheries have no option to produce post-smolt, as implementation has recently happened.

New land-based hatcheries, and generally new structures used in the aquaculture industry, is getting larger and packed with more technology than before. This becomes even more apparent when concerning new post-smolt facilities, which makes it possible to produce salmon, from egg to slaughter, at one location. Production of post-smolt is currently being utilized and several new facilities are under building, making the experience and results of the product available. Such new facilities are using a cleaning and reusing water system called RAS. The system will be described in Section 4.1.

In the later years, a closed containment system has become more relevant, which has led to research and knowledge regarding the system have increased. New technology has been developed, making solutions to previous challenges available. However, a lot of research is still necessary for closed containment cages to be installed and used in commercialized production. Instead, the new concepts used for the production of salmon are semi-closed, meaning that some water exchange is happening.

1.3 Objective of the Thesis

The overall objective of this thesis is to develop a conceptual design of a standardized floating hatchery for the growth of post-smolt salmon, from 100 grams up to 1000 grams. Standardized, will, in this case, mean a design that is not adapted to a specific site, but rather a design that can function at several locations. This will, though, only be the case for the initial design, while at a later stage the design may be more modularized and customized to fit specific locations. It will be a design that may grant older hatcheries a possibility to produce post-smolt salmon close to the original facility. The product is designed to be mass-produced, and thus be able to significantly increase the total biomass of post-smolt production. However, adding another facility by the original hatchery will require more area to a land site that already is quite large, and might be troublesome due to available space and large economical expenses. Therefore, the post-smolt facility will be built as a floating structure, close to the original hatchery on land and within sheltered fjords.

This work will require a thorough understanding of hatcheries and the production of juvenile and smoltified salmon, and the different components necessary for such a hatchery to function. A considerable understanding of design theory and how to apply it will also a major requirement. The obtained knowledge will be utilized to develop a general design that can be used in an early stage of the design process. To fulfill this, the following points must be covered:

1. Introduce design theory. The literature review's task is to form the basis for strategies and analyses relevant to the designing of the marine system. The design theory will especially focus on the *needs*, $function$, $form$ mapping model, where the need and requirements of a system greatly determine what functions the system performs, and how these will take physical form. Lastly, an established design method is used to approach a design.

2. Introduce the cleaning concept of newer hatcheries and production of smolt. Designing a hatchery requires an understanding of the production of smoltified salmon, and the components necessary for a hatchery to function. The necessary needs and requirements for the design process will become apparent in this review.

3. Break the main function of the system down to sub-functions, based on relevant needs and requirements. This will be done to discover the beneficial design solutions. The relevance for each function to the main function will be described, and introduce the physical effects that are included in them. Additionally, this will include the introduction of a new sort of water supply to hatcheries that reduces the necessity of pumps and may grant installation of hatcheries at places where they previously could not be located.

4. With the established functions in hand, solutions to these are found and developed as concept designs.

1.4 Structure

Chapter 2 presents the methodology used in this study, including discussions regarding the sources of information.

Chapter 3 and **Chapter 4** contains the literature review relevant for the study. This includes the relevant design theory, presented in Chapter 3, and the necessary information on smolt production and the cleaning system of hatcheries presented in Chapter 4.

Chapter 5 presents the functions the hatchery must facilitate.

Chapter 6 presents a concept design that fulfills the established functions.

Chapter 7 includes a discussion of the work.

Chapter 8 includes a conclusion and proposes further work of the paper.

Chapter 2

Methodology

Chapter 2 is added to present the methodology used in this thesis and can be summed up as a flowchart. It explains how a threefold approach is the most beneficial method to carry out the total work. Additionally, the chapter presents the different sources of relevant information.

2.1 Presenting the Methodology

The overall objective of the thesis is to develop a conceptual design of a floating hatchery for the growth of post-smolt salmon. There exist well-documented design strategies available for different marine systems, but not for a distinctive design as the hatchery will be. Therefore, it is found interesting to develop the design of the system. The work of this thesis spans several fields of studies, making insight into relevant analyzes and theories required. The overall methodology is formed by a combination of these methods.

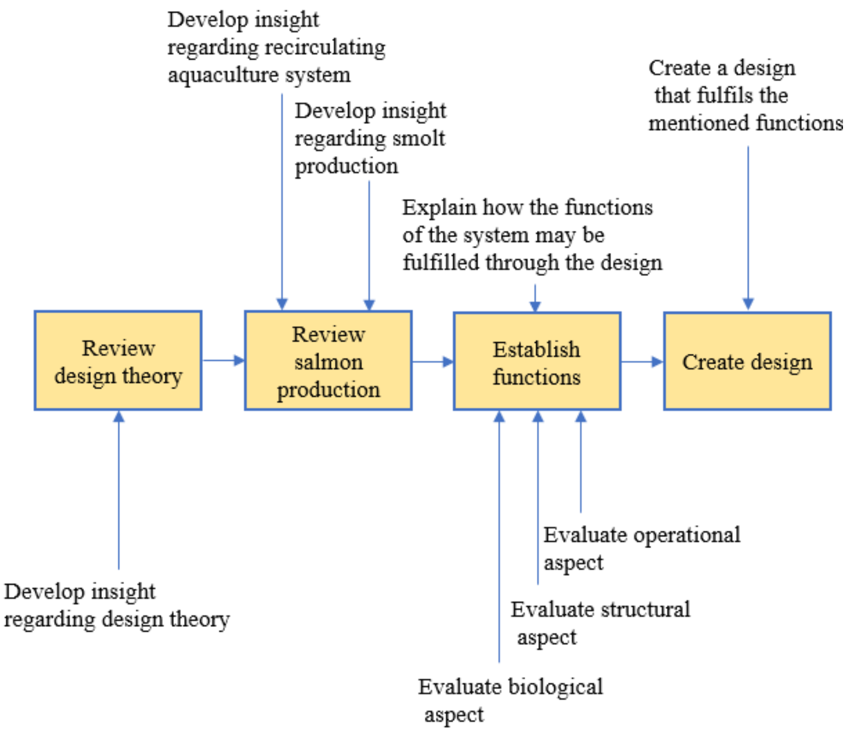

Figure 2.1.1: Flowchart that illustrates the methods which constitute the methodology of the thesis. A brief explanation of each step is given in the figure.

As seen in Figure 2.1.1, the initial step of the methodology is to conduct a literature review about design theory, recirculating aquaculture system, and smolt production. This review is performed to create insight into how to design systems, to provide a thorough understanding of the different components necessary for a hatchery to function, and how to maintain a beneficial environment for the fish in the system. The design theory consists of how to come up with a design based on the needs and requirements of the system. The thesis ought to come up with a conceptual design of a floating hatchery that can grow smoltified salmon from 100 grams up to 1000 grams. Hence, finding the necessary needs and requirements through the understanding of the recirculating aquaculture system and smolt production, and how to use these in the creation of a design is key for the overall goal of the thesis. The next step establishes and describes the functions the system will be designed to fulfill. Included are the evaluation of environmental effects, biological aspects, and working conditions and housing of personnel. In the end, the conceptual design will be made from the needs and requirements of these established functions.

2.2 The Threefold Approach

To solve the overall objective, it was deemed necessary to span more than one field of knowledge. This makes the threefold approach a viable option to use. As illustrated in Figure 2.2.1, the technological and biological aspects, along with system analysis and design, together creates the system solution. Each of the fields and its relevance is in the next paragraphs described.

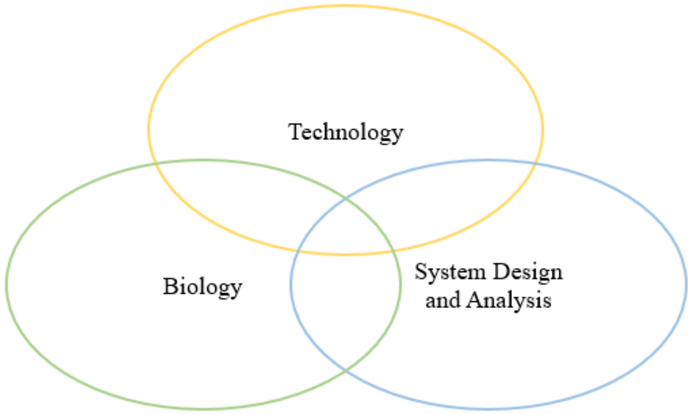

Figure 2.2.1: Illustration of the threefold approach.

Technology is, as defined, the sum of techniques, skills, methods, and processes used in the production of goods or services, or the accomplishment of problems, tasks, and objectives, such as scientific investigation (Wikipedia (2019)). It is applied to gain insight into an engineering process, to find problem solutions, or to improve already existing ones. Technology is, in the design of the hatchery, applied in the cleaning water system, but also to understand how marine structures and hydrodynamics interact.

The biological aspect is important due to the existence of live fish kept in the system. Fish welfare is required by law and must be a key factor for the design of the hatchery. Additionally, the fish, in the end, will be sold, making it is necessary to maintain the best quality of produced salmon for the hatchery to fulfill the economical goals. The cleaning system will also include biology due to the containment of actively growing bacteria as a part of the system.

Lastly, the goal is to conduct a system design to identify and fulfill an objective. System design focuses on how such an objective may be accomplished. System analysis is a problem-solving method that improves a system, and that each component functions as intended. It is applied to generate a design that fulfills the overall objective.

2.3 Sources of Information

Several new hatcheries are currently under building, and most of these utilize a water cleaning system. The system makes it possible to grow salmon at any place, for example in Florida, in the middle of Poland, or even in the middle of Dubai's desert. Information regarding the system has been gathered largely from the book *Aquaculture Engineering* (Lekang (2007)). The book focuses mostly on land-based production of salmon with the cleaning system at center. Additionally, information has been gathered through the subject $BI2065 - Akvakultur$ at NTNU and personal meeting with AKVA group Land Based AS, a company that globally is a leader regarding the system and land-based hatcheries.

The design theory mentioned in the thesis is largely inspired by the book *Engineering Design−A systematic approach* (Pahl et al. (2007)) and the lecture *Engineering design theory* in the subject *TMR*4135 - *Design Methods* 2 : *Special Vessels* (Asbjørnslett (2020)). Additionally, conversations with experts on the field Bjørn Egil Asbjørnslett and Svein Aanond Aanondsen was necessary.

Chapter 3

Design Theory

Design is a plan or specification regarding the construction of a specific object, systems, or the implementation of an activity or a process, in addition to the result of the plan or specification in form of a prototype, product, or process. A design is created to satisfy certain goals and constraints, and takes aesthetic, functional, economic, or socio-politic considerations into account, while it still is expected to interact with a specific environment. Design is, in engineering, a component of the engineering process (Wikipedia (2020a)). This chapter will include an overview regarding design, before an established design method for use in this thesis is explained.

3.1 Overview of Engineering Design

This section contains the overview of design where the *needs*, *function*, *form* mapping model and fundamentals of technical systems are explained.

3.1.1 Needs, Function, Form

A design process is often described as a mapping from a set of needs, via a set of functions, to a description of the system form, seen in Figure 3.1.1. The form will be the physical outline of the intended design, or in this case, a floating hatchery (Asbjørnslett (2020)).

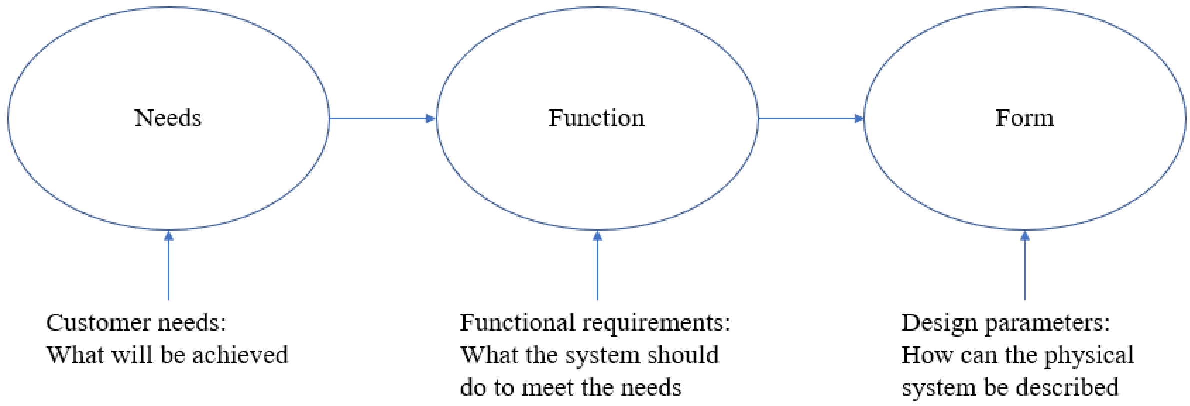

Figure 3.1.1: Illustration of the process of need, function, form.

The figure illustrates how design is directly connected to the needs and requirements of customers or shareholders, and are expressed as functional requirements. Hence, it is at the start of a design process necessary to gather needs as accurately as possible to get a beneficial design. If faults or certain aspects are lacking in the needs domain, these will also become apparent in the end design.

The needs domain is followed by the functional domain. Functions are, from mathematics, described as a relation between a set of inputs and outputs, where each input is related to exactly one output. In system design, however, the intended input and output relationship of a system whose purpose is to perform a task. Input is here the needs and requirements set, while the output is a system that performs the input. Tasks are defined by simple statements consisting of a verb and a noun, for example, "store fish", which may be defined in two aspects:

- **The process** - What the system does
- **The operand** - The object the process acts on

From the mentioned example, the process is "storing", while the operand is "fish". These may be matched in a matrix with other processes and operands, which again identifies alternative ways to perform a given function. In this case, the statement is performed through the farming of the fish (de Weck et al. (2011)).

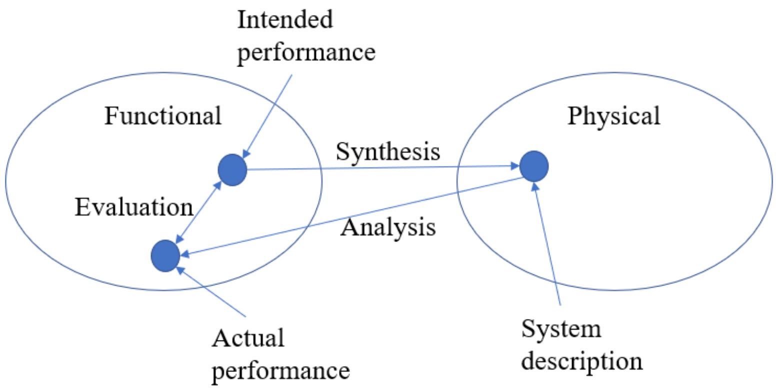

Figure 3.1.2: The process of analysis, synthesis, and evaluation.

Figure 3.1.2 describes the process of creating a system. Functional requirements are implemented in the functional domain as something the stakeholders intend to do. These intended performances are expressed in the form domain as a description of the system. This process is called synthesis. However, there is not certain that no deviation between the functions and form is the case, resulting in a deficiency. Hence, an analysis of the performance is necessary. This is furthermore followed by an evaluation of the comparison between the intended and actual performance. If this deviation is too large, another description of the system is necessary, which again is followed by analysis and evaluation, creating an iterative design process (Asbjørnslett (2020)).

3.1.2 Fundamentals of Technical Systems

Some fundamental concepts in the theory of technical systems are:

- **Functional interrelationships** define function structures, where an overall function is decomposed in several sub-functions that describe what the system should do.
- **Working interrelationships** describes how these functions are realized in terms of the physical laws that govern the system designed.
- **Constructional interrelationships** describe the working structure in further detail, enabling the physical realization of the system.
- **System interrelationships** describe the interaction between the system and its environment, including human interactions with it.

These fundamentals are easily connected to the need, function, form mapping model in Figure 3.1.1. Firstly, the functional interrelationships describe the design in the functional domain. Secondly, the working interrelationships map between function and form. Lastly, the constructional interrelationships detail the design further in the form domain (Pahl et al. (2007)).

3.2 The Systematic Design Process

The systematic design process is a design method proposed in the book *Engineering Design* (Pahl et al. (2007)). The book describes guidelines on good practices regarding how to perform engineering design. The mentioned design process consists of four phases:

1. Task clarification
2. Conceptual design
3. Embodiment design
4. Detail design

These phases are partly overlapping, and iteration forwards and backwards occur. The task clarification is greatly connected to the stakeholder's needs and requirements and includes the objective of the system as well as high-level properties the system should and should not have. By performing this, a list of requirements is obtained. The task clarification is often described by a detailed value proposition (Asbjørnslett (2020)).

The conceptual design is the main function to form mapping stage. The development of functional structures and mapping to physical components or modules is a key element of the stage. Alternative modules can further be combined in alternative ways, giving rise to numerous concept variants to test and evaluate against technical and economical criteria (Asbjørnslett (2020)).

In the third phase, embodiment design, the layout of the system is developed. In the case of a ship, this will be the general arrangement. In this step, it is important to understand what functional and other requirements impact dimensioning and material choices (Asbjørnslett (2020)).

Detail design is the design part that completes the embodiment of technical products with final instructions regarding the shapes, forms, dimensions, and surface properties of all components. This also includes the definite selection of materials, and final scrutiny of production methods operating procedures, and costs (Pahl et al. (2007)).

The first two phases will furthermore be explained, while embodiment and detailed design is excluded. This thesis is performed to create a conceptual design of a floating hatchery for smoltified salmon, and hence, will primarily include the two phases. The first phase includes information about requirement lists (from Chapter 5), while the second phase contains information on function establishment and developing of concepts gathered (from Chapter 6) of the book *Engineering Design* (Pahl et al. (2007)).

3.2.1 Setting Up a Requirement List (Design Specification)

It is important, as early as possible, to clarify the functionality, performance, deadlines, and costs of a product. Additionally, the design and development department must identify the requirements that determine the solution and embodiment, and document these. For this to be achieved, these questions must be answered:

- What are the objectives that the intended solution is expected to satisfy?
- What properties must it have?
- What properties must it not have?

This process results in a requirement list. The procedure for establishing a requirement list is separated into two stages. In the first stage, the obvious requirements are defined and formulated, while the second refines and extends the requirements by the use of special methods. Either, the requirements should be identified as demand or wishes. The demand must, under all circumstances, be fulfilled, while wishes should be taken into consideration whenever possible. Additionally, differentiating between implicit and explicit requirements might assist the process. According to this, specific types of requirements may be formulated:

- **Basic requirements** are always implicit requirements. Their fulfillment is self-evident and pivotal for the customer. An example may be the reduction of energy consumption and operating costs. It is essential for the design and development department to recognize the importance of the implicit requirements, and implement them in the design accordingly.
- **Technical performance requirements** are explicit requirements, and are expressed by the customer. These requirements are often specified precisely. An example might be, a new engine must have a power load of 20 kW, while still weighing less than 50 kg. This is used by the customer as a measure to compare competing products.
- **Attractiveness requirements** are as well implicit requirements. Customers are, typically, not aware of these requirements. However, they are used to differentiate between competing products and must be included in a design process.

3.2.2 Identifying the Essential Problems from the Requirements List

By clarifying a task with the help of a requirement list, the particular level of information is greatly increased. Next, the requirements list concerning the required function and constraints must be analyzed. It is advised that the functional relationship within the requirements list should be formulated explicitly and arranged in order of their importance. The analysis is summed up in the following step-by-step abstractions, which reveal the general aspects and essential problems of the task:

- **Step 1**: Eliminate personal preferences.

- **Step 2**: Omit requirements that have no direct bearing on the function and the essential constraints.
- **Step 3**: Transform quantitative data into qualitative data, and reduce them to essential statements.
- **Step 4**: As far as it is purposeful, generalize the results of the previous step.
- **Step 5**: Formulate the problem in solution-neutral terms.

Depending on either the nature of the task or the sheer size of the list, certain steps may or may not be omitted.

3.2.3 Establishing Functions

As mentioned, the requirements facilitate meeting the overall specifications of the final solution. This is done by establishing an overall function and matching sub-functions, contributing to the converge of an end goal. The link between requirements lists and functions is that the functions, in some cases, are based on information gathered from the requirements list.

An overall function of a system may more or less be complex. Therefore, breaking it down into lower complex sub-functions is necessary. By establishing some kind of function structure, the system's sub-functions may be structured. This facilitates the discovery of solutions, since the general search for them is simplified, as well as solutions to sub-functions can be elaborated separately. Each sub-function may be described by more concrete statements such as physical effects, geometric, and materialistic characteristics.

Establishing a structure for the function of a system is often distinguished in two parts; original and adaptive designs. This is done because of the degree of details used, which is dependant on the novelty regarding the task. For original designs, the basis of a function structure is the requirements list and the abstract formulation of the relevant problem. As for adaptive designs, the starting point is the function structure of the existing solution acquired by analyzing its elements.

Establishing functions should be done with these following points kept in mind:

- Start with the overall function of the system and break down into related sub-functions.
- Through analysis of known systems, derive further variants and optimize solutions from rough estimates of structure or function structure. This is done by breaking down or combining individual sub-functions, changing the arrangement of sub-functions, or moving the boundaries of the system.
- The function arrangement should, ideally, be kept as simple as possible, and encourage the

simple and economic solutions. To this end, it is advised to aim for the combination of functions to obtain an integration of function carriers.

3.2.4 Developing Concepts

The overall search for a solution is based on the function structure, and should, first and foremost, fulfill a technical function. Important characteristics such as performance, space requirements, weights, and task-specific constraints must all be known, at least approximately. More detailed information must be gathered to find a promising combination of the layout. The necessary data are essentially obtained with the assist of such proven methods as:

- Rough calculations based on simplified assumptions.
- Rough sketches or scale drawings of possible layouts, forms, space requirements, etc.
- Preliminary experiments or model tests used to determine the main properties or to obtain approximate quantitative statements about the performance and scope for optimization.
- Construction of models to aid analysis and visualization.
- Analogue modeling and systems simulation, often with the help of computers
- Search for patents and literature to narrow objectives.
- Market research of proposed technologies, materials, etc.

The selection of the concept provides the basis for starting the embodiment design phase. This often indicates a need for changes in organization and personnel due to the nature of the work alters. Hence, making the concept design the overall goal of this thesis, as an embodiment design will be too time-consuming. A large number of variants and decisions have to be reduced to one concept. At this point it must be emphasized that iterations often occur in the steps mentioned in the transition from functions to a concept, making the process a spiraled loop.

Chapter 4

Aspects of Current Salmon Production

The function of this chapter is to give the reader a sufficient understanding of the knowledge regarding the current production of salmon. This will include recirculating aquaculture system, smolt production, production strategies, and laws and regulations for aquaculture. The presented parts are described thoroughly as they establish needs and requirements of the design.

4.1 Recirculating Aquaculture System

This section will introduce the concept of recirculating aquaculture system. It will first present what it is, how it is used, and the benefits gained by using it. Secondly, the main components that make up the system will be described.

4.1.1 Description

Recirculating aquaculture system (RAS) is a system where the outlet water from fish tanks is used in another iteration instead of being pumped to the sea. The outlet water is cleaned and re-used, which means that new water amount can be reduced. By using RAS, the production of salmon smolt may happen at places where the amount of water is a limiting factor, for example at the Faroe Islands. Another use may be increasing in an already existing production method without the use of extra water resources. Currently, RAS is utilized on salmon hatcheries before the fish is moved to the ocean, and at the moment, most of the hatcheries being built, are utilizing RAS. At some places, RAS is even used for the complete salmon production, from egg to slaughter size.

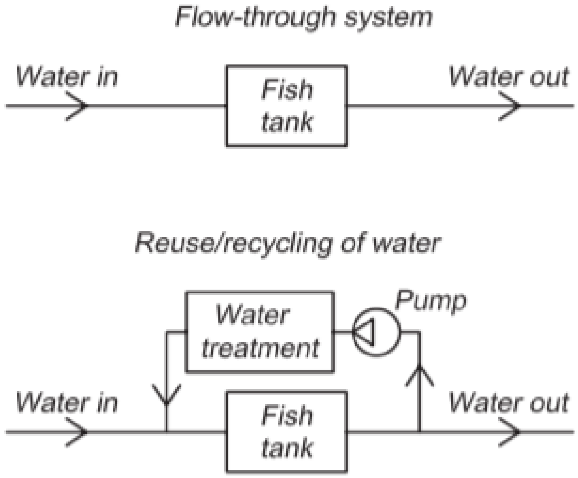

Figure 4.1.1: A simplification of a RAS facility compared to a traditional one (Lekang (2007)).

The salmon is brought to the facility as eggs. Initially, they are eggs kept in tubs and containers where they are continually affected by a flow of freshwater current, which is necessary to imitate the flow of natural rivers where salmon is naturally hatched to provide oxygen. Traditionally, direct flow from lakes, as shown in Figure 4.1.1, has been used for this simulation of a river, but RAS is presently preferred. The main benefits for RAS instead of flow is a continuous, high temperature and better control of what is physically entering the tanks where salmon juveniles are grown. A high temperature is beneficial for the growth of the salmon, as a higher temperature increases the appetite, which again leads to less time in the facility and further an increased capacity (Thodesen et al. (1999)). Still, a small amount of water will be excessive after use and is cleaned and disposed of, while an equal amount of new water is added to keep the circuit running. This will also reduce the environmental impact of the site compared to traditional flow sites where excessive wastewater is simply disposed of. Instead, RAS collects the wastes from tanks and may recycle it. For example, phosphorus, an element necessary for all life to grow, is wasted in the faeces of the fish, and end up on the seabed in the traditional production. It is, in RAS, collected and may be re-used in another format. Additionally, the inlet water must in traditional flow facilities, in the cold periods of the year, be heated to preferred levels, which is an energy-demanding task. This is not necessary for RAS, since the same water is used continually, and has controlled temperature throughout the process. However, RAS is not a perfect process, and requires high investment and operating costs, as the facilities are often large and complex, as seen in Figure 4.1.2.

Figure 4.1.2: Lerøy's RAS-controlled hatchery in Belsvika, which for a brief time was the world's largest land-based aquaculture facility (Gemini (2017)).

4.1.2 Components of RAS

The process of RAS starts with fresh, cleaned water being filled into tanks. However, with RAS it is not the intake of water that is the most important factor, it is what happens with the water after the fish has used it. The salmon takes up oxygen through the gills from the water and thus reduce the oxygen concentration. Salmon has optimum growth the higher the concentration of oxygen becomes, up to a certain point, and should preferably be at 100 % saturation. Besides, the production of faeces and feed will pollute the water quality and also need continuous removal.

Particle Removal

Used water from the fish tanks flows through pipes into the first line of cleaning; particle removal. This is usually done by a mechanical filter such as a drum filter, screens, or a swirl separator. These filters are simple and effective for the large particles, capable to filter particles down to 15 - 200 μM (Ali (2013)). A drum filter is a circular, rotating filter where the water flows through, as seen in Figure 4.1.3. It filters by having lateral walls made of netting with selected mesh distance that stops the particles. The swirl separator uses the principle that particles are denser than water, but also centrifugal forces are added to increase the difference (Davidson and Summerfelt (2005)). This can be illustrated by rotating a cup filled with water, and observe that particles are hurled towards the edges. In a swirl separator, the water enters along the top periphery of a circular tank. The particles are pushed towards the edges and sink to the bottom of the tank. Meanwhile, the water is drained out from the centre of the tank. An advantage with the swirl separator is the simplicity in construction and low price. However, it requires uniform water flow for optimal efficiency (Lekang (2007)).

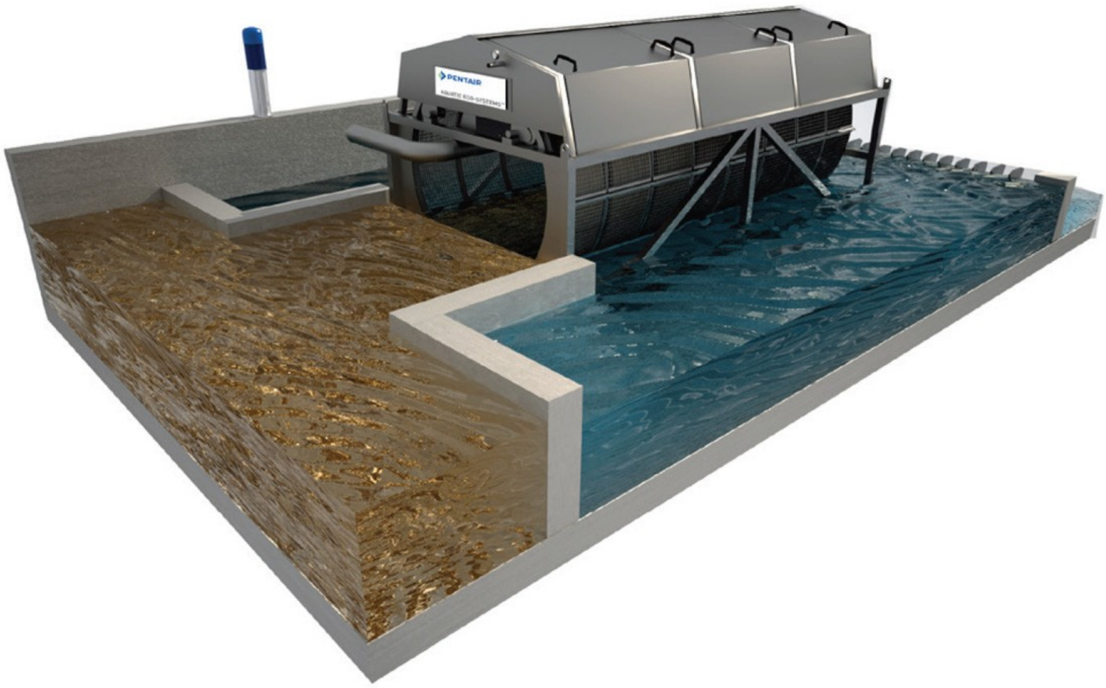

Figure 4.1.3: A conventional drum filter currently used in RAS. Dirty and clean water is indicated by the colour of the water (Aquaponic (2018)).

Biofilter

The next in line is biofilter. The biofilter consists of actively growing bacteria attached to plastic figurines with high surface area, seen in Figure 4.1.4. The high surface area makes more bacteria capable to grow on each figurine, increasing the efficiency. Just like the fish, the bacteria is dependant on oxygen to live and function. The bacteria decompose organic waste products, but also convert ammonia to nitrite and nitrite to nitrate. Ammonia is a byproduct of protein digestion, and it is estimated that 2.2 kg ammonia is produced from 100 kg feed (Masser et al. (1992)). Since both ammonia and nitrite are toxic to fish, while nitrate is not, the existence of the bacteria is necessary for the life of salmon in containers that use RAS. The process of transforming ammonia to nitrite releases H^+-ions to the water, leading to acidification and reduction of pH. This will have to be taken care of at a later stage. Additionally, the bacterial activity will release energy to the water, which assists in keeping the water temperature at the high levels (Bregnballe (2015)). In most facilities with RAS, ammonia is removed by fixed- or moving bed biofilters, or a combination of both. This describes how the bacteria actively function in the water, either by having water pass through an area of fixed figurines or in a pool where the figurines continually move around.

Figure 4.1.4: The plastic figurines used in fixed- and moving bed biofilters.

Disinfection

High degrees of water re-use will lead to accumulation in bacteria amount. Hence, it is important to have some sort of disinfection equipped in the circuit, for instance, UV-irradiation. Ultraviolet light is electromagnetic radiation with a wavelength of 1-400 nanometer, and thus located at the lower end of the spectrum of what the human eye can see. UV light damages the genetic material in micro-organism by attacking the chains, resulting in inactivation and death. The UV light's ability to inactivate and destroy micro-organisms varies on several factors, for instance, wavelength, where the optimum length is 250 - 270 nanometer, as well as the age of lamp, cleanliness, and how well the light passes through the given water characteristics. Usually, the UV lamps are placed in separate chambers where the water flows through, equipped with reflectors or turbulence discs to irradiate the water flow at a more efficient rate (Lekang (2007)).

Instead of UV light, or beside, ozone (O_3) can be equipped as a barrier of disinfection. Ozone is a very strong oxygenating agent and is highly toxic for all kinds of lifeforms. Ozone acts by damaging nucleic acids and cell membranes of organisms, and thus breaking long-chain molecules down unto simpler forms that are furthermore degraded in the biological filter, which inactivates micro-organisms. Additionally, ozone has another effect for use in RAS, as it reduces the amount of NH_3 and NO_2 (Tango and Gagnon (2003)). This is observed as improving the water quality in re-use systems, and may thus be preferred over other disinfection methods. Ozone also eliminates the yellow/brown water coloration which builds up in re-use systems. It is though important that the ozone treatment comes after all particles have been removed, otherwise, will the ozone be used to oxidize the particles (Lekang (2007)). When installing the ozone treatment is it important to ensure good mixing of the gas and water for it to be efficient. This mixing is done by a venturi and is quite commonly used.

pH-Control

High degrees of re-used water will lead to a drop in pH. The biofilters release H^+-ions to the water, while CO_2 is produced by the fish. This creates H_2CO_3, or in general terms carbon acid, starting acidification in the water, and a drop in pH. A pH-value below 4,5 is dangerous for fish, while a value between 7 and 8 is preferred. Controlling the pH is necessary and can be done by introducing buffers, bases, and acids according to the given pH-value in tanks (Lekang (2007)). An example of controlling the pH is to add calcium hydroxide ($Ca(OH)_2$). Calcium hydroxide releases OH^- when in contact with water, raising the pH of the water to a preferred level.

Degassing

As mentioned, the fish release CO_2 through the gills, and this may be accumulated if high amounts of re-used water are utilized. This is relevant for nitrogen (N_2) as well. High amounts of both CO_2 and nitrogen is dangerous or fatal for the fish, and thus must be removed (degassing). Degassing is carried out by aeration of the water, referred to as stripping. Aeration is accomplished by pumping air into the water, creating turbulence between the air bubbles and water, and drives out the gasses (Bregnballe (2015)).

Oxygenation

The final stage before the water can be recirculated into the tanks is oxygenation, the most important part. The main reason for supplying fresh water into the tank is to provide the fish oxygen, ensuring the optimum growth of the fish. Oxygenation function by pumping air through an air stone or a similar device, which creates small bubbles in the water and results in a higher surface area where oxygen can dissolve into water, or by using a high-pressure pump to mix oxygen into the water. After the water has been oxygenated and approaches 100 % saturation, pure oxygen can be added to further increase the saturation, called supersaturation. This part determines how much of the water is recirculated for each iteration, and how much fresh water must be added. Depending on the equipment, up to 99.9 % of water may be re-used, illustrated in Figure 4.1.5 and Figure 4.1.6.

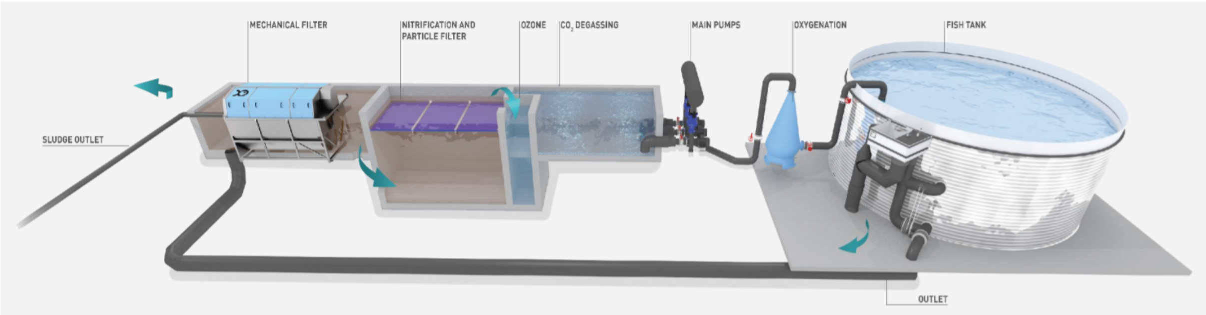

Figure 4.1.5: An overview of a design concept of RAS provided by AKVA group Land Based AS. The system recycles 100 % of the water each hour and reuses 99 % of the water input for the next iteration. This means that the complete system water will be exchanged for every 4th day.

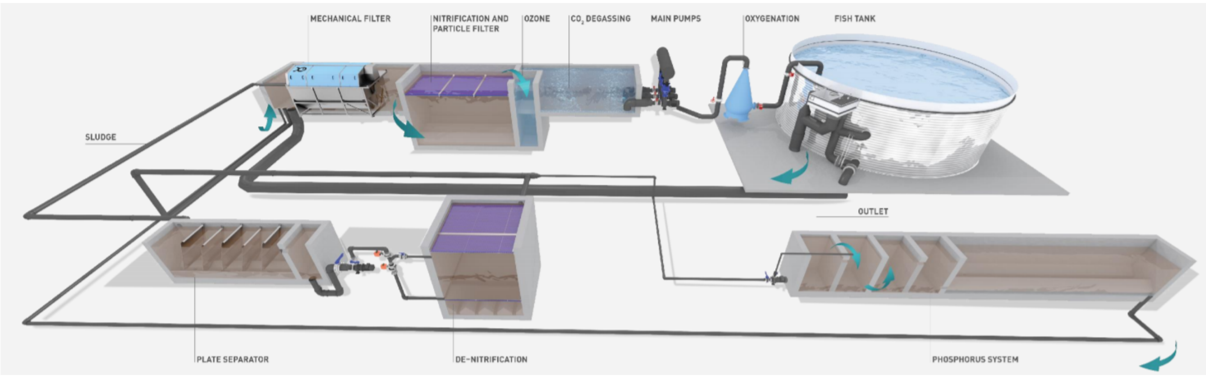

Figure 4.1.6: An overview of a design concept of RAS provided by AKVA group Land Based AS. The system recycles 100 % of the water each hour and reuses 99.9 % of the water input for the next iteration. The system water will completely be exchanged for every 40th day.

Centralized Principle

Most re-use systems utilize the centralized principle, meaning that outlet water from all tanks is collected in a common pipeline that leads to a centrally placed water treatment system with corresponding components. When finished treated, the water is returned to the tanks through a common inlet pipe, and ready to be utilized anew. The addition of new water or removal of excess is also performed here, either on a continuous or batch basis. Such a centralized principle has advantages as more investment may be put into the water treatment components since it is capable of handling several tanks and a greater volume of fish. However, it has a disadvantage regarding occurring of infection in the tanks, as they are all connected to the same pipeline system. This will, however, most likely be removed in the disinfection system (Lekang (2007)).

Problems

With RAS there may occur certain problems that must be avoided for production to exist. One of these problems is the occurrence of H_2S in the water. H_2S is a toxic gas for the fish and is produced by bacteria's decomposing of rotting sludge at the bottom of tanks or pockets in the system where the water flow is stagnant. Even in small doses of sludge, production of H_2S can become lethal for the fish. To produce the gas, sulphate must be introduced to the system. Seawater contains approximately 1000 times the amount of sulphate than freshwater, resulting in producers that fear to implement seawater in land-based aquaculture facilities (NIVA (2019)). Anyway, it is pivotal for all of the excess sludge to be removed at all times.

Layout

The description is not the exact solution for what a RAS facility should look like, whereas this is more of a description of different components in RAS. The layout of such a site depends a lot on preference since many components exist for the same function. However, some components are pivotal for the functionality of a RAS facility and must be equipped. Figure 4.1.7 illustrates a hatchery that utilizes RAS.

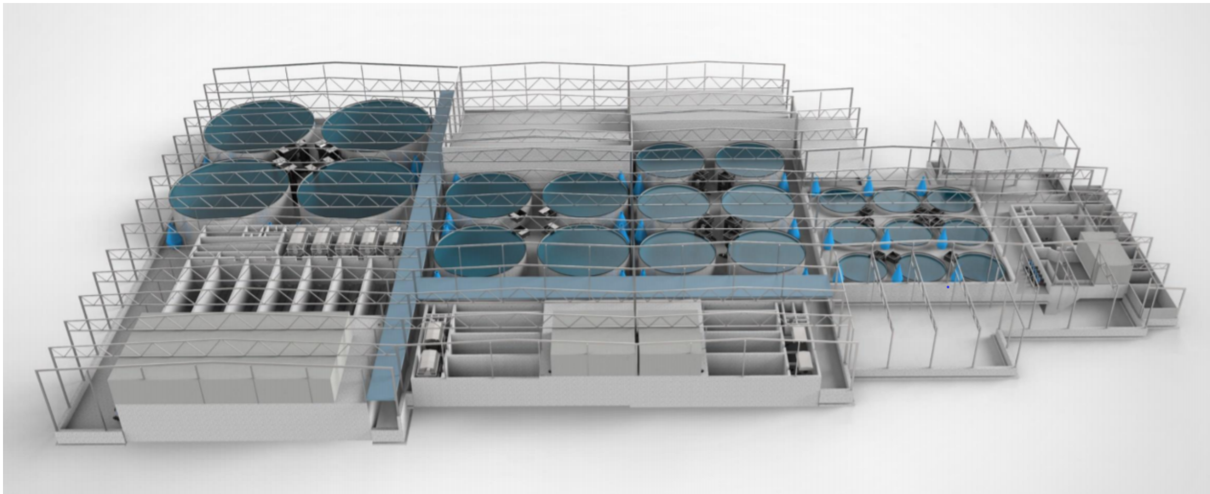

Figure 4.1.7: A layout overview of a hatchery that utilizes RAS provided by AKVA gruop Land Based AS. Tanks of different sizes are separated from each other, and have their own RAS section shown on the bottom of the figure.

4.2 Salmon Smolt Production

As mentioned in Section 4.1, the first part of the life of salmon is happening in hatcheries. The hatcheries are receiving fertilized eggs that hatch after approximately 500 day-degrees after fertilizing if the eggs have been stored in favorable conditions (AquaGen (2008)). By knowing the certain hatching condition, hatcheries may control the actual time of hatching. This will allow the process to delay or speed up to a more appropriate time, and optimize the growth operation throughout a period. After hatching the fish is transferred to bigger tanks, where they utilize nourishment from a sack on the belly, shown in Figure 4.2.1. When the sack is consumed, the juvenile fish need nourishment in another way. An advantage by growing salmon is that it is naturally carnivore, and must be fed components from fish from the start of the growing process.

This means it is capable of eating dry feed at an early stage. The salmon is transferred to other and larger tanks as it continues to grow. When the salmon reaches a certain size every individual is vaccinated to protect against a few of the known diseases.

Figure 4.2.1: Salmon fry (laks.no (2020)).

Salmon is an anadromous species, meaning it is capable of living in both fresh and seawater through a process called smoltification. The process changes behaviour, look, and physiology which makes a young salmon capable of living and growing in seawater. When ready, this process happens naturally a few weeks in the spring and is triggered by the increasing amount of sunlight. Hatcheries have several generations with salmon with different age and must be able to trigger the smoltification to assert continuous growth, and not be dependant on the cycles of the year alone. This is done by controlling the lighting where the tanks are located or adding a certain salt additive in the feed and thus assisting the juveniles to start the smoltification process. Typically, the salmon is approximately 100 grams at the end of the production and is ready to be transferred into cages in the sea, where the major on-growing of the fish is happening. The salmon is at this stage referred to as post-smolt. In hatcheries, post-smolt will still live and grow in tubs where water is supplied, but after the smoltification, the fish will prefer saltwater to freshwater. This means that salt must be added, or by adding a portion of seawater into the tanks. However, this amount of salt is preferred lower, as the salt content of 12 parts per thousand resulted in better welfare and growth than normal seawater at 34 parts per thousand (CtrlAQUA (2017)).

Figure 4.2.2: A traditional layout of a conventional hatchery that uses flow-through (iLaks (2017)).

The growth of post-smolt is the most exposed period during traditional growth as this stage has the highest mortality rate of each generation. The fish is most prone to diseases at a smaller size, and it would benefit generations to grow bigger before transferring to the sea. Therefore, post-smolt hatcheries are gaining more reputation as a new step for salmon production. Production of post-smolt would grow the salmon to a point where it is more robust and viable than a short period after smoltification, for example at 500 or 1000 grams instead of 100 grams. The Faroe Islands are utilizing such a post-smolt production where the salmon has been grown up to 250 grams. This has resulted in significantly lower mortality at spawn (Nofima (2013)).

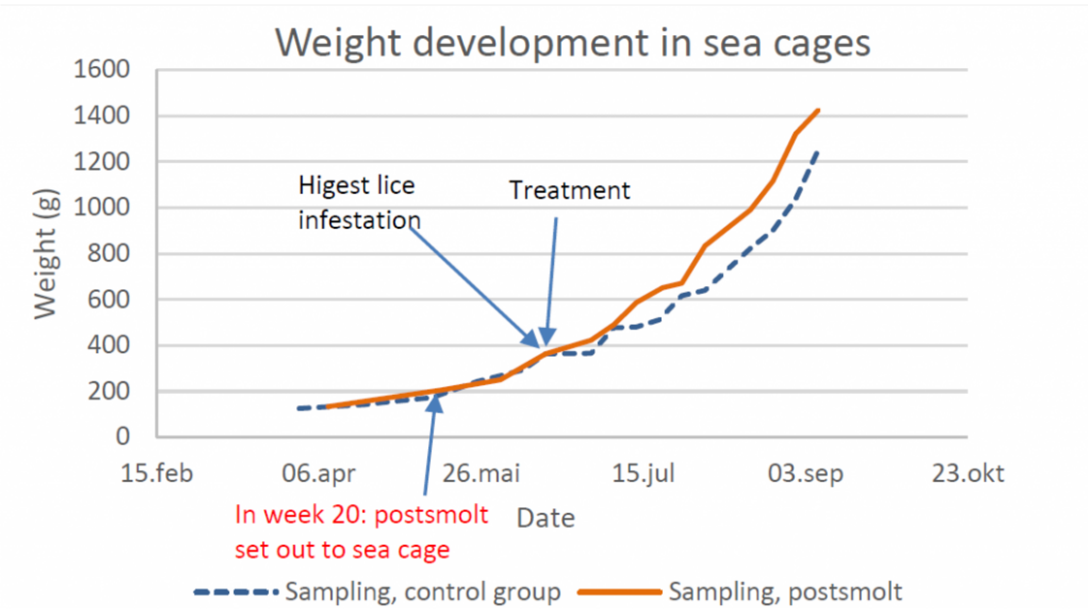

Figure 4.2.3: A study regarding the growth of post-smolt compared to traditional production carried out by Lerøy and Nofima (Holan and Kolarevic (2015)).

Figure 4.2.3 shows a comparison of growth between smoltified salmon set out to sea in a traditional manner versus smoltified salmon being kept in post-smolt facilities for another 5 weeks before this batch also was set out to sea. The two groups were quickly infested by lice, and treatment was deemed necessary. The treatment resulted in a stagnation of growth for the traditionally produced salmon, while the post-smolt was not affected to the same degree. This difference in growth after treatment meant that traditionally produced salmon and post-smolt had an average weight of respectively 1253 and 1426 grams. Additionally, mortality was at 30 and 100 days 10 and 4 times higher for the traditionally produced salmon compared to the post-smolt. At last, the study concludes that a longer period of production of post-smolt (up to 300 - 400 grams) may have given an even better result (Holan and Kolarevic (2015)).

By having a larger smolt produced in hatcheries, the on-growing phase at sea will be reduced. This means the total period where the salmon is prone to infected diseases, salmon lice, and escape is also reduced from 13-20 months to 10-11 months. If larger fish is set out into the sea, production per farm may increase, as the growth can be optimized. For example, if production lasts for 10 months, the fish may be kept in the sea while the water temperature is at its highest, and fallowed at its lowest. Additionally, ten months of production with two months fallowing will have a larger fraction of fallow time than twenty and two months, and would benefit the overall area. Fallowing means that every farm needs to remove all nets and disinfect the cages after the fish have been slaughtered. The nets must be cleaned and disinfected before they can be used again. This is done to prevent the spreading of diseases as Infectious salmon anemia (ISA) and Viral hemorrhagic septicemia (VHS), as well as lice. Lastly, when the fish already is to 1 kg, net cages with small meshes will be deemed unnecessary, and changing of cages, with all expenses and extra personnel, is avoided (Nofima (2013)).

4.3 Production Strategies

This section will describe the production strategies currently utilized for salmon production. This includes a traditional production plan along with the newer plan regarding post-smolt.

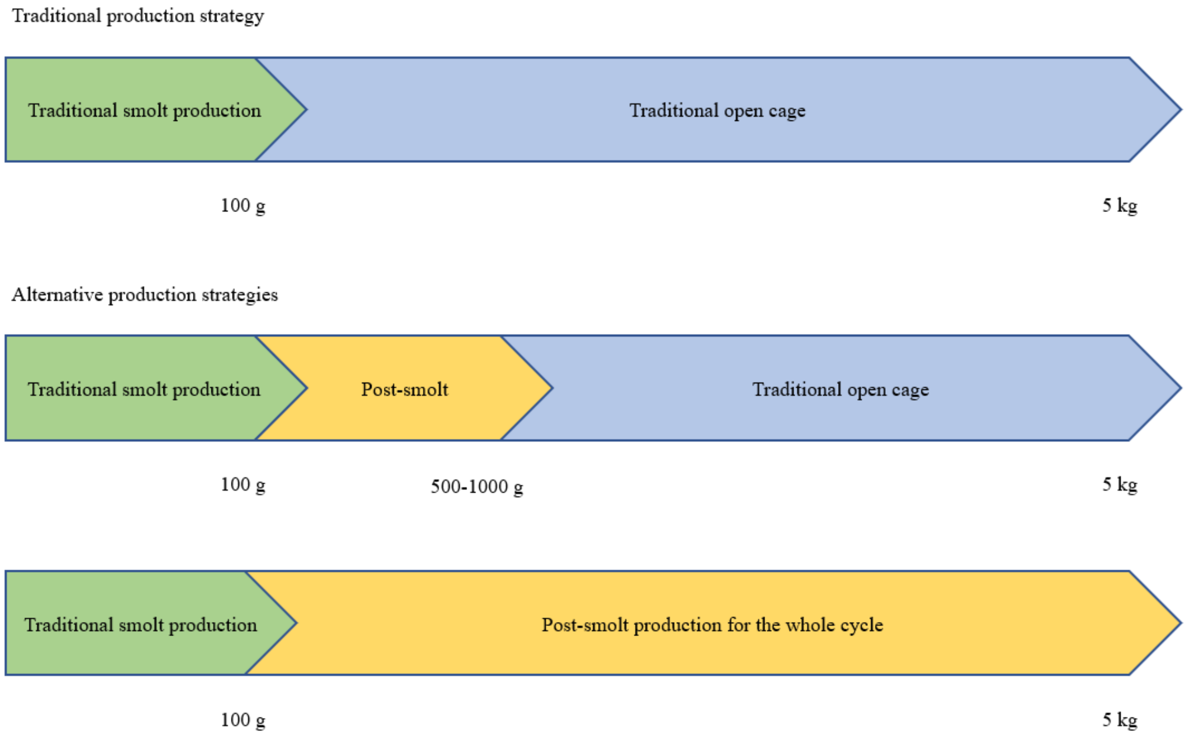

Figure 4.3.1: Production strategies of Atlantic salmon

Figure 4.3.1 illustrates the traditional production strategy and two alternative strategies that can be performed with the use of the land-based and the floating hatchery. The first alternative production strategy is mentioned in Section 4.2, and reduces the time window where the salmon is prone to lice, diseases, and escape. The salmon is physically larger and stronger, making it more robust and sturdy, which helps during pumping from well-boat to cage. This will also reduce overall production time and lead to economic benefits. The design process of the thesis will be based on this production strategy.

The second alternative strategy involves keeping the salmon in the floating hatchery for the entire on-growing phase. This strategy is currently used in Poland and Dubai with land-based facilities. The objective of the thesis is to create a standardized design, making it possible to use a general concept in several ways. This means the relevant production strategy may work for the hatchery, but will not be taken into consideration for the remaining of the thesis.

4.4 Laws and Regulations

The Norwegian national regulation for certification and inspection of regular fish farms is named NYTEK. It applies to all shareholders who farm fish in floating aquaculture systems in the Norwegian area. Its purpose is to prevent fish from escaping by ensuring adequate technical standards for each facility. NYTEK points to technical standards as NS9415, for certain technical requirements. NS9415 consists of requirements for the site survey, risk analysis, design, dimensioning, production, installation, and operation of a fish farm (Norsk Standard (2009)). However, these criteria are meant for net cages, and not for a floating hatchery. A floating hatchery may likely include standards from NS9416 as well, technical standards for land-based aquaculture systems. Its demands span risk assessment, engineering, embodiment, operation, user manual, and product data-sheet. It is applied to assist a reduction of escapes and make the general operation safer and easier (standard.no (2013)). The floating hatchery will not likely make use of requirements from only one of the standards, as it would be more probable to use interpolation of both sets.

However, this creates a new problem; will the amount of produced salmon for a concession be determined by maximum allowed biomass as in sea-based production or by the number of individuals as land-based production? Besides, sea-based production may allow a maximum density of 25 kg salmon per cubic meter, while land-based have an exemption to avoid this demand (Fiskeridepartementet (2015)). The limitations for sea-based production are based on location, environmental conditions, escape limitations, and ensuring sufficient values of oxygen. These factors, along with several others (no lice, no diseases, waste), are partly or fully avoided by producing salmon on land or by land-based facilities at sea. Hence, production at the floating hatchery should be allowed to utilize the laws and regulations for land-based production.

Additionally, some other laws must be included when deciding locations where the hatchery might be found. They are as followed:

- Water intake from freshwater to hatchery and cultivation fish must be treated and controlled with regards to demands stipulated in regulation the 20. February 1997 nr. 192 about disinfection of intake water and wastewater from aqua-cultural production if the entry of anadromous fish to the water source, other aqua-cultural production in a source, or waste from production to source (Lovdata (2008a)).
- The hatchery must be equipped with a device that prevents the escape of fish through wastewater (Lovdata (2001)).
- One concession may be given for a production capacity of 2,5 million seaworthy fish per year (Lovdata (2001)).
- Aquaculture facilities with a production of anadromous and marine fish in the sea, along

with new slaughterhouses and processing plants for marine fish, must be located at least 5 km from national salmon rivers. This is also relevant for hatcheries with marine species in the sea (Lovdata (2009)).

Chapter 5

Functions the System must Facilitate

This chapter presents the functions the hatchery must facilitate. The overall chapter is divided into a function decomposition and a description of sub-functions. It is carried out to map functions, and thus increasing the understanding of how to design the system, and how to discover what design solutions are most beneficial for the standardized design. Lastly, a new kind of inlet water system is introduced. The traditional system will be explained briefly, before an alternative method is established.

5.1 Function Decomposition

The function decomposition is based on the theory elaborated in Chapter 3. This decomposition is done on the basis of the needs and requirements necessary for the growth of salmon on a floating structure to be realized. The thesis attempts to obtain a solution by establishing functions that are favourable to the end design. Establishing adequate functions, while keeping the number of sub-functions at a relatively low level, is a necessity for the design process. This is done since several sub-functions are undesirable as input for the analyzes conducted in the next chapter. The listed sub-functions are based on information gathered from the literature review regarding RAS and smolt production, studying existing hatcheries, and conversations with people working within the relevant areas.

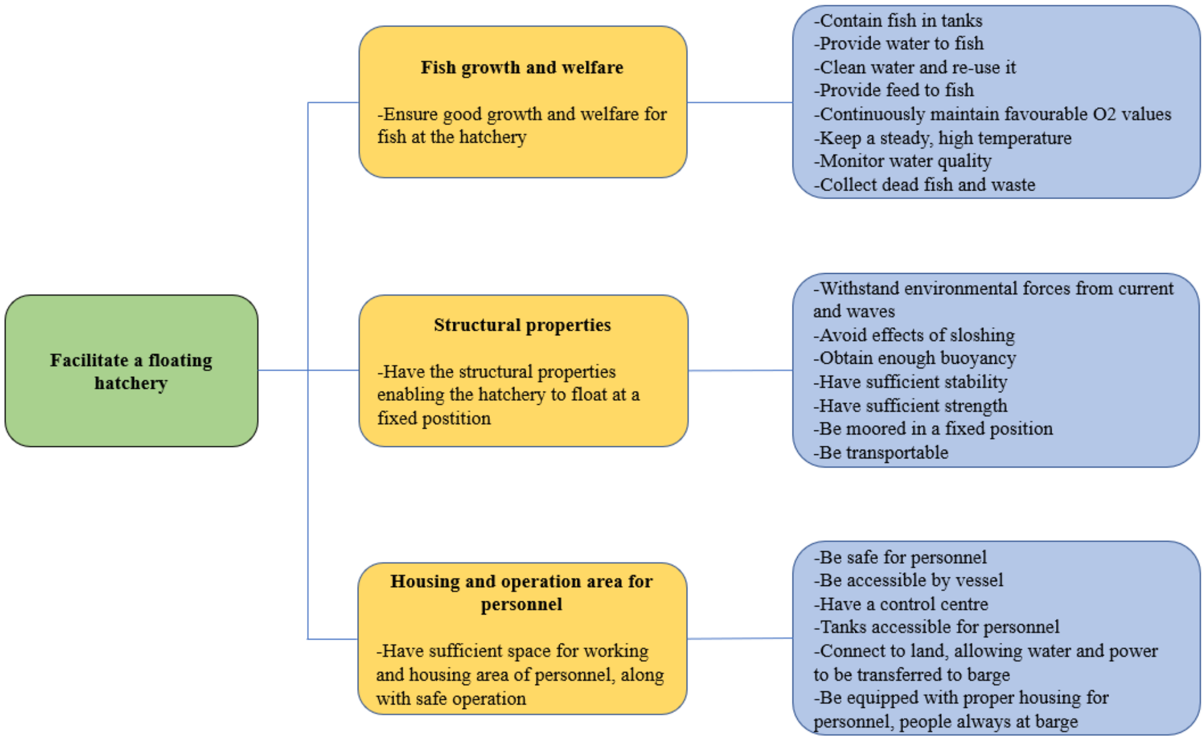

Figure 5.1.1: Function tree of the floating hatchery

Figure 5.1.1 illustrates the necessary established functions for the floating hatchery. The overall function of the tree is "Facilitate a floating hatchery", which is furthermore divided into the three sub-functions "Fish growth and welfare", "Structural properties", and "Housing and operation area for personnel". "Fish growth and welfare" covers the biological aspects of the production, ensuring sufficient biomass production. "Structural properties" regards the general design and what affects the overall structure. "Housing and operation area of personnel" describes the daily operation and the spacing of the working area including the safety of personnel.

These sub-functions will be thoroughly described in the following sections. The focus is to generally describe what is happening at the structure, and to explain why these functions must be solved to approach a design.

5.2 Fish Growth and Welfare

In this section, the sub-functions regarding "Fish growth and welfare" will be described.

5.2.1 Contain Fish in Tanks

The fish will, most of the time, be located in tanks. Circular tanks are the norm, but octagonal shapes are also used. It is found that both circular and octagonal shapes have a uniform flow, and similar water rotational velocity (Gorle et al. (2018)). An octagonal shape may, however, utilize the available area in a better manner than circular shapes. Tank diameter and depth depend on the given size of the salmon at a certain point in traditional hatcheries, but for this thesis, all tanks will remain the same size. Additionally, the quantity of salmon will determine the size of the tanks. The tanks must also have high enough walls to prevent the salmon from jumping out of the tanks. All tanks are equipped with an internal liner made from hard polythene, a material that is water repellent, and contribute to keeping the tanks clean (AKVA group (2018)).

It is easy to say that the design will completely neglect the escape of fish, but in reality, this is impossible. Firstly, salmon leaps often above the surface. Hence, the tanks must be equipped to proper walls extending a certain height over the water surface. The tanks must be equipped with a filter preventing the fish from exiting through the outlet water pipe, as this pipe a system that distributes water to another iteration of cleaning or a pipe exiting the structure. Complete neglect of escape can not be guaranteed, but is indeed something to prevent at all costs.

5.2.2 Provide Water to Fish

Inlet of water must happen at a continuous rate, where the same volume of water enters and leaves the tanks. As a rule of thumb, the water inside the tanks should be replaced once every hour. Clean water is pumped into the tanks and is drained in the bottom. This way, when the salmon has reached the wished size, the outlet pipes drains the whole tanks, salmon included. The pipe leads, in the end, to the hatchery's outlet pipe, which well boats may directly connect onto, where it is transported to traditional cages at sea. The inlet water enters along the periphery of the tub, which gives the water a circulating flow all throughout the water column. This is necessary for the fish, as it needs to be in a continuous motion to grow optimally. It is proven that individuals affected by higher flow velocity have faster growth (Forskning.no (2020)). Additionally, it is important that the water quality is as best as possible to ensure optimum growth.

5.2.3 Clean Water and Re-use it

The cleaning process of used water has thoroughly been described in Section 4.1. When cleaned, the water is pumped towards the tanks to start a new iteration. At this stage, a fraction of the water is disposed, while an equal fraction is acquired to maintain the same amount of water in the overall system.

5.2.4 Provide Feed to Fish

All aquaculture facilities that produce fish must be equipped with a proper option to provide feed, and the floating hatchery is no exception. Feed must be stored in separate, dry silos with hatches at the top (for filling) and a selector (for draining) at the bottom. The hatchery may be growing salmon of different generations, meaning that the size of the feed must be adapted to each generation. This will require that the feed must be stored in separate silos. Alternatively, the hatchery grows salmon of the same generation, eliminating the necessity for a feed of different sizes. The feed exits the silos via tubes driven by compressed air before it arrives at an elector, which distributes the feed to a certain tank. The feed may not be distributed with too high velocities, as this may crush the feed pellets when hitting curves in the tube. Crushed feed will be too small for the salmon, and will not make use of it.

An advantage with feeding systems on hatcheries and generally land-based production are the tubes leading the feed to tanks as these are metal tubes built in advance. In sea-based production, the feed is transported from feeding barge to each cage via plastic tubes. The tubes must be flexible to avoid breaking due to the motions of cages, barge, and sea, and hence is plastic preferred. However, these tubes are worn down by feed at high velocity, which scrapes off some of the plastic. This is then spewed out into the cages, and thus release microplastic into the sea. This will not be the case when feeding salmon at the floating hatchery.

5.2.5 Continuously Maintaining Favorable O_2 Values

Maintaining a sufficient amount of dissolved oxygen in the water is pivotal for biomass production. The reason is that oxygen is the main limiting factor regarding the metabolism and food conversion of the fish. High levels of oxygen saturation maintain a high appetite, while oxygen levels that are too low decrease the appetite. This again leads to a reduction in growth rate. The appetite decreases gradually with the oxygen saturation, until levels where the fish experience respiratory stress, which may have fatal consequences. As for the oxygen consumption, it is dependant on both body weight and water temperature. At higher temperatures, the salmon need a higher concentration of oxygen than at lower temperature levels. Additionally, the specific oxygen consumption is lower the bigger the fish is. This means that 10 kg of 5 fishes needs less oxygen than 10 kg of 10 fishes (Remen et al. (2016)).

Maintaining high levels of oxygen saturation is one of the advantages RAS offer. Tanks are continually monitored, making sure that the favorable conditions may be applied at all times.

5.2.6 Keep a Steady, High Temperature

Water temperature is one of the most decisive parameters for aquaculture production, and highly impacts the growth rate of the fish, up to a certain point. Atlantic salmon is a cold-blooded animal, meaning the water's temperature is used for the regulation of its body temperature (Bjørnstad (2014)). The optimal temperature for the growth of Atlantic salmon is at 8-14 °C, illustrated as the shaded area in Figure 5.2.1.

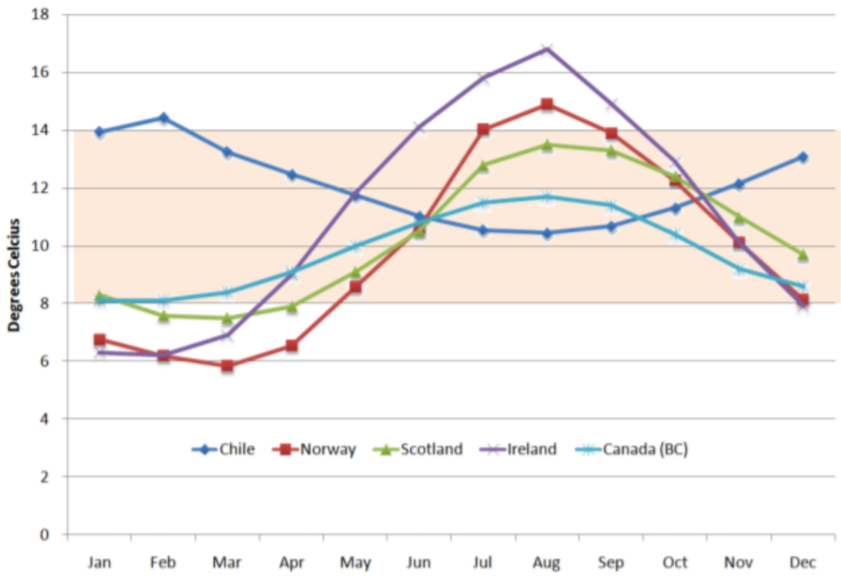

Figure 5.2.1: Graph illustrating optimum temperature and temperatures in countries producing Atlantic salmon (Marine Harvest (2018)).

In traditional production, the sea temperature cycles through the year, making the growth vary due to the calendar as well. However, this is avoided in production that utilizes RAS. As mentioned in Section 4.1, the biofilters release energy into the water, consistently providing heat to the overall system. This means that even though some temperature leaks out to the ambience, the water may oversee a steady, high, and beneficial temperature. Having a steady temperature of 12-14 °C in December to April will assist the growth immensely instead of producing in temperatures as cold as 6 °C. However, during the summer there might be necessary to cool the water, due to temperatures exceeding the beneficial values.

5.2.7 Monitor Water Quality

The cleansing of the water must be deemed to fulfill the "Water quality" requirements set by *Akvakulturforskriften*. Water quality is defined as:

“The sustainability of the water is based off the necessities of the fish, whereas the water’s chemical (oxygen, carbon dioxide, totalammonium, nitrogen, aluminum, etc.), physical (temperature, turbulence, salinity, and power), and hygienic (pollutants as feed, faeces, and fouling) quality (Lovdata (2008b)).”

Furthermore, the regulation states:

“Water amount, water quality, water flow, and velocity ought to be such as the fish has sufficient living conditions, based off the species, age, stage of development, weight, and physiological and behavioral necessities.”

"Water quality and interactions between the different water parameters ought to be surveilled based on the risk of bad fish welfare. Saturation of oxygen, temperature, and other water parameters that may have significant importance for the fish, ought to be measured systematically."

An advantage with RAS is the possibility to control water parameters in a simpler manner than in traditional operation at sea. These parameters are continually surveilled in hatcheries, asserting that no unforeseen events may jeopardize the fish.

5.2.8 Collect Dead Fish and Waste

For a favorable tank environment, dead fish and waste must be removed as quickly as possible. Dead fish and waste fall to the tank bottom, where it will be collected and removed. This may be done by equipping and adjustable central tube that leads out of the tank and into a small tub mounted on the tank exterior. This tube is continually able to suck up excess feed, faeces, and dead fish (AKVA group (2018)).

5.3 Structural Properties

This section will contain the structural properties and effects of the structure as a whole.

5.3.1 Withstanding Environmental Force from Current and Waves

The hatchery will be located at sea, and it hence is necessary to describe the theory and methodology to carry out the calculation of hydrodynamic forces from current and waves on the system. Current and waves will contribute to the largest forces, but wind forces will also contribute to effects as the structure will have sections above the surface as well. A floating hatchery will, therefore, be suspected to current, incident regular waves, and wind effects illustrated in Figure 5.3.1.

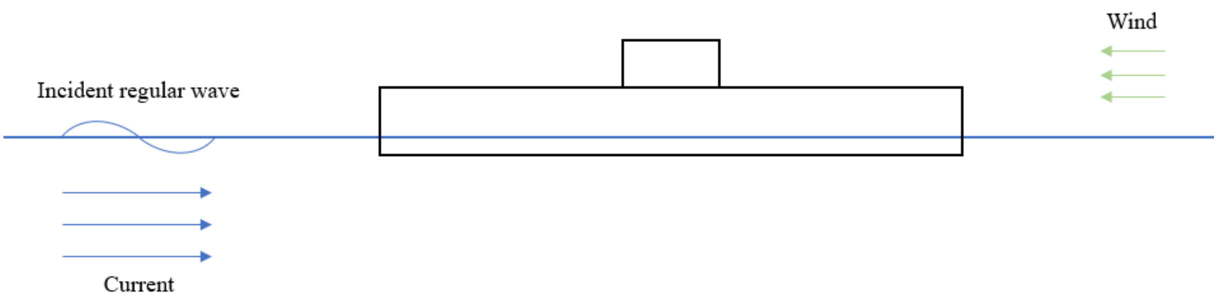

Figure 5.3.1: A floating hatchery suspected to current, waves, and wind

The structure will have quite large areas where suspected forces may affect the structure. Solid walls will also contribute to no deformation, hence no distribution of forces. The system mass will become large, due to the sheer weight of the structure, but also due to the amount of water added in the tanks and within the RAS sections. Values regarding these parameters will come into hand in the next chapter when the designing starts.

First order wave loads

The first order loads are loads that oscillate motions in six degrees of freedom; surge (η_1), sway (η_2), heave (η_3), roll (η_4), pitch (η_5), and yaw (η_6). When these are calculated, the velocity potential only includes first order terms, thus neglecting all terms of higher order (Faltinsen (1990a)). Estimation of these forces requires the use of simplifications and assumptions.

The initial simplification is that linear wave theory is used. By superposing results from regular waves, irregular waves results are obtained. The regular waves have a sinusoidal shape, and may be described by the parameters presented in Figure 5.3.2.

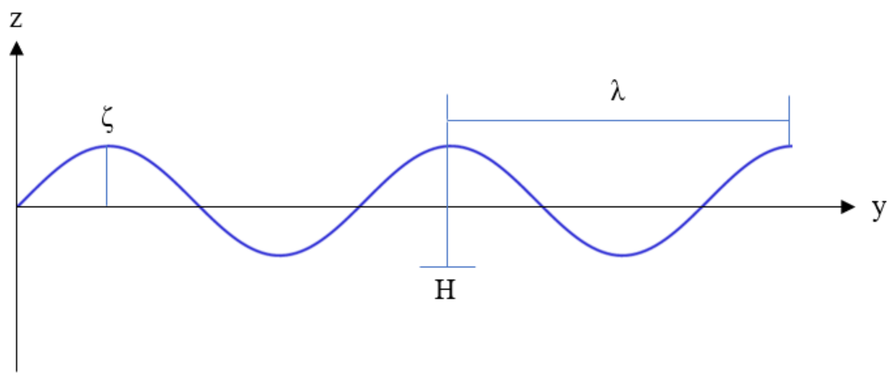

Figure 5.3.2: Parameters for regular waves

For linear wave theory to be applied, the potential flow must first be assumed. Potential flow describes the velocity field as a gradient of a scalar function (velocity potential). The assumption requires the water to be incompressible, inviscid, and the flow to be irrotational. Additionally, a steady-state condition must be assumed. This means that no transient effects due to initial conditions are included. The linear dynamic motions and loads affecting the structure are, hence, harmonically oscillating at the same frequency as the waves that excite the structure (Faltinsen (1990a)).

Deriving the velocity potential for deepwater waves takes the mentioned assumptions into consideration. Additionally, the boundary conditions presented in Figure 5.3.3 must be included.

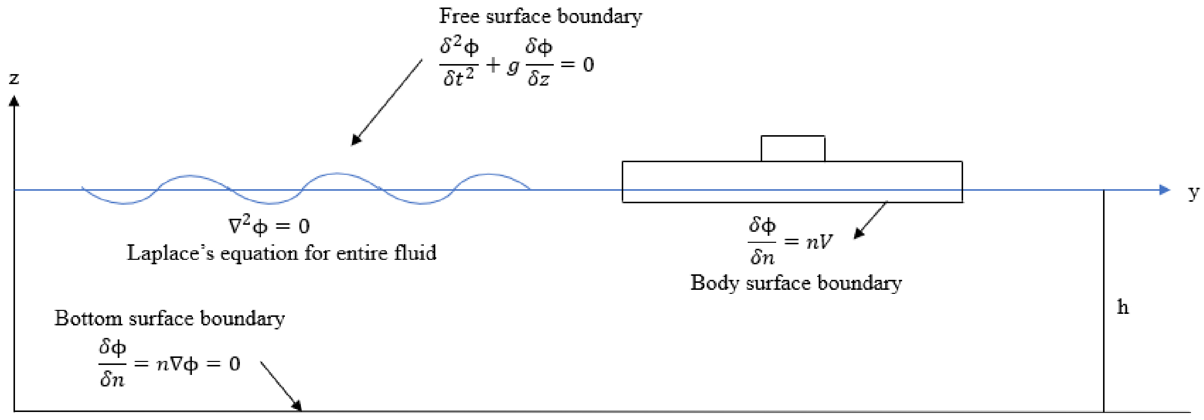

Figure 5.3.3: Boundary conditions for deep water

The velocity potential for deepwater waves is found by solving Laplace's equation, and may be seen in Equation 5.3.1. By using it, horizontal and vertical velocities and accelerations of wave particles and the dynamic pressure may be found. Furthermore, this is used to calculate wave loads affecting the structure (Faltinsen (1990a)).

$$\phi_{01}(y, z, t) = \frac{g\zeta_a}{\omega} e^{kz} cos(\omega t - ky) \tag{5.3.1}$$

The hydrodynamic force may, due to the linearity of first order loads, be found from two different contributions of the force; excitation and radiation forces (Faltinsen (1990a)).

Excitation

Excitation loads are divided into Froude-Kriloff and diffraction forces and moments. These forces and moments act on the structure when it is restrained from moving, and incident regular waves interact with the structure. This is illustrated in Figure 5.3.4 (Faltinsen (1990a)).

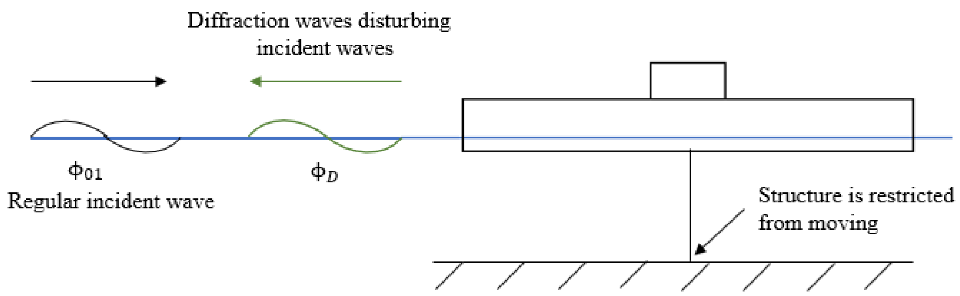

Figure 5.3.4: Excitation load

As excitation loads are divided into Froude-Kriloff and diffraction forces, it might be expressed as shown in Equation 5.3.2 (Faltinsen (1990a)).

$$F_{2,Excitation} = F_{2,Diffraction} + F_{2,Froude-Kriloff} \tag{5.3.2}$$

The diffraction load seems, due to the disturbing of the incoming wave, to change the uninterrupted pressure field that causes diffracted waves, illustrated in Figure 5.3.4. Hence, diffraction load is found by integrating the dynamic pressure of the diffraction along the wetted surface, and may be calculated by Equation 5.3.3 (Faltinsen (1990a)).

$$F_{2,Diffraction} = -\int_S \rho \frac{\delta \phi_D}{\delta t} n_2 dS \tag{5.3.3}$$

The Froude-Kriloff load has its source from hydrodynamic forces induced on the structure by the uninterrupted incident wave. This wave creates a corresponding uninterrupted pressure field that may be calculated by integrating the first order velocity potential with the strip theory applied, and is shown in Equation 5.3.4 (Faltinsen (1990a)).

$$F_{2,Froude-Kriloff} = -\int_S \rho \frac{\delta \phi_{01}}{\delta t} n_2 dS = -\int_S P_{dyn} n_2 dS \tag{5.3.4}$$

Radiation

Radiation is the second contributor to first order loads. These forces are hydrodynamic loads associated with the added mass (A), damping terms (B), and restoring terms (C) from the water that surrounds the structure. They occur when a structure generates waves from forced oscillation at an equal frequency as incoming waves, and is illustrated in Figure 5.3.5 (Faltinsen (1990a)).

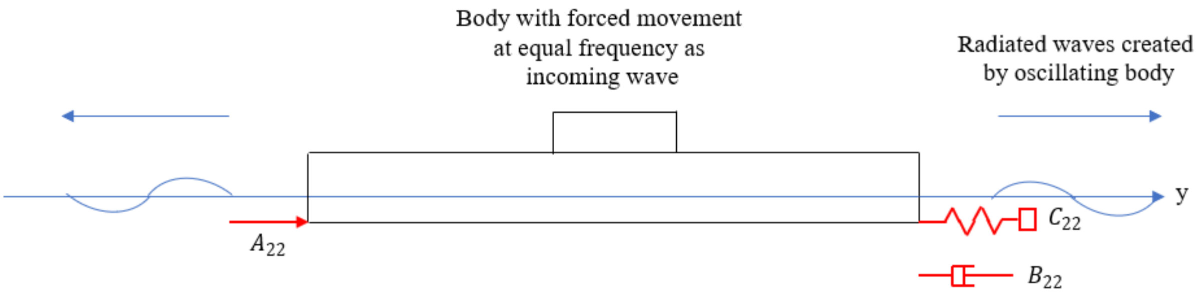

Figure 5.3.5: Radiation loads

Added mass force is generated by a pressure change on the basis of accelerated water surrounding the structure. Damping forces arise from energy transferred by a structure when oscillating and generating waves. Lastly, the restoring term is associated with the static pressure affecting the wetted surface and changing of buoyancy when it oscillates. Hence, the radiation force in sway is calculated by Equation 5.3.5 (Pettersen (1990)).

$$F_{2,Radiation} = -A_{22}\ddot{\eta}_2 - B_{22}\dot{\eta}_2 - C_{22}\eta_2 \tag{5.3.5}$$

Second order wave loads

Second order wave loads consist of three different contributors; mean wave drift forces, difference frequency- (slowly varying), and sum-frequency forces (high frequency). Mean wave drift has its source from the mean effect of incident regular waves affecting the structure. Frequency forces are the combined effect of different waves in an irregular sea state, which again creates high frequency and slowly varying loads. For marine structures, mean wave drift forces and difference frequency forces are important for several contexts, such as mooring line tension and general design of mooring systems (Faltinsen (1990b)). For a stationary, floating hatchery, these loads will, therefore, be highly relevant.

An irregular sea state is described as several incident wave components collected in one case, as shown in Figure 5.3.6 where two regular waves act on the floating hatchery. Each wave causes a drift force, and is combined to a mean drift force. Additionally, the difference frequency force and sum-frequency force is added.

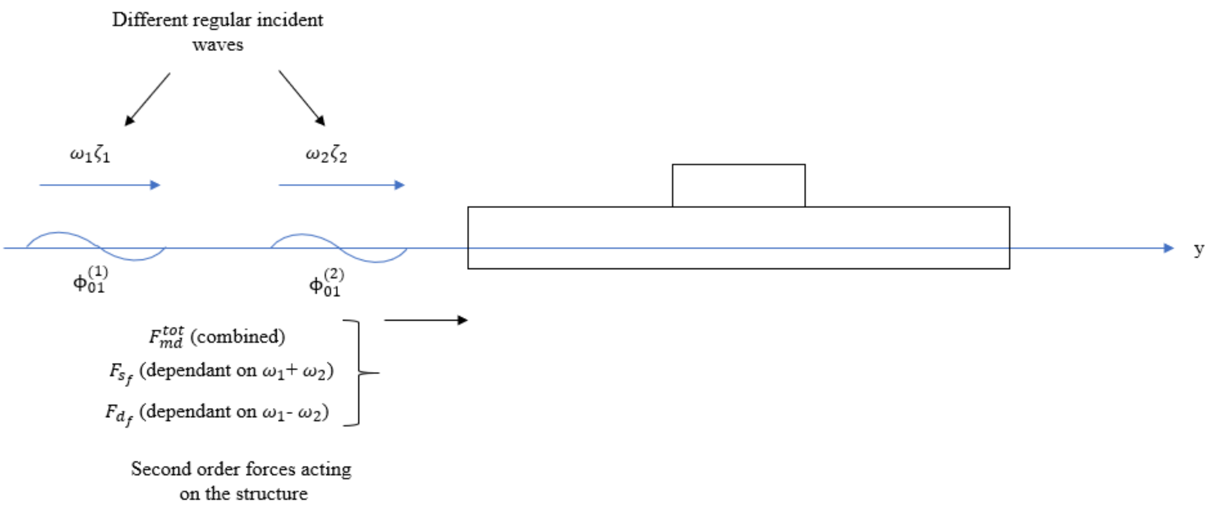

Figure 5.3.6: Second order wave forces acting on the floating hatchery

Mean wave drift forces

Each regular wave in an irregular sea state exerts a force on a structure. This force is the basis for second order mean drift force. The estimation of these forces is performed with the same assumptions as to the estimation of first order loads in hand. The difference, however, is that the second order terms concerning the velocity potential need to be accounted for when the pressure distribution over the wetted surface of the hatchery is evaluated. This may be calculated by two methods; direct pressure integration over the wetted surface, or by evaluating the conservation of fluid momentum for a certain volume by the use of Maruo's formula (Faltinsen (1990b)). This thesis will only focus on the latter of the two mentioned methods.

Maruo's formula

Maruo's formula is a two-dimensional equation where incident deep water waves interact with a fixed or freely floating body. Its objective is to calculate the mean wave drift force in sway direction. The two-dimensional term indicates that the result is given as specific force at the surface, N/m, and requires to be multiplied with the surface length of incoming waves. Incident waves with wave amplitude ζ_a acts on the structure, creating reflected and transmitted waves. The reflected waves are the sum of diffraction and radiation waves propagating in the negative y-direction, notated with a wave amplitude A_R. The transmitted waves are made of incident, diffraction, and radiation waves, propagating in positive y-direction, notated with wave amplitude A_T. The formula is given in Equation 5.3.6 (Greco (2019)).

$$\bar{F_2} = \frac{\rho g}{4}(\zeta_a^2 + A_R^2 - A_T^2) \tag{5.3.6}$$

This expression may be simplified further by making an additional assumption. This includes the energy flux through the body surface is zero, making the body a perfect absorber of energy, which again implies that there is no work affecting the body during one period of oscillation. Hence, there are no waves generated due to the body's excitation in the sea. Moreover, the variation of the energy has zero value, leading to the expression in Equation 5.3.7.

$$\zeta_a^2 = A_R^2 + A_T^2 \tag{5.3.7}$$

Perfect absorption of energy in the body leads to zero generation of transmitted waves, and thus $A_T = 0$. This means that ζ_a and A_R terms of equal value, leading to Maruo's formula becoming the expression shown in Equation 5.3.8 (Greco (2019)).

$$\bar{F_2} = \frac{\rho g}{2}\zeta_a^2 \tag{5.3.8}$$

When the transmitted wave is assigned a zero value, the largest value for the reflected wave is used. This indicates that Equation 5.3.8 provides the largest value of the mean drift force without current and forward speed, ensuring that the hatchery is designed with the harshest conditions and maximum values of environmental effects (Greco (2019)). Additionally, the hatchery will be a large structure with great masses placed on it. This means the structure will not likely be excited by the relatively small waves in the sheltered areas it will be located. Hence, the assumption of zero transmitted waves is deemed relevant.

Sum and frequency forces

Sum and difference frequency effects are occurring due to the combined effects from multiple different regular waves in an irregular sea state, and is illustrated in Figure 5.3.6. It may be specified by a case where two regular wave frequencies, ω_1 and ω_2, are considered. These sum frequency $(\omega_1 + \omega_2)$ effects are associated to high-frequency loads, and might cause resonance between the oscillating force periods, and the hatcheries natural period of motion with vertical excitation in the degrees of freedom heave, roll, and pitch. This occurs due to the lower natural periods connected with vertical motions for large volume marine systems (Faltinsen (1990b)).

As for the difference frequency effects $(\omega_1 - \omega_2)$, they are connected to slowly varying loads due to the higher oscillation periods. This means the slowly varying loads have a greater chance of creating resonance with the horizontal natural periods of the structure, affecting the degrees of freedom surge, sway, add yaw (Faltinsen (1990b)).

Large eigenperiod in sway

As mentioned, resonance happens due to the interaction of wave forces (slowly varying loads) and the floating hatchery, and may lead to severely amplified overall forces. Hence, it is necessary to investigate. This is based on an undamped eigenperiod in sway direction (η_2). It is assumed that the hatchery will have a perfect geometrical shape, and the damping will be neglected. This neglect will cause deviations compared to the real eigenperiod, but is approved due to small values of viscous and hydrodynamic damping (Greco (2019)).

The equation of motion, observed in Equation 5.3.9, is used to find an expression for eigenperiod in sway. It is assumed that the body is oscillating with no external impacts that may excite the structure.

$$(M + A_{22})\ddot{\eta}_2 + B_{22}\dot{\eta}_2 + C_{22}\eta_2 = F_{2,excitation} = 0 \tag{5.3.9}$$

This may, by calculations and assumptions, be expressed as the eigenperiod, T_{2n}, shown in Equation 5.3.10 (Faltinsen (1990a)).

$$T_{2n} = 2\pi\sqrt{\frac{M + A_{22}}{C_{22}}} \tag{5.3.10}$$

The restoring term (C), may be expressed as the mooring line stiffness, k_{22}, or even more specific, $\frac{EA}{l}$. Hence, it is influenced by material and geometrical components. An apparent notation from Equation 5.3.10, is the evident increased total structure mass $(M + A_{22})$ will indicate a larger natural period for the structure. The added mass in sway may be found through empirical data obtained from the use of Computational Fluid Dynamics software. It is based on the Navier Stokes equations, and simulates the water flow the surrounds the structure (Hall (2015)). The added mass affects the structure as a virtual change of weight, and is relevant due to the acceleration of water and its change of pressure surrounding the structure when moving.

The floating hatchery will not be an ordinary aquaculture facility, where the large mass will especially stand out. The large natural period will make the structure more prone to resonance associated with slowly varying loads with high mean periods. The hatchery's characteristics share many similarities with large volume marine structures, and there has occurred several incidents with semi-submersibles where the mooring line has failed. The faults have been pointed to insufficient estimation tools and predictions revolving slowly varying forces. With this in hand, paying attention to slowly varying forces when designing the hatchery is key (Faltinsen and Løken (1979)).

Forces from current

The structure will have quite a large part of its body under the surface, and thus will be subjected to water particles which induce drag force. The drag force is dependent on the structure's shape and projected area, and is caused by currents. Without specifying designs of the hatchery, Figure 5.3.7 illustrates how drag forces influence a rectangular figure. The drag occurs due to pressure field changes revolving the structure when water particles are forced to bypass.

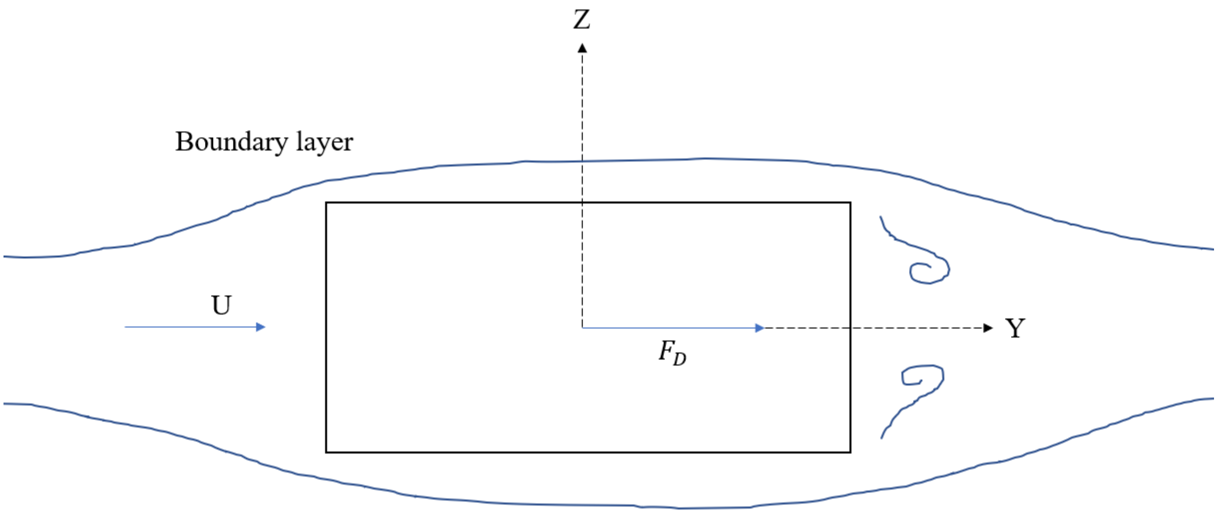

Figure 5.3.7: Rectangular floating hatchery in steady current, U

Estimation of drag forces may be calculated by Equation 5.3.11, where ρ is the water density, $\bar{U}$ is the mean current velocity, A is the projected area of the structure that is affected by the current, and C_D is the drag coefficient which is dependent on the shape of the structure, the flow, and the Reynolds number (Faltinsen (1990c)). Due to the sharp edges of the rectangular structure, a high drag force will occur. Therefore, in the design process, it may be beneficial to make a different geometrical shape.

$$F_D = \frac{1}{2}\rho C_D A\bar{U}^2 \tag{5.3.11}$$

The projected area will include the total area subjected to the flow of the whole structure. Thus it will be summed up by several terms depending on the end design. Calculating the drag force with a uniform current may be quite conservative if a maximum of high values is used, and non-conservative for the opposite. The current will, in reality, continually vary, and will affect the structure accordingly. However, using the method will give an estimate, before a more thorough calculation is done.

Forces from wind

Wind loads can be estimated similarly as the current loads, thus replacing the density of water with the density of air. The structure will expose large areas that the wind might affect, causing issues regarding the motions of the structure. Wind may generally be identified as

- a mean wind responsible for mean loads and other loads, and
- a fluctuating part as a gust, causing transient and slowly-varying loads.

Addition of these parts creates the expression shown in Equation 5.3.12 (Greco (2019)).

$$F_D = \frac{1}{2}\rho_{air} C_D A\bar{U}^2 + \rho_{air} C_D A\bar{U}u^{'} \tag{5.3.12}$$

Alternatively, empirical or experimental data is necessary (Faltinsen (1990b)).

Ensuring that the system can withstand the environmental forces

As mentioned in Section 4.4, NS9415 and NS9416 must be taken into consideration when designing the structure, ensuring that the system may withstand the environmental forces affecting the given site. Certain product specifications are required for specific components and several analyzes must be conducted thoroughly. Accreditation from Norwegian Accreditation bodies must be performed. Some accredited bodies include AkvaSafe, Aquastructures, DNV GL, and Åkerblå (Norsk Akkredutering (2020)).

The following analysis must be conducted and accredited: a local and global strength analysis, a mooring analysis, and a fatigue analysis. The local strength analysis includes accurate views regarding the stresses of structural connections, and is typically performed with the Finite Element Analysis (Aquastructures (2018a)). The global analysis is necessary to ensure that the structure has sufficient capacity overall, and is done through the software tool Wamit, a program that is used for calculating wave loads and motions of offshore structures in waves. The mooring analysis is required to document that the mooring may withstand the environmental forces affecting the hatchery. This is, for a traditional aquaculture site, done for cages and feeding barge. For the hatchery, however, this will be done for only one component. This component, although, is bigger and heavier, and must have mooring dimensioned accordingly, ensuring that the hatchery maintains its fixed position. Additionally, the analysis detects weak spots and fatigue of the mooring components, assuring that reinforcement is possible (Aquastructures (2018b)).

Overall forces for the conceptual design

Even though the environmental forces are explained above, they will not be calculated and estimated for the conceptual design. The conceptual design focuses primarily on the actual structure and the systems equipped, and hence the environmental forces are not included. Still, these forces will largely affect the structure, given the individual location, and will thus be calculated more thoroughly in an embodiment design phase with proper tools. This does not indicate that they are entirely neglected, as decisions regarding the overall design are taken based on the mentioned theory above.

5.3.2 Avoid Effects of Sloshing

Sloshing is a phenomenon happening due to an internal wave caused by external forces affecting a structure. Imagine walking down a corridor with a full cup of coffee in one hand. When affected, the fluid will move back and forth, crashing into walls. The internal wave is dependent on the structure's geometry related to its motion and mass of the internal water. Hence, waves will develop based on the period of oscillation of the structure and its geometry. Sloshing has structural and motional effects, and may lead to several problems to the structure. This includes material damage and further amplification of motions. Additionally, it may cause problems concerning the welfare of the fish. Furthermore, if the system achieves oscillation with the same period compared to one of the highest natural periods, undesired sloshing resonance may occur (Faltinsen (1990d)).

Due to the high total mass of the system, sloshing effects are assumed as non-existent for the hatchery. It will, however, be necessary to perform a sloshing analysis at a later stage.

5.3.3 Obtain Sufficient Buoyancy

As indicated in the description, a floating hatchery need to be designed with adequate buoyancy. The principle of Archimedes introduces the buoyancy force is equal to the weight of the displaced water (Holm, H. (2008)). The net force of an object partially submerged in a fluid is the differentiation between its weight and buoyancy in Newton. If the net force is positive the object is ascending, if the force is negative it is sinking, while if it is zero the object is neutrally buoyant. The buoyancy acts in the geometrical centre of the submerged part, while the weight acts in the centre of the object's mass. Figure 5.3.8 illustrates the buoyancy force, F_b, the weight of the object, F_w, and the submerged volume, V.

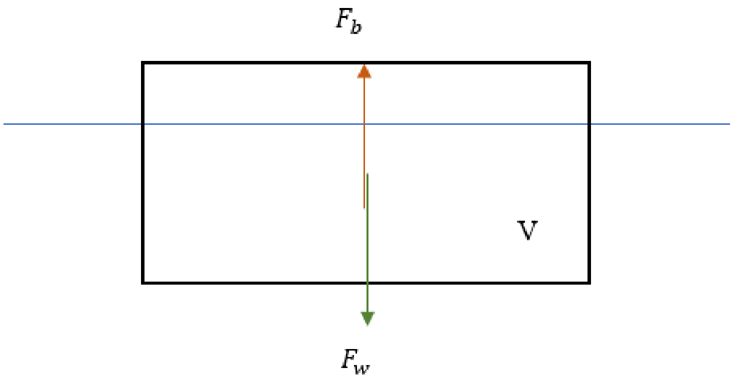

Figure 5.3.8: Partially submerged object

For the floating hatchery, it is necessary to calculate the weight of the different components, and summarize for the whole structure. This will require knowledge regarding necessary components and what systems are equipped. It will also include the weight of structural materials. However, this thesis will use estimates and allow assumptions regarding these values. The total weight will be compared against the buoyancy, to find a feasible and required depth of the structure.

5.3.4 Have Sufficient Stability

The buoyancy analysis involves summarizing all weights on the structure. However, with these weights, another problem comes into play; stability. For a structure to be stable it must be assigned with equal weights on each side of the centre of gravity. If this is not the case, an instability occurs where one side is lower than the other, and in worst cases may lead to capsizing. However, the hatchery will be designed symmetrically, making all masses cancelling out each other and not creating imbalance. Still, there is a factor that might affect the hatchery's stability, as the tanks will be partly filled by fluids. When the structure is affected by forces and moves, the water inside the tanks starts to move as well. This changes the water's centre of mass and creates an imbalance. The changing centre of mass in combination with forces affecting the structure must be reviewed at a later stage.

5.3.5 Have Sufficient Strength

To ensure safe design, the floating hatchery must have sufficient strength. This means it must be able to support the weight equipped on the structure while maintaining its properties. As mentioned, the hatchery will be located in relatively sheltered waters, and due to assumptions, the structure will be observed as a rigid structure. The structure will be symmetrical, meaning that all forces are mirrored, and makes for a simpler assessment. However, doing a structural analysis and proper layout of the structural component and their dimensions will not be included in this thesis.

5.3.6 Be Moored in a Fixed Position

The mooring will be an important component for the hatchery, as it will ensure that the structure maintains its fixed position and withstands the environmental forces. Depending on the dimensioning of the hatchery, the forces may become significant. Hence, the mooring must be able to hold large forces in all directions. Mooring systems consist of freely hanging, catenary lines connecting the hatchery to anchors, or piles, on the seabed, positioned at some specific distance. The mooring lines are laid out, often symmetrically in plan view, around the moored structure. Traditionally, steel-linked chain and wire rope have been used for floated mooring structures. Each line forms a catenary shape, relying on increasing or decreasing of line tension to lift off or settle on the seabed, and to produce a restoring force as the surface structure is displaced by the environment (Chakrabarti (2005)).

Monohulls and semi-submersibles are traditionally moored with spread catenary systems, connected to various locations on the hull. The result is an essentially fixed heading. However, a fixed position causes large loads on the mooring system from excessive offsets caused by the environment. Catenary mooring lines are laid from a submerged hull of a structure to an anchor at the seabed. Usually, the horizontal dimension of the line is 5-20 times the vertical dimension. The behaviour of mooring lines may be described by catenary equations, that further derives line tensions and shape for a single line of a mooring pattern (Chakrabarti (2005)).

Different bathymetry of separate locations affects the mooring design of moored structures. For instance, with the requirement to operate in increasing water depths, the suspended weight of the lines become a critical factor. More detailed, steel chain becomes less attractive at greater depth due to the sheer weight of the mooring line. This has led to taut synthetic fibre been designed and installed as alternatives for deep-water mooring. This is something that must be analyzed for each separate location of the hatchery (Chakrabarti (2005)).

The main task of the mooring is to withstand and overcome the forces and effects that are working on the structure. This will firstly include direct forces in sway direction (waves and current), but also the varying loads. These will excite the hatchery, forcing it to move. The motions of the structure are countered by the mooring and recover the original position, before it is affected by new loads again. This may create a resonance, and may be dangerous for the capacity of the mooring, which may lead to breaking of the lines. This is important to study in later designing. NS9415 states that all main components regarding growth at sea except the mooring system must be product certified. Hence, the mooring system should be designed by a company or a person that is certified, and will not be conducted in this study (Norsk Standard (2009)).

5.3.7 Be Transportable

One of the key features for the floating hatchery is the possibility for it to be transported and located at non-specific locations. At this stage, the standardized terms come into place. It will not be designed for a specified location, but rather is designed to match several conditions of environmental effects. As mentioned, this design is made to give an option to the farmers who are not utilizing post-smolt production. Hence, it must be transportable, and may be towed to the site of the operations and relocated quite easily. This means that the mooring needs to be detached from the structure before it is transported to another site and connect onto a new mooring system. For the towing aspect, as well as forces from current, due to large forces, it may be relevant to equip the structure with an appearance that cuts through the water in a better manner than a quadratic shape.

5.4 Housing and Operation of Personnel

This section will contain the aspects regarding safety and daily operation of the hatchery and the direct interaction between the structure and personnel.

5.4.1 Be Safe for Personnel

The main objective the hatchery does regarding personnel and operations is to create a safe work environment. Without proper safety, the hatchery can not be built, as safety determines the overall operation. The aquaculture industry is the second most hazardous profession in Norwegian industry, and creating a design that facilitates a reduction in these stats should be performed (Thorvaldsen et al. (2017)).

5.4.2 Be Accessible by Vessel

The hatchery will be connected to shore only by water and power supply, and hence transportation to the site must occur by boat. Bollards and fenders must be equipped on certain areas along the edge. Additionally, feeding vessels and well boats need accessibility to the hatchery. Feeding vessels use, for the most part, Dynamic Positioning (DP), and do not require mooring. Well boats, however, moors onto cages for longer pumping operations, and it is assumed the case for the hatchery as well.

5.4.3 Have a Control Centre

Nowadays, traditional on-growing sites at sea are being operated more and more remotely. This involves a control center on land that supervises the feeding of several sites, reducing the amount of personnel necessary at the individual sites. However, the hatchery will contain several systems, making it unthinkable for it to be controlled from a control center on land, as more problems may occur than at a standard site. Hence, the hatchery must be equipped with a proper control center that may run and oversee feeding, growth, water flow, oxygen levels, etc. for all tanks. Hatcheries that utilize RAS need even more control of the process, making the supervising even more thorough.

5.4.4 Tanks Accessible for Personnel

Most of the work for the personnel is maintaining stable conditions for the fish, which is mostly done by computers. However, interaction and inspection by the tanks must be done regularly, meaning the surrounding area of the tanks must be designed with operation in hand. An elevated path over the tanks shown in Figure 4.2.2 is also relevant for this use.

5.4.5 Connect to Land for Power and Water Supply

The hatchery is equipped with several systems that depend on power and water supply, making a supply system necessary. Both power and water supply are available if the hatchery is located near the original hatchery. The floating hatchery will be induced motions, which require that the supply cords are made elastic to avoid snapping. Additionally, as mentioned in Subsection 5.3.7, the hatchery will be transportable, and hence the cords must be detachable.

5.4.6 Be Equipped with Proper Housing

The hatchery will maintain continuous operation through day and night. This requires that personnel is located on the hatchery at all times, which again requires that sufficient housing of personnel is available. This will include bedrooms, kitchen, living room, bathroom, and other necessities for daily life. Personnel will work and be located on the hatchery for a week or two before another shift takes over the operation. This practice is currently used in the aquaculture industry for on-growth production at sea.

5.5 Alternative Water Intake System

This section introduces a new approach for water intake into hatcheries used in salmon production. The traditional system will be explained briefly, before an alternative method is established.

5.5.1 Traditional Intake System

In the traditional water intake system, as mentioned in Section 4.1, cleaned fresh water from nearby water resources at a higher altitude, such as lakes, is used to supply hatcheries. This means that the water flows directly to the hatchery, where it is pumped into tanks. With traditional flow hatcheries, enormous water amounts are required to ensure operation, as the water is used only once. Firstly, pumping these amounts into tanks require a large amount of electric energy. Secondly, getting concessions for new water resources is more and more challenging. A major factor to this is due to hydropower plants already using concessions on major watercourses in the country, limiting hatcheries to secondhand resources. However, there is a way to ensure new resources to hatcheries without reducing the amount of water to hydropower production.

5.5.2 Alternative Intake System

By allowing hatcheries to use the same concessions as hydropower plants already use, re-use of water is enabled. This may be done by attaching pipes to the hydropower plant, downstream from the generator, leading to a nearby hatchery. No extra water resources are used, while the generation of electricity remains the same and increasing of smolt production is possible, as resources become more available. Another major factor is the impact of connecting hatcheries to hydropower plants, as an excessive pressure in the water exiting the plant.

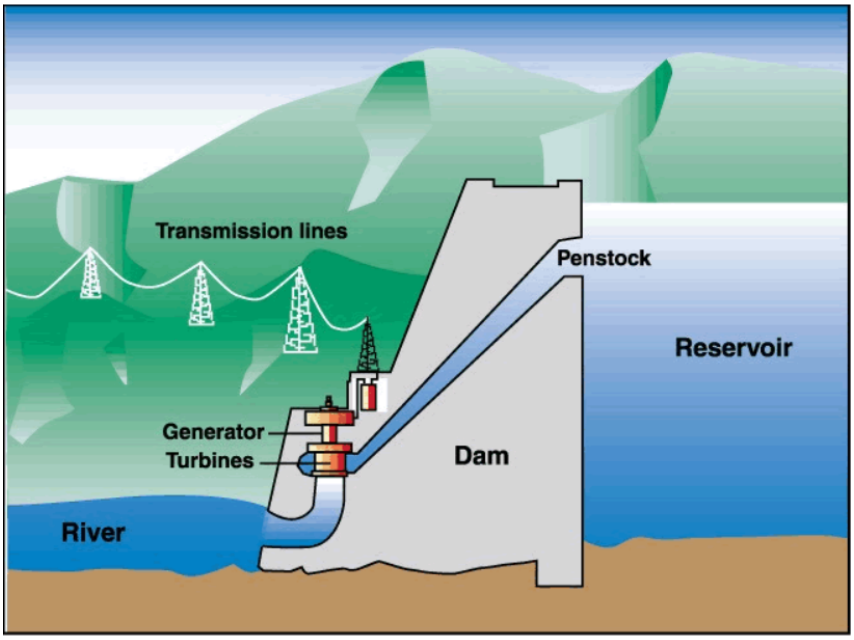

Figure 5.5.1: An illustration of a hydropower plant (US Army Corps of Engineers (2018)).

Hydropower produces energy due to gravity, letting water with a given mass fall with a given velocity through a turbine, which generates electricity, as indicated in Figure 5.5.1. However, after the water exits from the turbine but before it enters the river, the water still has hydrostatic pressure, as the turbine does not acquire every bit of the energy. This excessive pressure is simply released from the power plant to the river or sea below, instead of being utilized for another purpose. If connected to a hydropower plant, the hatchery may utilize this pressure to fill the tanks, instead of using pumps that demand a lot of power. It is, however, important to have a pipe bypassing the turbine for when the operation is down, reducing the necessity for the power plant to be continually active for the operation of the hatchery.

An application where re-use of hydropower water would benefit the production may be found at Flatanger. A company producing smoltified salmon wish to expand production, but are refused due to no available water resource. However, nearby exist a hydropower plant that has a concession for available water in the proximate area. If the hatchery could utilize these resources, an expanse would have been plausible.

Another option of use for the floating hatchery in combination with power plant production is to fully use it as a traditional flow hatchery. Hence, the whole section of RAS is removed and may be replaced by more tanks or reduce the total area. The water flows directly to the tanks, which require no pumping forces due to already pressurized water. However, the inlet water amount will have low temperatures in the winter months and requires heating. This may, for example, be done by exchanging heat with seawater at 20 meters. This thesis will, however, not focus on this concept for the remaining parts.

5.5.3 Hydropower Production in Norway

Hydropower production is the largest contributor of Norwegian power production (96-99 % of the electric energy produced in Norway), and is one of the main reasons for making the industrialization during the start of the twentieth century possible. Hydro electrics are especially useful in Norway due to high elevations and large water amounts with low evaporation. There exists in a total of 1393 hydropower plants in Norway, located as follows (Wikipedia (2020b)):

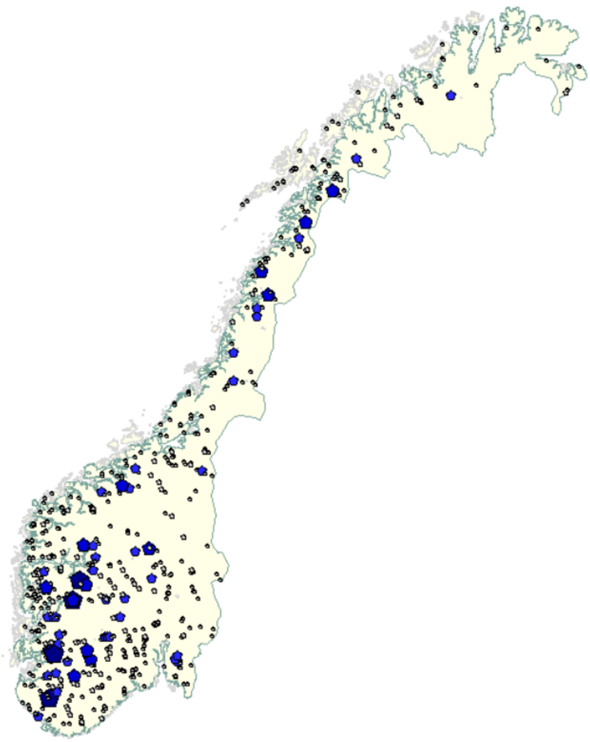

Figure 5.5.2: Mapping of the registered hydropower plants in Norway, where size on the map indicates performance (Hagen et al. (2000)).

As seen in Figure 5.5.2, several of the plants are located close to the sea, where the rivers exit into fjords. This is also the location where hatcheries traditionally are placed, but where plants are located, the existence of hatcheries is suppressed. Allowing hatcheries to use the same water as hydropower plants might increase overall biomass production of salmon, which the Norwegian government has said will happen. This is done without using extra water resources that currently is used, and with the same energy input as of now.

Chapter 6

Concept Design

This chapter will include the decisions regarding the design. It will focus on dimensioning, layout, buoyancy analysis, appearance, and risk assessment of the RAS units.

6.1 Dimensioning

The section will focus on specific dimensioning aspects that greatly determine the design of the structure. The systems that must be dimensioned are especially tank size and RAS sections, but also control center, housing area, and feed storage.

6.1.1 Tanks Dimensioning and Quantity

As mentioned in Section 4.4, 2,5 million seaworthy fish may be produced per concession per year. As this is the basis for the industry, it is used for the design at the current stage. By maintaining a steady water temperature of 13-14° Celsius in RAS facilities, the average growth of salmon from 100 - 1000 grams spans four to five months (Bjørndal et al. (2018)). Due to further operations regarding pumping in and out of the hatchery, an assumption of two production cycles per year is comprehensible. This does not take into consideration that the salmon is transferred to the hatchery at different times, only the quantity of salmon that must be produced throughout the year. The concessions for salmon growth at sea are limited in tonnes, while concessions for land-based production is limited in quantity. This means that sea-based growth must juggle around concessions for separate production sites to optimize overall growth and production, while it is not relevant for the production in this thesis. It could, however, be done to assure a more continual operation, but the purpose of the thesis is to provide a design for potential companies, not to determine how they operate the hatchery. Hence, 1,25 million salmon are grown at the hatchery for each production cycle.

Salmon is traditionally required to live in cages with a biomass density of a maximum of 25 kg/m^3. As mentioned in Section 4.4, land-based production has an exemption to avoid this demand. It is researched and proven that densities of around 75 kg/m^3 have no impact on the salmon's welfare (CtrlAQUA (2017)), and is hence preferred for further calculation. This reduces the demand for available tank volume a threefold, which makes the designing simpler and more compact. In other words, when the salmon has reached an average weight of 1 kg, a volume of 16'667 m^3 is required, calculated from Equation 6.1.1.

$$Volume = \frac{n_{salmon}\bar{M}}{\rho_{Biomass}} \tag{6.1.1}$$

This volume is reachable in several manners, but still with some constraints. The structure will utilize the centralized principle mentioned in Section 4.1, and place tanks surrounding the RAS units. This will enable the hatchery to be designed symmetrically, which again assists the overall stability of the structure. By locating tanks in a surrounding manner to the RAS sections, a possibility of reduction of pipe length is achieved, which again leads to a compact design and short travel paths of inlet and outlet water. The hatchery will be equipped with octagonal tanks, where the likewise length and width are required to uphold the internal, rotational flow. The tanks may not be too large, as this will lead to a vast width of the whole structure (large tanks on each side of the RAS section). They should neither be too small, as this will lead to an unneeded high amount of tanks scattered around the structure. Traditional production at sea utilizes often 6-12 cages at a site, depending on the amount of production licenses used, and this number of tanks may be applied at the hatchery as well. For this stage of the process, a number of ten tanks are deemed as a suitable amount. Hence, each tank must contain a volume of 1'667 m^3. Figure 6.1.1 and Figure 6.1.2 illustrates the measurements of the tanks.

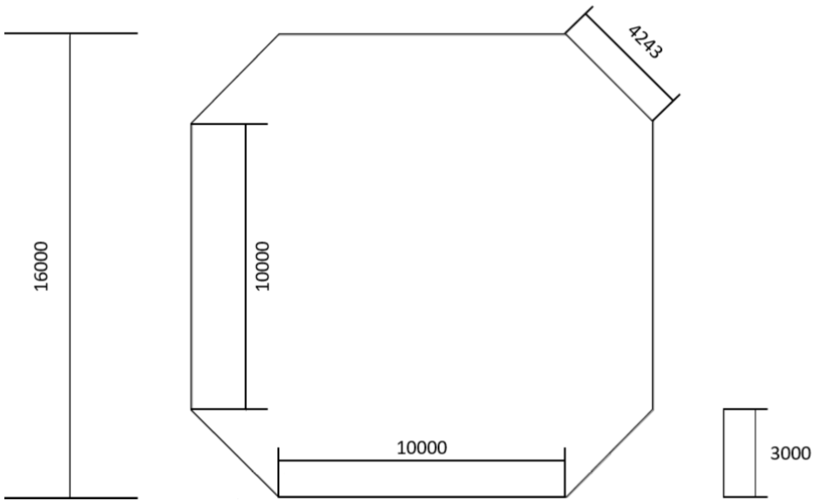

Figure 6.1.1: Horizontal dimension of tanks in millimeter

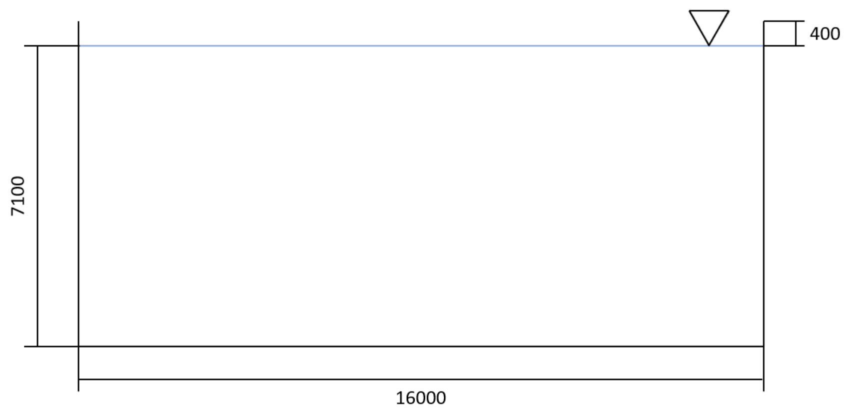

Figure 6.1.2: Vertical dimension of tanks in millimeter

Each tank will have sides that measure 16 meters across. However, with an octagonal shape, the corners are removed and replaced by diagonal walls. The removed sections are triangles with catheti of 3 meters, creating an octagonal with four sides of 10 meters and four sides of 4.243 meters ($\sqrt{3^2+3^2}$). Volume is by these measurements found to be 1'690 m^3. The tanks are equipped with 0.4 meter high walls to prevent the salmon from leaping out.

6.1.2 Dimensioning of RAS

The volume of water in the tanks is known, and is further used to estimate the dimensions of the necessary RAS sections. The RAS sections may either, due to the number of tanks, be dimensioned as two equal sections or by two slightly larger sections for three tanks plus two smaller sections for two tanks. Four RAS section will offer a system less prone to incidents than two larger sections, since fewer tanks are affected by a failing RAS unit. However, it may be more expensive due to a higher number of individual components instead of up-scaled components. Nofitech is currently utilizing a centralized principle for a RAS section that cleans four tanks, where the tanks are larger than decided for the floating hatchery (Nofitech (2019)). Hence, equipping only a large RAS section for five tanks is chosen. This will require thorough maintenance during operation, but also in between. The hatchery will grow, as mentioned in the previous section, two generations throughout the year, each about four to five months. This will create a time window between the two generations where maintenance and testing of equipment may happen, ensuring a safe growth without incidents that jeopardize the salmon. A risk assessment regarding the RAS sections is described in more detail in Section 6.6.

Two large RAS section must clean the water of five tanks or 8333 m^3. Normally, RAS exchanges the water inside tanks once every hour, likewise in traditional sea-based operation. In other words, each of the two RAS sections must be able to clean 8333 m^3/h or 138.88 m^3/min. To design the system for the best result, the work ought to be done by a company with proper expertise within the subject. It will, however, be designed an initial RAS system based on the information mentioned in Section 4.1 and comparable hatcheries currently existing. Through conversation with Ole Jonny Nyhus at AKVA group Land Based AS, one of the leading suppliers of RAS worldwide, a simple size estimation of RAS area is achieved by multiplying the surface area of water with 1.5-2. The RAS systems will be designed according to this area constraint. The floating hatchery will mount the tanks in a surrounding manner and close to the RAS section, which minimizes pipe length for the system. It is assumed, through the utilization of such a compact system, that the minimal multiplication product of 1.5 is used for further calculation. Hence each RAS section needs an area of 1'785 m^2. Each section must primarily be equipped with mechanical filters, biofilters, pH-controlling, ozone disinfection, CO_2 degassing, and oxygenation.

6.2 Layout

This section will provide a discussion regarding the layout and arrangement of the structure. It will consist of the RAS units, tanks, pipes, and the living and working conditions of the personnel.

6.2.1 RAS

As mentioned in the previous section, the RAS system must span an area of 1'785 m^2. This is done by a rectangular area with sides of 40 and 45 meters. The layout has been designed by combining Figure 4.1.5 with ModulRAS by Nofitech (Nofitech (2019)), and is seen in Figure 6.2.1. Each tank is assigned a separate section of water cleaning from the start to finish. Firstly, drum filters (bottom of the figure) to remove larger particles are equipped at an end of the RAS section. The drum filters are the first barrier of cleaning, and directly connected to the tanks. Hence, five filters are installed, one for each of the tanks. Following this, the water enters larger pools where the biofilter is located. In this section, calcium hydroxide is added to prevent the H^+-ions from acidifying the water. Furthermore, the water is moved to the disinfection section where ozone is added. Next up, the water is degassed of CO_2 before it is pumped to oxygen cones at the top of the figure. The water is brought up to oxygen saturation of favorable levels, and is ready to be used by the fish again. It is important that the water level of the tanks and RAS sections are on the same level to reduce the necessary pumping to as low as possible. The RAS sections are covered with a roof with closed walls, assuring a dry internal environment without external factors affecting the system.

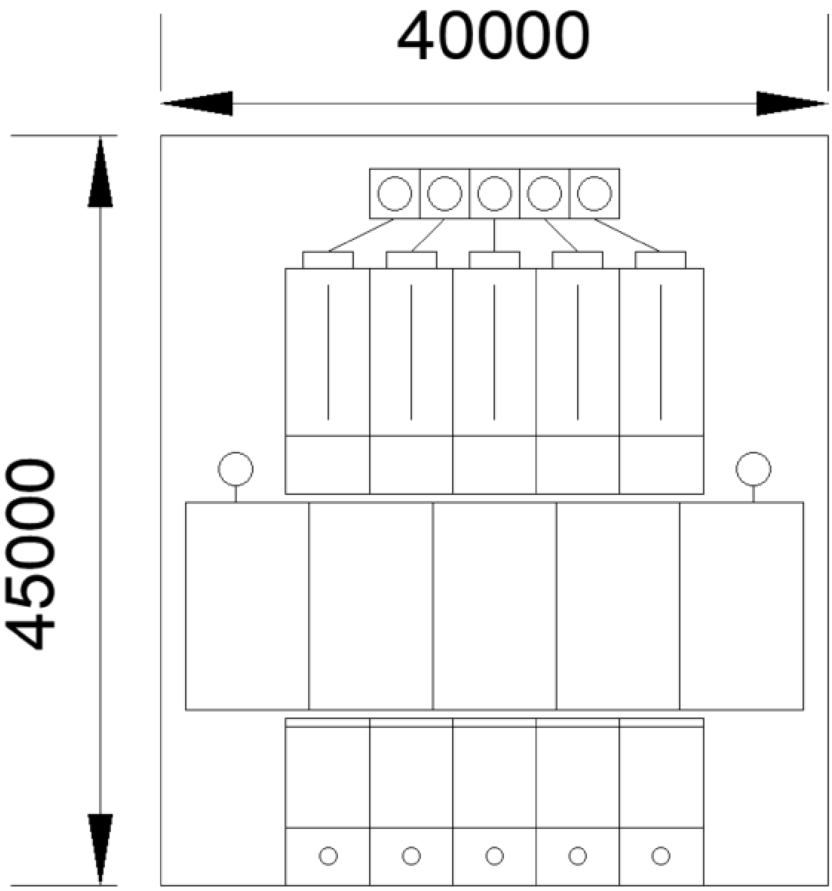

Figure 6.2.1: Initial design of the RAS system. Five drum filters are located at the bottom of the figure, leading into larger pools of the biofilter. Two tubs containing calcium hydroxide are equipped to the biofilter. The water enters five ozone pools, before leading into the degassing. Lastly, it is pumped into oxygen cones.

It is important to state that this RAS section is a rough sketch of how the RAS section might look. It functions as an initial design to assign the crucial components a location, and overall placement for the whole section at the structure.

6.2.2 Tanks

The next part determines how the tanks will be placed according to the RAS section. In theory, the structure will be a land-based post-smolt site relocated onto the sea. Hence, the layout regarding the equipped systems must be designed with this in hand. A floating structure ought to be as small and compact as possible, reducing unnecessary empty spaces. This is easier to neglect when building on land, as there is often plenty of available space to use. This requires, for this case, the tanks to be designed in close combination to the RAS sections, which reduces the overall required pipe length and area. Additionally, it is beneficial for them to be placed in a manner that reduces environmental forces on the overall structure. In other words, the hatchery should have different geometry than the rectangular shape mentioned in Subsection 5.3.1. Hence, two tanks are placed on each of the longer sides, while one is placed above the oxygen cones at the top of Figure 6.2.1. The walls will span around the tanks, creating a large room spanning the geometrical shape. The tanks need to be placed in areas that are sheltered from the environment. This is done to prevent the warm water temperature leaking out to the ambient area, and to reduce uncertain effects where rain interacts with the RAS. An enclosed space surrounding the tanks would also remove the possibility of personnel falling overboard, creating a safer working environment. The top end of the tanks functions as outer walls of the structure in addition to walls against the RAS on the opposite end, assuring compact exploitation of space.

Outer edges of the structure are drawn around the five tanks, and the overall appearance of the structure is created, shown in Figure 6.2.2. This whole structure is mirrored to create another likewise part of the structure.

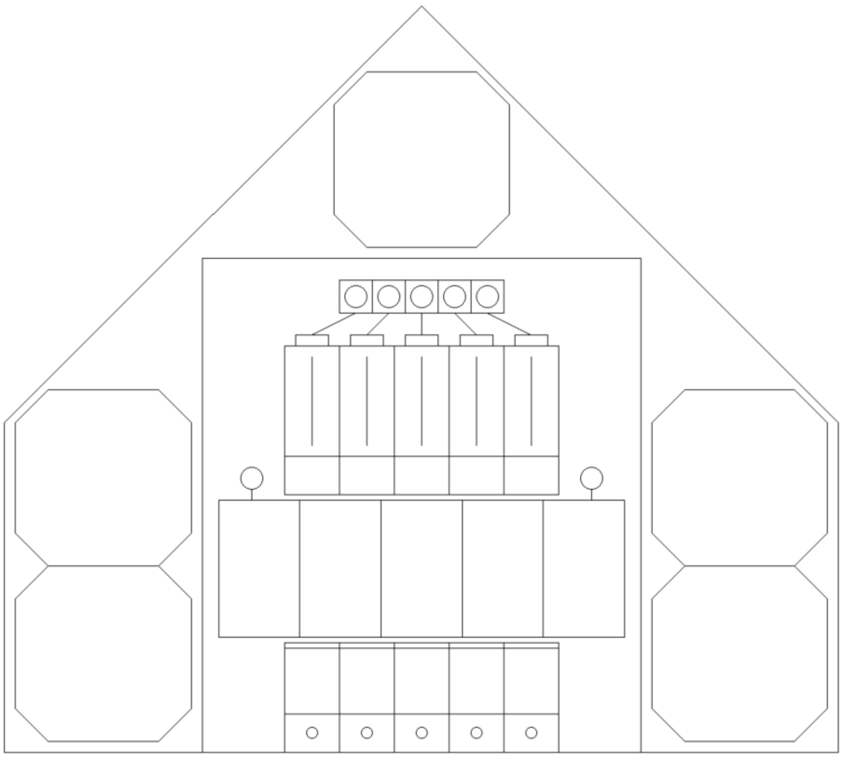

Figure 6.2.2: Initial design that focuses on how the RAS sections and tanks are placed according to each other

In between the two parts, the main building and feeding system is placed, where the main building is located in the center of the structure. This is done as a three-story part where each section is assigned a separate story. It will be described in more detail in Subsection 6.2.4. Feed storage will occupy a section beside the center section. An advantage of growing the fish of the same generation is that the same type and size of feed is used on all tanks. In other words, all of the feed may be stored in just one silo, which reduces the necessity of a chooser that distributes feed from different silos. Alternatively, salmon of different generations may be grown at the hatchery, which requires several feed silos due to different feed size. By assigning a weight on the side of a structure, an imbalance might occur. However, the feed and feeding system is, in comparison to the size and weight of the structure, assumed not to be grand enough to create instability.

6.2.3 Pipes

The pipes will have the function of transporting water to-and-fro RAS section and tanks, and feed from feed storage to tanks. As for the outlet water from RAS, it exits the oxygen cones and is distributed to the tanks along the periphery of the section ends, as seen in Figure 6.2.3. The water enters the tanks and exits through a central drain that empties an equal amount of outlet water as inlet water. This pipe leads down and underneath the tanks, before it is transported to the drum filters for another iteration of cleaning. A secondary pump is installed at this stage for each of the pipes leading to the drum filters. Hence, a pump draining the RAS sections of water, while another is filling. As for the feeding, it requires fewer pipes as only an inlet pipe towards the tanks are necessary.

All tanks are equipped with an elevated pathway spanning the tanks, as in Figure 4.2.2, which assists in performing a daily operation within them. This construction will also assist in supporting feeding pipes leading to each tank. Hence, these are in Figure 6.2.3 drawn over the tanks.

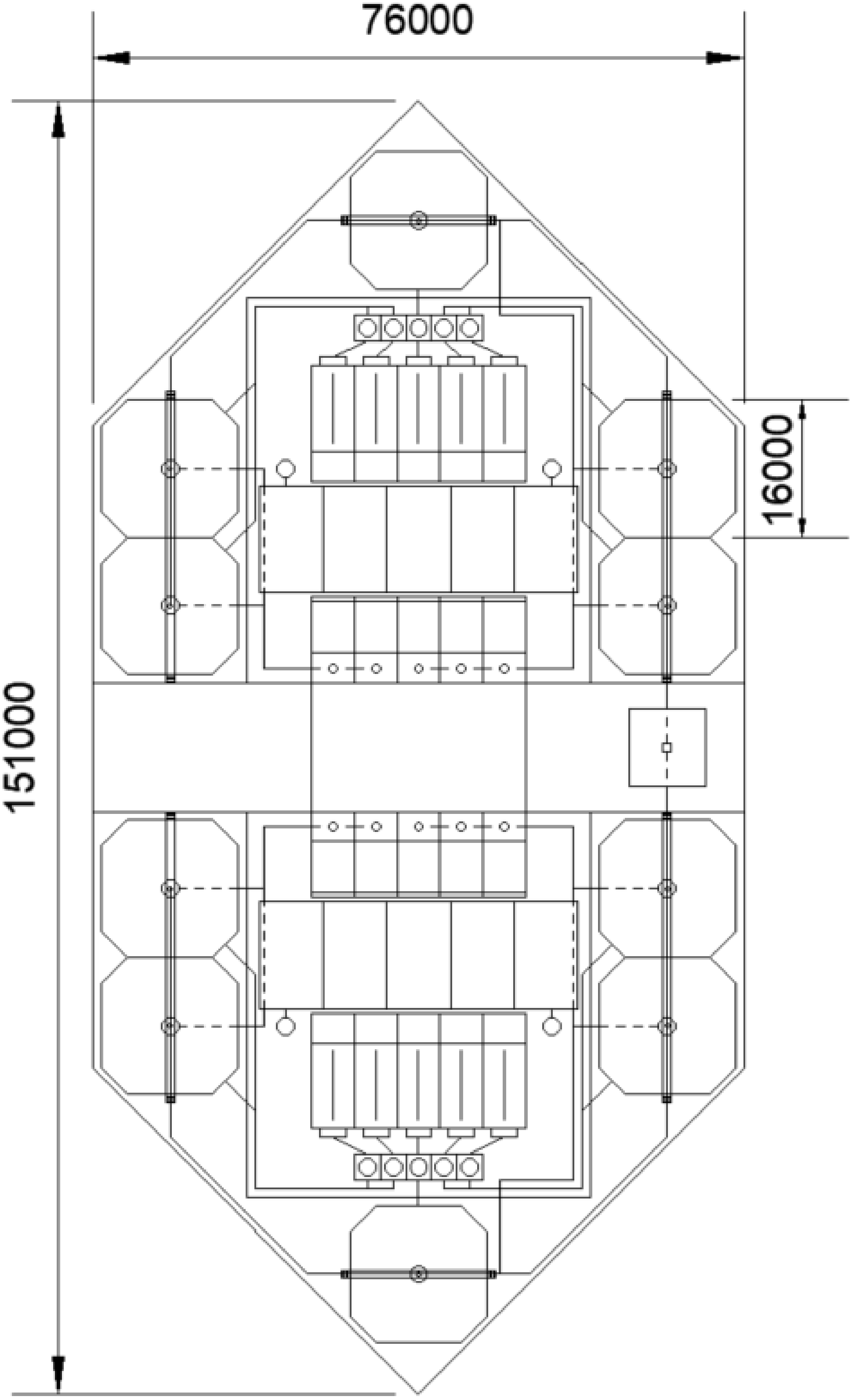

Figure 6.2.3: The design of the pipes' interaction with the RAS sections, tanks, and feed storage for the whole structure. Dotted lines indicates pipes underneath another component.

6.2.4 Main Building

The main building is divided into three parts where each part is assigned a separate level. The first level will include a workshop, storage, and a wardrobe with a toilet and shower. The second level will consist of offices and equipment for supervising the RAS sections, maintaining oxygen levels, feeding system, and overall tank environment, as well as a kitchen. The last level will have the necessary facilities to provide the personnel with a normal life while on the hatchery, such as separate sleeping rooms, a living, and a fitness room including an additional bathroom. It is assumed a number of 10-15 people to operate the hatchery throughout the day and night, making proper living conditions with a sufficient amount of cabins key. Each level must facilitate the implementation of the relevant functions presented in Section 5.4.

6.3 Other Decisions

The structure will be made from steel with concrete at the structure bottom, externally shaped like a stretched hexagonal figure. The tanks and RAS sections are placed onto the structure's base floor, meaning the floor must be dimensioned accordingly. An alternative to a reinforced, strong bottom would be to place the tanks directly in the water, where large RAS sections had cleaned and supplied the water to several individual cages. The cages would not have been a part of the structure, making it much lighter. However, the tanks are not placed directly into the water, as the high water temperature within the tanks would be cooled by the enclosed, cold water, leading to the removal of temperature benefits regarding RAS.

The top end of the tanks and RAS sections, as well as the main building, will be placed on a level plane spanning the whole structure, except the tank and RAS areas. This will be the overall main deck of the structure. The tanks and the RAS sections are sheltered from the environment with walls and a roof. The walls are made as sandwich walls, assuring, along with proper ventilation, a dry environment. It is assumed that walls at a four meter height will be sufficient for the RAS and tanks. Enclosed tanks may also benefit safety as the possibility of personnel falling overboard is reduced.

The RAS system will ensure that 99 % of the water in the tanks will be cleaned and re-used for another iteration. However, the remaining 1 % must be added by external measures. This is done through a freshwater pipe connected to the land. The pipe, due to the inclusion of vessels is located a few meters under the surface. The pipe is continually affected by current while transiting the distance from shore to hatchery, and additionally, the hatchery is forced to move, demanding the pipe to be flexible while still having to strength to perform its tasks. A flexible pipe like this may not be the safest and most secure component, and the inlet water should hence be supplied as a secondary option as well. The tanks are supplied with water filled with a salt content lower than the contents of regular saltwater due to the preferences of the fish, as mentioned in Section 4.2. However, as a back-up solution, there should be no problems in supplying saltwater to the fish and RAS for a while, if the freshwater pipe experiences failure. The flexible pipe, in addition to a seawater inlet pump, is attached at the side of the structure facing land, while the feeding silo is at the opposite end due to vessels approaching from open waters. The pipe and pump are here connected to pre-fabricated tubes, leading to a distribution system below the main building. Here, short pathways to each start of the RAS sections are achieved, ensuring minimal transport of the water. Ideally, the inlet water is connected onto a system mentioned in Section 5.5, making a pump prior to the distribution system worthless due to the water already being under hydrostatic pressure.

The area below the main building will also be storage of wastes from the salmon production such as faeces, feed, silage from dead fish, and other smaller particles. Hence, the nutritional parts of these components may be recycled instead of disposed of.

6.4 Stability Analysis

As mentioned in Subsection 5.3.3 and Subsection 5.3.4, the structure must provide the given buoyancy and stability to maintain its floating state. This will be done by estimating all masses on the structure, and then find out at what draught the structure displaces the given volume necessary to float. These masses include all the water within the tanks and RAS sections, all components the RAS consist of, and structure materials for the overall structure.

To approach an estimate for further designing, a few assumptions are established and are as followed:

- Steel thickness of 8 mm for the whole submerged section and main deck.
- 20 cm of concrete on top of the steel for the whole bottom of the structure. This is added to reinforce the floor as the fish tanks are placed onto the floor.
- The structural layout is seen in Figure 6.4.1. It is important to state that this layout is a general layout created to estimate the total weight of the hatchery. The figure shows structural elements with different colours, which indicates the element type and weight. Red elements are stiffeners that expand in the width direction, where the beams IPE S355J2+AR dimension 220 with 26.81 kg/m is assumed and chosen. Green elements are bearers in the length direction, where beams the IPE S355J2+AR dimension 300 with 43.18 kg/m is selected. The yellow elements are 8 mm thick exterior walls and supporting walls within the structure. The tanks measure 7.5 m from bottom to top, where the top 1.5 m is located at top of the main deck. In addition, the tank bottom must be elevated from the bottom, ensuring that pipes may exit underneath it. Hence, the tanks are placed 0.5 m above the bottom. This means that the main deck is located 6.5 m above the bottom, making the walls 6.7 m high (Smith Stål (2011)).

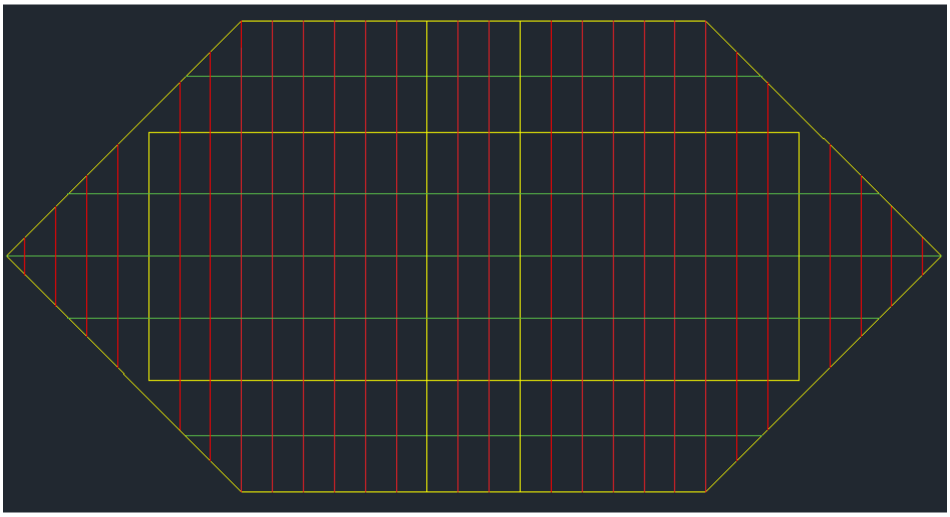

Figure 6.4.1: Assumption of the structural layout at the bottom

- Each wall is attached by frames for every meter, spanning the whole height of the walls. S355J0 with thickness 6 mm and width 100 mm at 4.80 kg/m is chosen (Smith Stål (2011)).
- The main deck is made from double 8 mm steel sheets strengthened with beams and stiffeners in between, assumed to measure the same as a sheet. This area will span the areas surrounding the tanks and RAS sections.
- The main building will be 25 m x 15 m, with a 3 m high wall as the first story. In between the stories are double 8 mm steel sheets similar to the specifications above. The same arrangement is used for another story. The last story will have the same walls equipped, while the roof is assumed to weigh the same as the decks in the main building. Additionally, the main building is assumed to contain equipment measuring a ton. The overall building will contain several windows, which are not considered in this phase.
- The ten tanks will contain an amount of 1'667 m^3 with a density assumed to be 1'010 kg/m^3. It is assumed lower than the density of regular saltwater due to a lower amount of salt particles mentioned in Section 4.2. The fish has the overall same density as the water, and are hence included in the estimate of the mass in the tanks.
- The RAS units must continuously contain water to keep the process running. The water amount in the tanks is required to maintain the same due to regulations of biomass density, which requires a separate extra water amount for the RAS section. This water amount is assumed to be the same contents as the volume of one tank, 1'667 m^3. As for the individual components that compose the overall RAS sections, simple weights will be presented. A drum with the chosen dimensions is assumed to weigh 250 kg. The biofilter consist of plastic figurines within a concrete pool, assumed to be a ton. The calcium hydroxide mixers are small containers attached to the biofilter pool, assumed to be 100 kg each. The disinfection and degassing units are, like the biofilter unit, concrete pools with few extra

components. The overall system is, however, estimated and given a weight of 2 tons. The pumps attached must manage to pump water two or even three times more than during normal operation, due to redundancy and the reallocating of paths during failure. Hence, each pump is estimated at 50 kg. Lastly, the oxygen cones are assigned a weight of 200 kg.

- A standard feeding barge for sea-based facilities may contain 300 - 400 tonnes with dry feed, while the larger ones easily surpass this. However, these barges will, for the most part, grow fish larger than a kilogram, fish that is much larger than at the hatchery. The hatchery will, hence, be equipped with a feed storage of 200 tonnes.

- An additional 10 % of the total mass is added as extra weight for the analysis. This will take piping, walls, and roof regarding the RAS sections, and other minor masses into consideration, resulting in a wider aspect of the mass estimations.

Table 6.4.1: Estimated weights on the floating hatchery

Component	**Weight [kg]**
Steel and concrete bottom	4 675 307
Strengthening elements	211 212
Exterior walls	157 473
Main deck	488 158
Main building	142 968
Tanks	16 836 700
RAS	3 378 740
Feed storage	200 000
Extra 10 %	2 609 056
Sum	28 699 614

With these assumptions in hand, the floating hatchery obtains a total mass of 28'700'000 kg as seen in Table 6.4.1. The general part of this mass has its roots in the tanks and the water of RAS sections, where those two components alone may provide a decent estimate of the overall mass. The structural components, stiffeners and bearers, make up a small fraction of the total mass, making the detailed designing of strengthening elements not crucial to be estimated with high accuracy. However, all the mentioned assumptions are used, and the calculation can be seen in the fullest in Appendix A. The purpose of the analysis is to estimate the draught that facilitates the displacement of water equaling the mass. The draught is found by dividing the mass by saltwater density and the surface area of the structure. This results in the hatchery obtaining a draught of 3.26 meters. The current draught further indicates a freeboard of 3.44 meters, resulting in an exterior appearance along with actual waterline seen in Figure 6.4.2, while a 3D-model is shown in Figure 6.4.3.

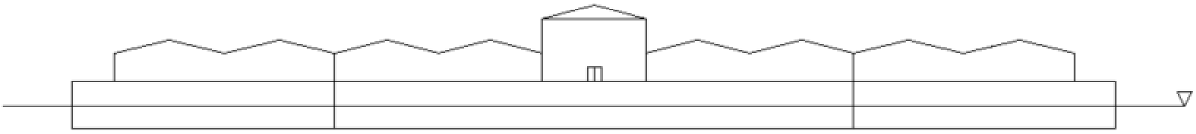

Figure 6.4.2: Exterior appearance of the structure with actual waterline included.

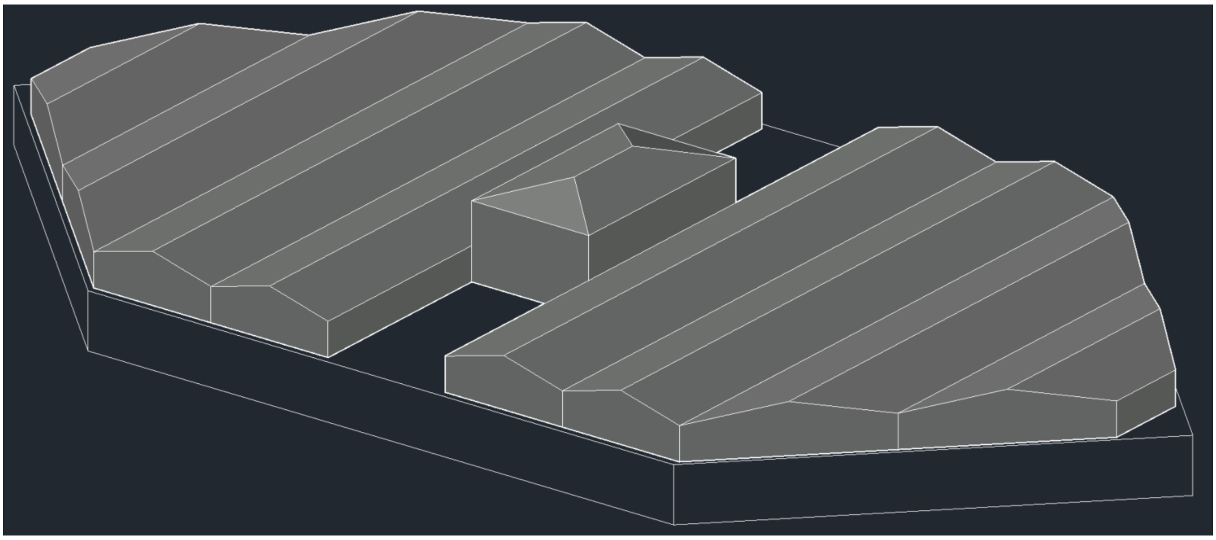

Figure 6.4.3: 3D-model of the floating hathcery.

6.5 Mooring

The previous section explains why a mooring analysis will not be conducted at this stage. However, this section still will describe the functionality and provide an initial design of the mooring equipped on the structure. As mentioned in Subsection 5.3.6, monohulls are traditionally moored with spread catenary systems, connected to various locations on the hull. The structure consists of six corners where each of them is connected to two mooring lines, creating a mooring system that holds the hatchery in place from all directions, and neutralizes the eigenperiods in sway directions from sloshing. The length and dimension of each mooring line is dependant on the relevant bathymetry, depth, and environmental forces of the individual locations. Figure 6.5.1 shows how the mooring lines are connected to and distributed from the hatchery.

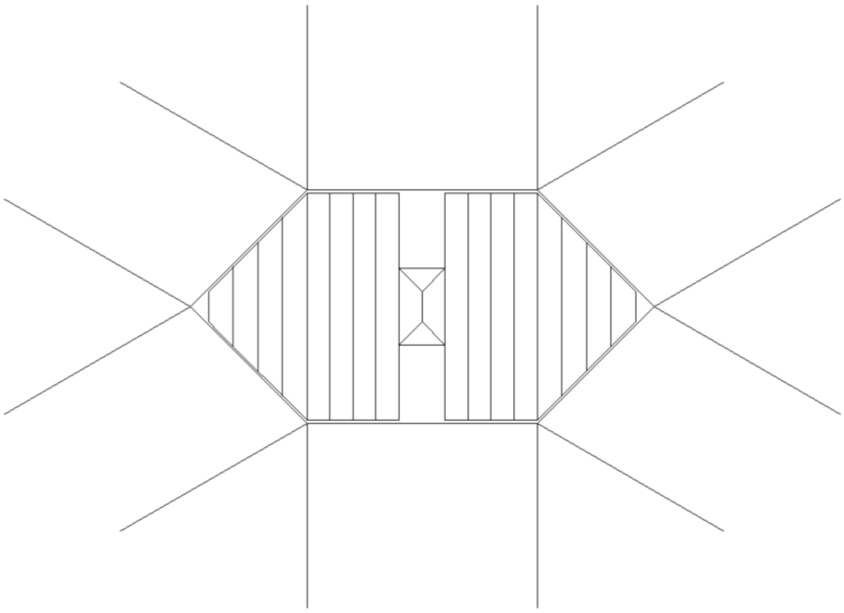

Figure 6.5.1: Layout of the mooring lines from the hatchery

The mooring lines are a crucial component regarding the general production of post-smolt at the hatchery. A mooring that is not sufficient enough, jeopardizes the general structure including the safety of personnel, economic investments, and endangers the surrounding areas by the shoreline. Hence, the lines are dimensioned according to the forces affecting each given site.

6.6 Risk Assessment

This section will focus on equipment that may fail and cause further problems or completely shut down the production of the hatchery. This is most relevant for the RAS sections.

The RAS sections are necessary for the overall production at the hatchery, as it provides clean water to the fish and ensures sufficient growth. However, the sections may fail and cause catastrophic events like loss of biomass. Causes to this may be a failure in each of the equipped components mentioned in Section 6.2 or accumulation of H_2S due to rotting sludge that is not collected.

The drum filters, biofilters, ozone, degassing units, pumps, and oxygen cones are all assigned a tank each, assuring redundancy. This is done in pathways, where each tank has a pathway of RAS components. Hence, if a component fails, another pathway must take its place for the relevant tank. The pipes entering the RAS section must be able to relocate the flow to another cleaning pathway. In correspondence with AKVA group Land Based, the water exchange was said to be increased from once an hour up to 3 - 4 times per hour. This means that the components may operate at a significantly higher rate, and thus relieve a component under maintenance. If a component fails, say one of the drum filters, the entire cleaning path for this tank is stopped. Instead, the water flow from the relevant tank is relocated to another tank's cleaning path while the drum filter is under maintenance. Pipes that relocate the flow are also necessary at the end of the RAS section, where the flow returning to the tanks is adjusted. Additionally, there are equipped two tubs of calcium hydroxide to raise the pH-value of water, which acts in the biofilter. These two units interact with all of the biofilter units, and are equipped to have redundancy regarding the pH-control of the RAS section.

Another trait with the operation of the hatchery is the cycles of growth. The hatchery will grow two generations during a calendar year with a significant stop in production in between. This production stop will, however, only be relevant for the production method in this thesis, as the continual operation may be more beneficial for the companies operating the hatchery. The downtime of equipment will ensure the components are given the necessary maintenance to last throughout the next production cycle. This kind of system provides maintenance for the crucial cleaning components, without having to buy additional equipment that is not continually used, or by slowing down the operation. The daily operation is not halted if a component fails, as other components make up for the lost component's working load. All in all, failure of a component is primarily neglected due to the production stop where maintenance is conducted, ensuring continuous operation without failures for the four to five months of growth.

Still, a risk assessment regarding the failure of the RAS section must be performed. It will be based on NS5814, a standard for requirements of risk assessment regarding operations in Norway (Standard Norge (2013)). This assessment will focus on the operation and failure of RAS components, as this is directly linked with the welfare and safety of the fish. Table 6.6.1 introduces the risk classes of failure, Table 6.6.2 describes the frequency of possible failures, while Table 6.6.3 lists the consequences of relevant failures. These are matched in Table 6.6.4, which creates an overview of measures taken regarding the operability of the RAS.

Table 6.6.1: Risk classes and their relevant meaning

Risk Class	Description
	Large risk (unacceptable)
	Medium risk (assess measures)
	Small risk (no measures necessary)

Table 6.6.2: Description of the term "Probability" in the risk matrix.

Class	Probability
1	Once every 2 years or less frequent
2	At least once every year
3	At least twice every year
4	At least once every month

Table 6.6.3: Description of the term "Impact" in the risk matrix.

Class	Consequence
1	Failure of a component, operation not halted
2	Failure of several components, causing halting of operation
3	Failure of components leading to some mortality
4	Failure of components leading to complete mortality

Table 6.6.4: The Risk Matrix, where risk is evaluated by probability and consequence.

Probability	Consequence			
	1	2	3	4
1				
2				
3				
4				

Chapter 7

Discussion

This chapter includes discussions regarding the methodology, and lastly, the findings of the thesis.

7.1 Methodology of the Thesis

The general objective of this thesis is to create a concept design of a standardized floating hatchery that may grant companies the option to produce post-smolt salmon. For this to be achieved, a methodology was applied. This methodology is discussed below.

The initial part that determined the direction of the thesis, was the literature review, with design theory, RAS, and smolt production being most crucial. The design theory established the mapping model *needs*, $function$, $form$, which consists of systems taking form based on initial needs and requirements the system ought to perform. The needs of the floating hatchery became apparent during the literature review regarding RAS and smolt production. This was furthermore gathered in the main function of the system, which again was decomposed in sub-functions. The main goal of the mapping of functions was to discover how the information in the literature review could be made into beneficial design solutions. Beneficial functions were established to create a view of what the system does, but due to limited time, there is not certain that all the relevant functions are covered. However, through the established functions, a thorough understanding of the overall system was obtained. Although, the function "Withstanding Environmental Force from Current and Waves" made clear how knowledge on vast structures as the floating hatchery is limited.

Based on the functions established, initial designing started. The first process involved finding the beneficial dimensions of the relevant parts, the tanks with the right volume, and the area of RAS sections. This resulted in ten tanks, where the tanks were assisted and cleaned by two RAS units. When this was selected, the general designing surrounding the tanks and RAS was performed. This consisted of assigning locations and weights to components, while ensuring that the functions established were performed. Additionally, as an important factor in the design, the stability analysis was performed. It was a crucial part as it determined at what draught the hatchery would operate with. To approach a value, a proper understanding of the overall structure was necessary, as the analysis assumed the weight of relevant components. Lastly, a general risk assessment regarding the RAS section was performed. It has the function of what to expect of faults and how it affects the overall growth and operation of the hatchery.

7.2 Findings of the Thesis

The aquaculture industry is facing challenging times due to concerns regarding some of the existing problems. This involves salmon lice, diseases, and escape. Some of these risks may be reduced if smoltified salmon, ready to be put in the sea, would have been grown in closed cages or hatcheries to a larger size before transferring. An example of this would be the increased robustness of the salmon, as it would be less prone to suffer injuries or death due to handling and operations, whereas the apparent mortality at spawn is likely to be reduced. Additionally, the salmon would be less exposed to diseases, and lice as the overall period at sea is lowered.

Several companies that crave expansion or desire to produce post-smolt salmon, face difficulties due to limiting factors as available land area. With traditional hatcheries taking up large quotas of available space where a post-smolt facility is likely to be placed, new measures must be taken. Hence, relocating onto water may grant the possibility of an expanse in production. A major benefit of the floating hatchery is the standardized ability to be transported and relocated. This gives the option for the hatchery to be located wherever a company wants within legal rights if water resources are available. This may also increase the possibility of the establishment of new hatcheries at places that previously would have been unavailable. Additionally, the hatchery requires less engagement in the nature as land-based facilities do, making it easier to pledge when operation comes to an end.

Another advantage of the hatchery is that smaller amounts of waste are disposed of. Traditional growth at sea produces large amounts of phosphorus waste through the feed and faeces. Additionally, significant amounts of plastic are released from the tubes leading to the cages. None of these wastes will be relevant for the floating hatchery at all. All of the feed and faeces is collected in the filters or directly in the tanks. It is stored on the hatchery, before it is recycled at a later stage. As for the plastic waste, it is completely removed due to metal tubes at the hatchery. However, growth at the hatchery will only be conducted from 100 - 1000 grams, meaning that the traditional growth at sea is performed afterward. Here, these wastes will be relevant again. The floating hatchery will not solve these problems alone, but it will contribute to lower wastes per kilogram produced salmon than overall growth at the current stage.

Chapter 8

Conclusion and Further Work

8.1 Conclusion

This thesis presents a conceptual design of a floating hatchery able to produce post-smolt salmon from 100-1000 grams. By doing so, companies have the option to grow post-smolt salmon, if they previously do not have the option to do so. This way, they will experience the advantages of post-smolt compared to salmon that has not been grown further after the smoltification process. These advantages may include healthier salmon, as it is less exposed to lice, diseases, and escape. Additionally, the fish is kept in water with a high, steady temperature leading to faster growth. It will also be more robust and strong, making it more capable to deal with operations than right after the smoltification, leading to lower mortality. The ability to relocate, may although, be the largest advantage, as each company can produce post-smolt salmon at places that previously would be impossible, or just to expand production from an established hatchery on land. Hence, it creates an option where companies can choose an operation customized to their liking. Lastly, the salmon is produced while waste is collected and recycled, which possibly leads to a more sustainable product. This is even more relevant if the alternative water intake system is used, as excessive pressure and water resources are further used. Due to these findings, an embodiment design phase of the concept may start.

8.2 Further Work

As the master thesis marks the end of the concept design, the more detailed embodiment design starts. Hence, areas that must be reviewed more thoroughly are noted below:

- Review relevant laws and regulations anew and assign the floating hatchery within these.
- Conduct a thorough hydrodynamic force study.
- Conduct a thorough mooring line study, with regards to the hydrodynamic study.

- Analyse the possibility of sloshing within the tanks
- Conduct a more detailed stability analysis.
- Conduct a thorough structural analysis and create a structural design that supports the structure.
- Check for locations that may build structures of the given size.
- Conduct a cost estimation of the concept and compare it against building costs on land.
- More visualization.
- Study motions of water inside tanks, and how this may affect stability.

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Appendix A

Buoyancy Analysis

Buoyancy analysis							
Component	**Area [m2]**	**Volume [m3]**	**Density [kg/m3]**	**Length [m]**	**Specific weight [kg/m]**	**Quantity**	**Weight [kg]**
Steel Bottom	8 588,00	68,70	8 050,00				**553 067,20**
Concrete bottom	8 588,00	1 717,60	2 400,00				**4 122 240,00**
Stiffeners				76,00	26,81	14,00	28 525,84
				66,00	26,81	2,00	3 538,92
				56,00	26,81	2,00	3 002,72
				36,00	26,81	2,00	1 930,32
				26,00	26,81	2,00	1 394,12
				16,00	26,81	2,00	857,92
				6,00	26,81	2,00	321,72
							39 571,56
Bearers				151,00	43,18	1,00	6 520,18
				131,00	43,18	2,00	11 313,16
				93,00	43,18	2,00	8 031,48
							25 864,82
Walls, exterior	360,06	2,88	8 050,00	53,74		4,00	92 750,94
	502,50	4,02	8 050,00	75,00		2,00	64 722,00
							157 472,94
Walls, interior	268,00	2,14	8 050,00	40,00		2,00	34 518,40
	703,50	5,63	8 050,00	105,00		2,00	90 610,80
							125 129,20
Frames, exterior walls				6,70	4,80	208,00	6 689,28
				6,70	4,80	148,00	4 759,68
							11 448,96
Frames. Internal walls				6,70	4,80	78,00	2 508,48
				6,70	4,80	208,00	6 689,28
							9 197,76

Component	Area [m2]	Volume [m3]	Density [kg/m3]	Length [m]	Specific weight [kg/m]	Quantity	Weight [kg]
Main deck	2 526,70	20,21	8 050,00			2,00	325 438,96
Main deck, reinforcement							162 719,48
							488 158,44
Main Building, walls	225,00	1,80	8 050,00			2,00	28 980,00
	135,00	1,08	8 050,00			2,00	17 388,00
							46 368,00
Main Building, floor and roof	375,00	3,00	8 050,00			2,00	48 300,00
							24 150,00
							24 150,00
							96 600,00
Tanks		1 667,00	1 010,00			10,00	**16 836 700,00**
RAS		1 667,00	1 010,00			2,00	3 367 340,00
					250,00	10,00	2 500,00
					1 000,00	2,00	2 000,00
					100,00	4,00	400,00
					2 000,00	2,00	4 000,00
					50,00	10,00	500,00
					200,00	10,00	2 000,00
							3 378 740,00
Feed storage							**200 000,00**
Total							26 090 558,88
Additional extra weight, 10 %							2 609 055,89
Sum							**28 699 614,77**

Area, barge	8 588,00	m2
Density, salt water	1 025,00	kg/m3
Draught	3,26	m

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