Acoustic velocity measurements during Atlantic salmon post-smolt production in RAS

Bachelor Thesis

Lauran Verstraeten

HZ University of Applied Sciences
Delta Academy
Water Management

HZ Supervisor: Bram Verkruysse

Nofima AS
Company supervisor: Jelena Kolarevic, PhD

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Author	L. Verstraeten 61711
Institution	HZ University of Applied Sciences
Study	Water Management / Aquatic Eco-Technology
Course	Graduation
Supervisor	B. Verkruysse
Internship institution	Nofima, The Norwegian Institute of Food, Fisheries and Aquaculture Research
Supervisor	Jelena Kolarevic (PhD)

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The Delta academy offers a unique choice of HBO/Bachelor studies in the field of water management and life in delta areas, within the HZ University of Applied Sciences. The study aquatic eco-technology focuses on the diversity of water ecosystems. By studying the core subject areas of biology, chemistry, ecology and technology.

The Nofima Food Research Institute was established on 1 January 2008; following a political decision to merge four research institutions, currently one of Northern Europe's largest industry-oriented research institutions in the areas of fishery, aquaculture and food industries. The Nofima centre for recirculation located in Sunndalsøra carries out research on recirculation in aquaculture on a broad basis.

Preface

Before you lies the bachelor thesis “Velocity measurements during Atlantic salmon post-smolt production in RAS”. This thesis is the final product concluding my graduation phase of the study aquatic eco-technology at the HZ University of Applied Sciences in Vlissingen. I was engaged in researching and writing this thesis in the period of February 2015 to June 2016.

This research on acoustic velocity measurements in aquaculture rearing units was undertaken on behalf of the Nofima research institute. As part of this project I undertook an internship at the Nofima centre for recirculation in Sunndalsøra under the guidance of Jelena Kolarevic (PhD). Here I explored the possibility of using the Vector instrument produced by Nortek in taking acoustic water velocity measurements. I would like to thank my supervisor Jelena Kolarevic for her guidance and support during the internship, always finding the time to answer any questions I had. Furthermore I would like to thank all colleagues who supported me during my stay at Nofima in particular Astrid Buran Holan, Britt Kristin Megard Reiten and Yuriy Marchenko for their help during sampling trips and around the station; and Dag Egil Bundgaard and Kristin Skei Nerdal for their help around the laboratory.

The graduation phase proved to be a challenging time on a personal level as well. I thank Bram Verkrusse for helping me with finishing my thesis and protfolio after this period of absence. Finally I would like to offer thanks to Monique Flipse who, despite her own graduation, found the time to support me throughout this entire period and keep my spirits up.

Lauran Verstraeten

Goes, June 20, 2016.

Acoustic velocity measurements during Atlantic post-smolt production in RAS

Water velocity in rearing units for Atlantic salmon post-smolt can influence fish robustness. Studies have shown that training at velocities between 1-2 body lengths/second (bl/s) increases disease resistance in salmonid species. Monitoring and timely adjustments to the water velocity during post-smolt production could therefore prevent losses after transfer to sea cages. The objective of this study is to explore which factors significantly influence the water velocity in the rearing units. Four 3,2 m^3 and 0,5 m^3 tanks have been calibrated by adjusting the inlet pipe and the flow in the tank. Two of the 3,2 m^3 tanks were set to a flow of 140 L/min and contained 90 kg/m^3 of post-smolts while the other two tanks were set to a flow of 40 L/min and contained 25 kg/m^3. These densities correspond to the same mass specific water use 1,5 (L/min/kg). The 0,5 m^3 tanks were set to a flow of 30 L/s and contained 10 fish. Velocities in the tanks were measured while being empty and when containing fish, both while feeding was off as well as during continuous feeding. The Vector 3D current meter by Nortek was used in the 3,2 m^3 tanks to measure the velocity in 36 locations evenly divided over the entire tank volume in order to create complete tank profiles. Results showed that (1) Feeding regimes have no influence on acoustic water velocity measurements; (2) fish presence can decrease tank velocities by up to between 20 and 30%, both at a density of 25 kg/m^3 as 90 kg/m^3. As this decrease was uniform for both flow settings a decrease of 20-30% occurs at a mass specific water use of 1,5 L/min/kg. It can be concluded that the presence of post-smolt in rearing units significantly decreases the water velocity in the tank. After fish transfer the water velocity in the rearing units should be adjusted accordingly to 1-2 bl/s to apply the optimal training regime increasing fish robustness. The Vector instrument using acoustics to measure water velocities proved to be a reliable alternative to traditional instruments and capable of efficient and accurate measurements.

KEYWORDS: RAS, Atlantic salmon (*S. salar)*, water velocity measurements, acoustic Doppler current profiler

Table of contents

1. INTRODUCTION 6
1.1 Atlantic salmon post-smolt 6
1.2 Water velocity 7
1.3 Vector 3D acoustic velocimeter 8

2. PROJECT GOAL 11
2.1 Project goal 11
2.2 Research questions 12
2.3 TSS 13

3. METHOD 14
3.1 The factors influencing the water velocity using the Vector acoustic velocity meter 14
3.1.1 3,2 m³ rearing units 14
3.1.1 0,5 m³ rearing units 17
3.1.2 Commercial scale 17
3.1.3 Data processing and statistical comparison 18
3.2 TSS 19
3.2.1 Standard method for measuring Total suspended solids (2540 D.) 19
3.2.2 Preparation of stock solutions 20
3.2.3 Effect of salinity on the standard TSS method 20
3.2.4 Test 1: Effect of the post-filtration rinsing water volume on TSS measurements in brackish and salt water . 21
3.2.5 Test 2: The effect of temperature of post-rinsing water on TSS measurements in brackish and salt water 21
3.2.6 Test 3: The effect of TSS concentration on TSS measurements in brackish and salt water 21

4. RESULTS 22
4.1 Velocity measurements 22
4.1.1 3,2 m³ tanks 22
4.1.2 Water velocity decrease 25
4.1.3 0,5 m³ tanks 26
4.1.4 Commercial scale 27
4.2 TSS 27
4.2.1 Stock solution 27
4.2.2 Test results 28

5. DISCUSSION 30
5.1 Water velocity measurements 30
5.2 TSS 31

6. CONCLUSION 32
6.1 Acoustic water velocity measurements 32
6.2 TSS 32
6.3 Recommendations 33
6.3.1 Water velocity measurements 33
6.3.2 TSS 33

LITERATURE 34

APPENDIX 37
Appendix 1: TSS measurements method 37
Appendix 2: Water velocity results 39
Appendix 3: TSS results 54
Appendix 4: Nortek mail 60
Appendix 5: Recommended method for acoustic velocity measurements using Vector 61

1. Introduction

1.1 Atlantic salmon post-smolt

Norway is the leading producer of Atlantic salmon (*Salmo salar)*, having seen a substantial growth of the salmon aquaculture industry over the last forty years, producing 1.232.095 tonnes in 2012 (The Norwegian Ministery of Trade, Industry and Fisheries). The rearing of *S. salar* is based on intensive systems. Control and improvement of the rearing conditions increases survival rate and reduces the grow-out phase compared to wild conditions. However, the high fish densities present in intensive aquaculture systems, like tanks or nets, also increases the risk of a disease outbreak. While in recent years vaccination of fish has led to a substantial decrease in the use of antibiotics, there still are infection types for which no vaccine has been developed yet (The Norwegian Ministery of Trade, Industry and Fisheries). Therefore it is important to optimise rearing conditions at the early life stages in order to produce post-smolt robust enough to survive the grow-out phase.

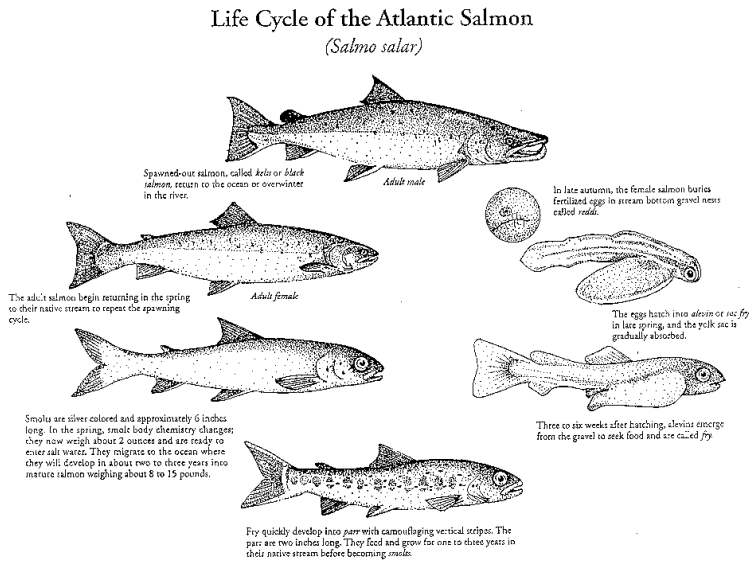

Figure 1.1: Life cycle of the Atlantic salmon (Salmo salar).

S. salar is an anadromous fish species; meaning it is hatched in fresh water, spends most of its life in salt water and migrates back to fresh water in order to spawn. This migration is seen as an adaptive survival strategy, utilizing the best-suited habitat during different stages of the lifecycle, to increase individual fitness (Thorstad, Whoriskey, Uglem, Moore, Rikardsen, & Finstad, 2012). Eggs hatch in fresh water where the salmon spends the first phases of its life. The first of these phases is the alevin stage at which the fish feed themselves using the remaining nutrients in the yolk sack. During this phase the juvenile salmon develops by growing, forming gills and becomes a predator. At this stage the salmon is called fry and starts to feed on invertebrates and occasionally small fish. At the final freshwater phase the fish develops into parr and prepares to migrate to salt water (Shearer, 1992), triggered by environmental factors as temperature or an increased water discharge (Jonsson & Ruud-Hansen, 1985). During the migration to salt water the transformation from parr to smolt takes place, this process is known as smoltification. During smoltification morphological, behavioural and biochemical changes prepare the smolt for transition to seawater (Folmar & Dickhoff, 1980). Because smoltification also occurs in the commercial rearing of *S. salar* the production process consists of a land-based hatchery phase and a grow-out phase in sea cages for post-smolts up to slaughter size. Smoltification takes place during the hatchery phase under controlled circumstances (Bergheim & Fivelstad, 2014).

One of the challenges faced in the rearing process of *S. salar* is the mortality rate caused by transfer to sea cages. In 2008, 34 out of 235 million fish (15%) died after transfer to sea cages in Norway (Castro, et al., 2011). While more recent surveys state post-smolt mortality in sea cages located in mid-Norway was 16,1%, of which as much as 38% of the mortality was a direct consequence of the smolt quality and thus related to the conditions in the hatchery phase (Bergheim & Fivelstad, 2014). Hatchery-reared *S. salar* has a lower survival rate compared to wild post-smolts during the salt-water stage. Both in the Atlantic Ocean as in the Baltic Sea survival rate of reared salmon is half that of wild *S. salar* (Jonsson, Jonsson, & Hansen, 1998) (Kallio-Nyberg & Ikonen, 2004). Hatchery reared smolts differ from wild smolts in physical condition and physiological status, and have been protected from selective factors encountered in the wild. Such factors influence smoltification timing and the preparedness to survive in the wild (McCormick, Hansen, Quinn, & Saunders, 1998). In addition to the factors stated above hatchery reared smolts are exposed to multiple stressors during production such as: handling, disease and varying water qualities and velocities. In order to decrease mortality rates training regimes have been developed, creating optimal rearing conditions by controlling and closely monitoring water quality and velocity, temperature and feeding rates.

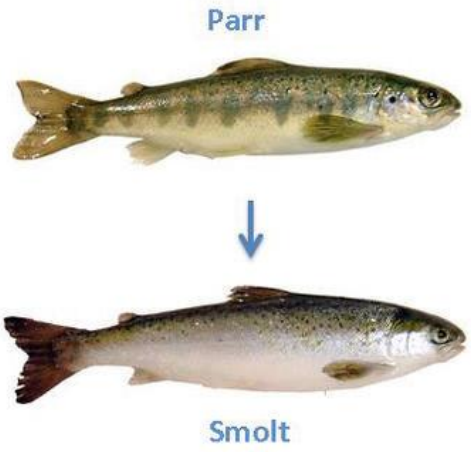

Figure 1.2: Morphological changes induced by smoltification in *S. salar* (Sundel, 2008).

Figure 1.3: Atlantic salmon (Salmo salar) (Knepp 2003).

1.2 Water velocity

Water velocity in the rearing tanks is an important factor when production of *S. salar* is concerned. It is the general opinion that training at velocities between 1 and 2 (body-lengths/second) improves growth and food conversion efficiency in many salmonid species (Davison, 1997) (Jorgensen & Jobling, 1993) as well as increased fin wound healing (Jorgensen & Jobling, 1993). While exercise does not lead to improvement of the osmoregulatory capacity of fish undergoing parr-smolt transformation (Jorgensen & Jobling, 1993), a recent study showed that certain training regimes could increase robustness of post-smolt in the form of higher disease resistance after transfer to sea cages (Castro, et al., 2011). Therefore knowledge on the water velocity, and the factors influencing this variable, during grow-out is essential to production.

Maintaining these optimal training regimes asks for frequent monitoring of the water velocity using accurate instruments. Traditional instruments like propellers may not be up to this task as measured values may differ considerably (Boyd & Tucker, 1998), making it difficult to carry out a fast and efficient monitoring programme (Malcolm, Youngson, & Gibbins, 2008). In addition propellers require frequent calibration (Kurnawal & Oak, 2014), may be affected by fish presence and have a limited detection range at low water velocities (Morlock & Fisher, 2002), while also inevitably disturbing the flow by the presence of the instrument itself (Oca, Masalo, & Reig, 2004). Furthermore, these types of instruments are used for measuring a stream wise velocity; meaning exact positioning is of importance to the accuracy, which is difficult due to the circular current flow in *S. salar* rearing tanks (Terjesen, et al., 2012).

A proposed alternative to traditional instruments is the use of Acoustic Doppler profilers, which enable fast and accurate monitoring in changing flow conditions (Yorke & Oberg, 2002) (Water survey of Canada, 2006). Acoustic Doppler profilers have been used extensively by oceanographers as these instruments provide high quality velocity data on turbulent ocean currents (Beardsley, 1987) (Irish, Plueddeman, & Lentz, 1995), during the last decade Doppler profilers have also been introduced to aquaculture research (Viadero, Rumberg, Gray, Tierney, & Semmens, 2005). A current profiler is a type of sonar used for studying the effect of current velocities. The profiler instrument includes a transducer to generate sound pulses. These pulses scatter back as echoes from plankton and small particles present in the water. The echoes received by the profiler have a Doppler frequency shift proportionate to the relative velocity between the scatters and the transducer. The instrument uses this data to calculate the water current velocity (Brumley, Deines, Cabrera, & Terray, 1997) (Rowe, 2004). Acoustic Doppler profilers contain no moving parts meaning the instrument can be used for extended periods without the need for calibration (Kraus, Lohrmann, & R., 1994) and the high sampling frequency compensates for fish presence during the measurements, making the instrument suitable for use in *S. salar* rearing tanks.

1.3 Vector 3D acoustic velocimeter

Nofima procured a Vector 3D acoustic velocimeter produced by Nortek, in order to enable accurate monitoring programmes during research projects. The Vector instrument measures water current velocities using the Doppler effect described above. The instrument measures an area of $1cm^3$ approximately 10cm underneath the instrument, meaning the probe does not disturb the measurement, by emitting acoustic pulses at a frequency between 8 and 64 Hz. The travelling time of the sound waves gives an estimate of the distance while the frequency shift of the echo is proportional to the water velocity along the acoustic path.

Three receptors attached at the beams of the instrument (Fig: 1.4) receive the reflected pulses and measure the velocity along three axes: north, east and vertical. By combining these three data sets a 3D image of the water current velocity is created (Fig: 1.4). This means that the exact positioning of the instrument does not influence the measurements, as the stream wise velocity is calculated from the three data sets. In addition to water velocity the instrument also measures pressure at the same sampling rate while temperature, tilt and orientation measurements are taken at a frequency of 1Hz. While the instrument does not require any physical calibration, the deployment settings can be used to adjust measurements for certain specific situations.

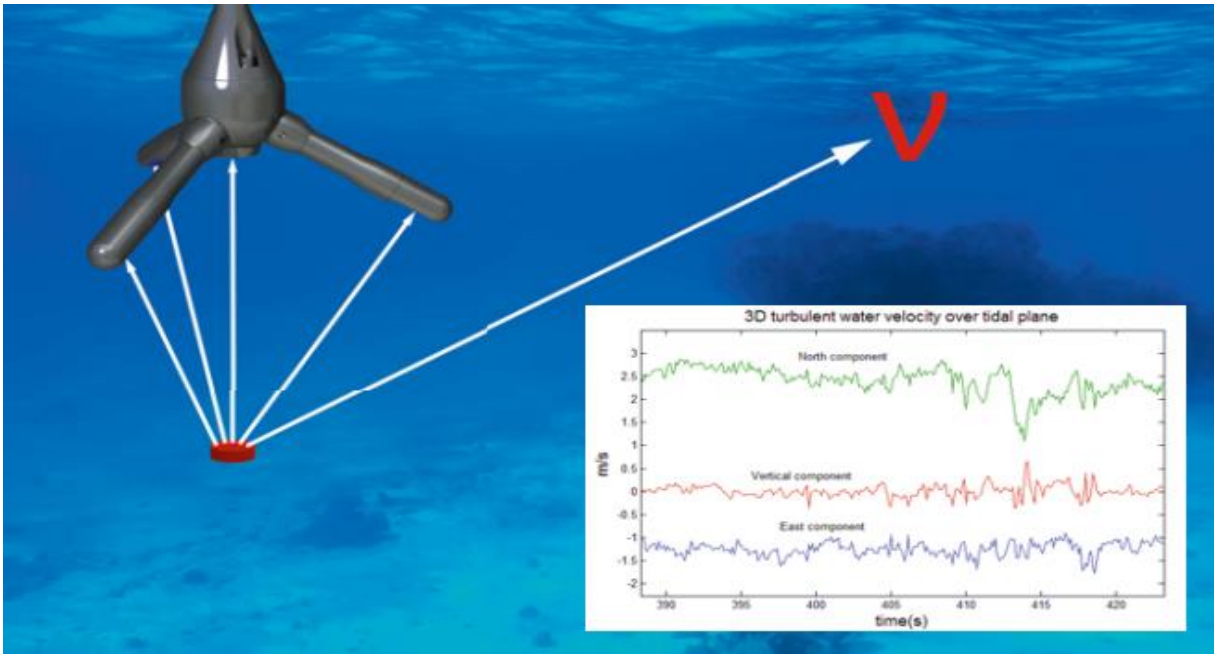

Figure 1.4: The three lines displayed in the graph representing the water velocity measured over three different vectors (North, East and Vertical) create a 3D image used to calculate the real velocity (Nortek A.S., 2013).

An indication for adjustment of the deployment settings is the correlation between data points. The correlation is shown during the measurements and should be above 80% to produce reliable results. Low correlations are caused by disturbances like for example a high Signal to Noise Ratio (SNR) interfering with the sound pulses transmitted by the instrument. These settings include information like salinity, sampling rate, geography and the use of continuous sampling or burst intervals. While it is not possible to set a sampling time for the Vector instrument, with the help of the Explore V software the data sets can be cut to a specific timeframe. Figure 1.5 shows the three data sets measured with the Vector instrument as displayed by the software program. The green and red lines indicate the vertical and horizontal current velocity while the blue line displays the stream wise velocity. As is expected in most situations without turbulent water conditions the vertical and horizontal measurements are close to zero. However, these two data sets can be used to adjust the stream wise velocity (Nortek A.S., 2013).

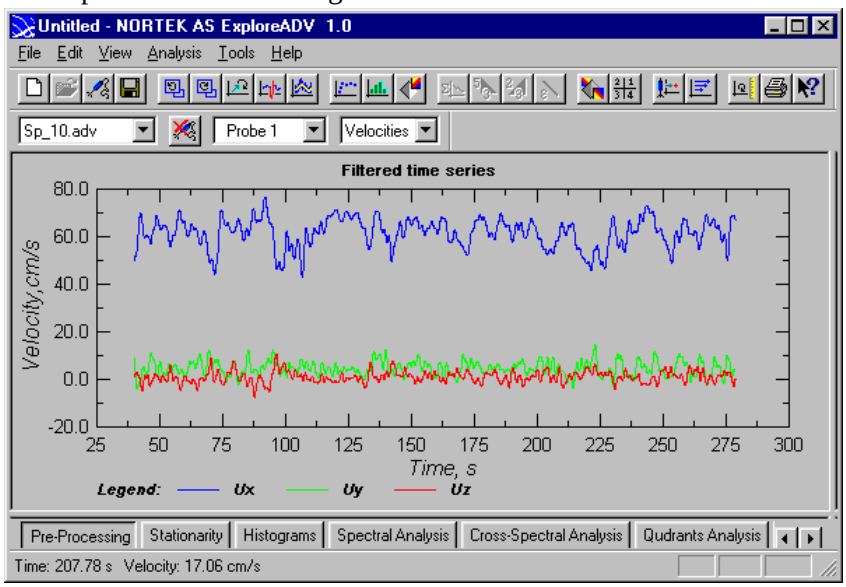

Figure 1.5: Vector measurement results as shown by the accompanying software programme (Nortek A.S., 2013).

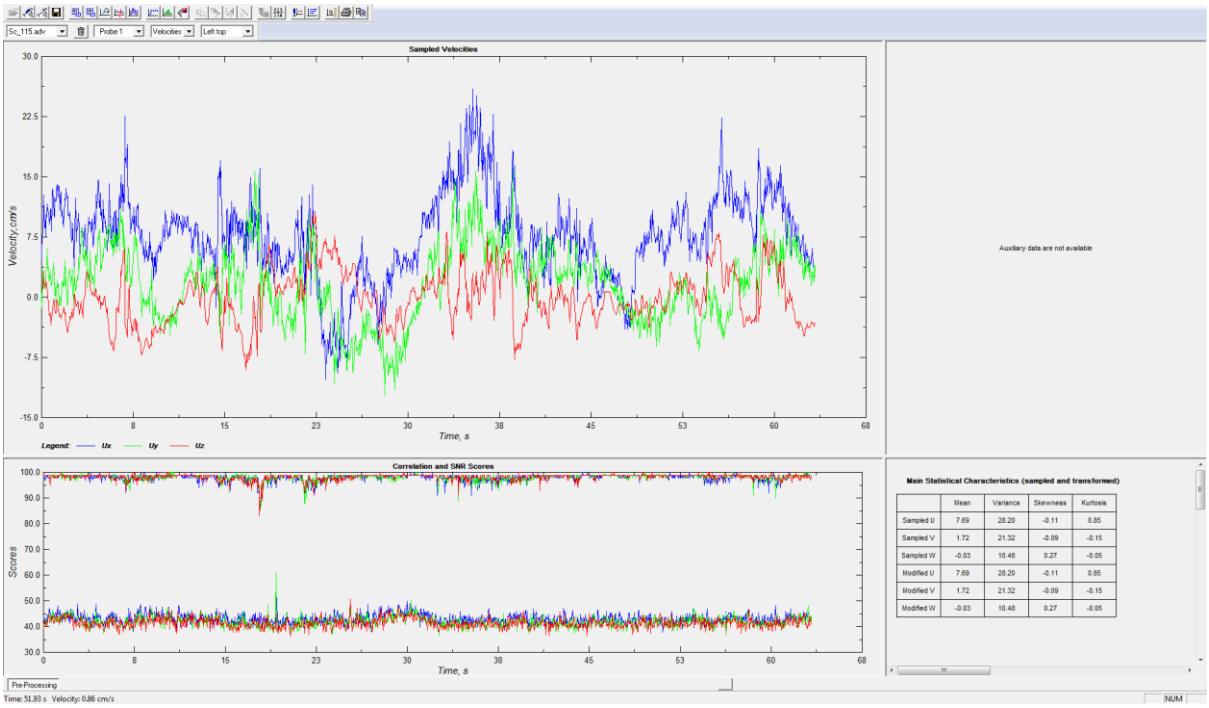

Figure 1.6: Explore V start-up screen showing a loaded velocity data set (upper graph) correlation of this data set (lower graph) and a table displaying the average water velocities for all data sets (Nortek A.S., 2013).

Measurement results are saved on the internal memory of the instrument and while this data can be read in the accompanied software the results will need to be imported to the Explore V software program for data processing. Explore V allows for reviewing, editing and analysis of large data sets. Figure 1.6 shows the Explore V start-up screen with an imported data set loaded. The top graph displays the three velocity measurement data sets, while the bottom graph shows a high correlation (lines at the top of the graph). The table on the lower right (Fig.: 1.7) displays the average water velocity for both the sampled data as the modified data sets. Modification of the measured results is carried out with the help of the data filtration tool. This tool allows for removal of certain data points by setting parameters on values influencing the measurements. For example, removing all data points with a correlation lower than 80% creates a higher overall correlation, resulting in more reliable results. Another parameter is the SNR; removing data points with a high SNR means the modified data set will have a low noise disturbance, again increasing reliability of the results. Another option is to install filters, like the spike filter. Fish swimming through the Vector sampling area can cause spikes in the velocity measurements, this filter allows for removal of these deviating data points. While Explore V allows further data analysis aimed at turbulence and wave dynamics, the basic data filtration described above is sufficient for water current velocity measurements (Nortek A.S., 2013).

Main Statistical Characteristics (sampled and transformed)

	Mean	Variance	Skewness	Kurtosis
Sampled U	7.69	28.20	-0.11	0.85
Sampled V	1.72	21.32	-0.09	-0.15
Sampled W	-0.03	10.48	0.27	-0.05
Modified U	7.69	28.20	-0.11	0.85
Modified V	1.72	21.32	-0.09	-0.15
Modified W	-0.03	10.48	0.27	-0.05

Figure 1.7: Explore V display of the average velocity for both the measured data as the data modified using the program (Nortek A.S., 2013).

2. Project goal

2.1 Project goal

In order to enable accurate and efficient monitoring of water current velocities, using the Vector acoustic velocimeter (Fig: 2.1), in *S. salar* rearing tanks the factors influencing the water velocity are examined. Knowledge on how factors as fish density, presence of feed-pellets, water quality and tank size influence the water velocity will result in a measurement plan for water velocity measurements using the Vector instrument at the Nofima centre for recirculation in aquaculture (Terjesen, et al., 2012) and *S. salar* rearing units in general. This measurement plan will enable adequate monitoring of water current velocities during research projects and the possibility to maintain optimal training regimes.

The main focus of the project is to measure water velocities. However, a survey of total suspended solids (TSS) measurements in salt water, described underneath, forms a side project that ties in to the main project goal. Acoustic velocity meters make use of the particles suspended in the water to measure the water velocity. Therefore, low concentrations of TSS could influence the reliability of the measurement. Salinity affects TSS, due to the effect of salt on the settling velocity of suspended particles. Salt ions collect suspended particles; binding them together. This increases the particle weight and thus the likelihood of settling to the bottom. This increase of particle weight disturbs TSS measurements (Hakanson, 2005). Different filter rinsing methods are tested to find the best variation of the standard method 2540 D. (APHA, 1999) for measuring TSS in salt water.

Figure 2.1: Vector 3D acoustic velocimeter, Nortek (Nortek A.S., 2013).

Project Goals:

Water velocity:	*Explore the different factors influencing the water velocity in Atlantic salmon (S. salar) rearing units using the Vector acoustic velocimeter. Knowledge on these factors will result in the development of a standardised plan for monitoring water velocities in research experiments.*
TSS:	*Optimising the standard method for measuring TSS (2540 D.) in salt water by testing different filter rinsing methods.*

2.2 Research questions

Main research question: Does the type of production unit, with differences in water quality, fish density, flow changes and TSS, affect the water velocity in the rearing unit and the reliability of acoustic water velocity measurements?

Hypotheses: *The main factor influencing the water velocities will be the fish density. Other factors will be the presence of feed in the rearing units and the orientation of the inlet pipes. A monitoring plan using the Vector instrument will take short measurements along all tank axes in order to determine the average tanks velocity, while water quality and fish density will ask for compensation of the system settings in order to ensure accurate monitoring.*

Sub-questions:

1. Do the following variables significantly influence the water current velocity (cm/s) in aquaculture rearing units?

    - Fish presence and density
    - Feed presence
    - Inlet pipe orientation
    - Water quality
    - Tank size

    Hypotheses: *Fish presence and density will have a significant influence on the water velocity, while the other factors will influence the velocity to a lesser extent. The presence of feed pellets could possibly disturb measurements as fish will move more to gather pellets, these changes can probably be accounted for by increasing sampling rate.*

2. How does the depth and distance from the tank edge of the measurement location influence the measurement?

    Hypotheses: *The instrument at least has to be submerged in order to be able to perform measurements; this makes it impossible to measure the area just below the water surface. Measuring the bottom of the rearing unit may also cause problems as the bottom may disturb the transmitted pulses. The sides of the tank will probably not disturb the measurements as the pulses are directed downwards, and the instrument design does not allow the transmitter to be positioned close to the tank edge.*

3. How many locations have to be measured using the Vector instrument to create a reliable velocity profile of the rearing units, and which location resembles the average tank velocity the closest?

   Hypotheses: *In order to create a tank profile locations will be measured over four axes. These locations differ in depth and distance from the tank edge. For monitoring purposes all axes will need to be measured as well as average velocities will differ at different axes. The location in the centre of the axis resembles the average axis velocity the closest.*

4. Does the average water velocity differ between the different tank axes?

   Hypotheses: *The average velocity over the axis will decrease as the axes move further from the tank inlet.*

5. What is the optimal Vector deployment setting for measuring water velocities in Atlantic salmon rearing units?

   Hypotheses: *The standard deployment settings of the instrument are probably sufficient for basic velocity measurements. Fish presence however may ask for an increased sampling rate to produce reliable results.*

2.3 TSS

The following research questions are focussed on the optimisation of the standard method for measuring TSS:

1. Does the standard method lose its accuracy when measuring samples of increasing salinities?
2. Does the rinsing water volume influence the accuracy of the measurement?
3. Does the rinsing water temperature influence the accuracy of the measurement?

Hypotheses: *The standard method will lose its accuracy where higher salinities are concerned, caused by salt connecting to the solids present in the water. This problem can be solved however by using an increased volume of rinsing water at an increased temperature.*

3. Method

3.1 The factors influencing the water velocity using the Vector acoustic velocity meter

To test which factors influence the water velocity in Atlantic salmon rearing units the water velocity was measured with the use of the Vector acoustic velocity meter (Nortek AS, 1999). These factors include: positioning of the inlet pipe, fish density, presence of feed in the water and the water flow in the tanks. In order to test these factors four 3,2 m^3 and two 0,5 m^3 tanks in the Nofima centre for recirculation in aquaculture (NCRA) (Terjesen, et al., 2012) have been used. In addition the instrument has been used at a commercial site to test the practicality of the Vector during samplings. In the following chapters the method for examination of each factor is described separately.

In preparation to the project a course in operating the Vector instrument was given at Nofima in Sunndalsøra. A Nortek employee gave a presentation concerning the instrument design and explained the measurement principle as well as the software used for data processing. Afterwards a demonstration of the instrument was given in the Nofima centre for recirculation. During this demonstration specific deployment setting were suggested taking into account the tank size, measured velocities and fish presence.

3.1.1 3,2 m^3 rearing units

3.1.1.1 The inlet water flow

Figure 3.1: 3,2 m^3 rearing unit inlet tube.

The 3,2 m^3 rearing units do not contain integrated flow meters, meaning the inlet water flow had to be determined manually. The inlet of tanks 105 and 106 were set to a flow of 140 L/min while tanks 102 and 103 were set to a flow of 40 L/min. To replicate identical conditions in both tanks is of importance when comparing eventual measurements. Therefore determining the inlet flow was done in cooperation with the research technicians working at the centre for recirculation to ensure reliability. Taking the inlet tube and collecting the water in a bucket for exactly 10 seconds determined the flow. By weighing the bucket the amount of litres discharged every 10 seconds is determined, one litre of water weighing 1 kilo. By multiplying this amount by 6 the discharge per minute is calculated. Subsequently the inlet valve was adjusted and the measurement repeated until the inlet flow of 140 or 40 L/min was reached. When the desired flow was reached the measurement was repeated at least three times to ensure reliability.

3.1.1.2 *Empty tank measurements*

A total of 36 locations were selected and velocity was in four 3,2 m^3 tanks to create a velocity profile for each tank (Fig 3.2). For all measurements done in the 3,2 m^3 tanks flow through salt water was used, taken from the nearby fjord. These locations were measured along four axes, each axis comprising 9 measurement locations. The four axes are named A, B, C and D with axis A being the one closest to the tank inlet (Fig 3.3). In order to create an overview of water velocities throughout the entire rearing unit the measurement locations were evenly distributed over each axis. The measurement locations are situated 20, 45 and 70 cm from the side of the tank, at three depths: 20, 50 and 80 cm underneath the water level.

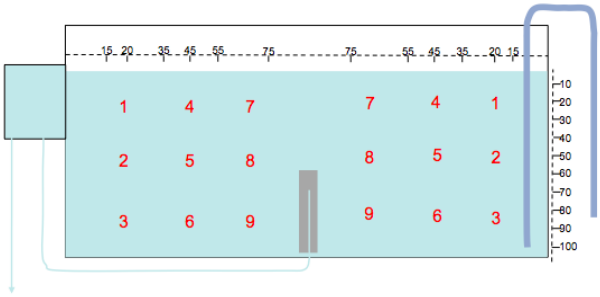

Figure 3.2: Section of a 3,2 m^3 tank with designated measurement locations (n=36).

The Vector instrument (Nortek AS, 1999) is used to measure each location for 5 minutes. The Vector was positioned by placing a wooden beam over the tank and putting the instrument through one of the three holes drilled in the beam (see figure 3.4). These three holes correspond to the three lengths measured from the tank edge (20, 45 and 70 cm). The instrument was lowered through the hole to measure at three designated depths. Tape was used to make three marks on the instrument, these marks helped to ensure exactly the same depths were measured in all tanks. The instrument measures a sampling area situated roughly 10 cm underneath the transmitter. Taking this into account the instrument was placed 10 cm above the measurement location. The instrument remained connected to the computer during all measurements to be able to keep track of the correlation, which needs to stay above 80%. Following the advice given during the Nortek presentation only minimal changes were made to the deployment settings. Sampling rate was set at 8 Hz and salinity at 35ppt. All recorded data were automatically stored in the internal memory and were imported to the computer for further analysis as described in 3.1.1.

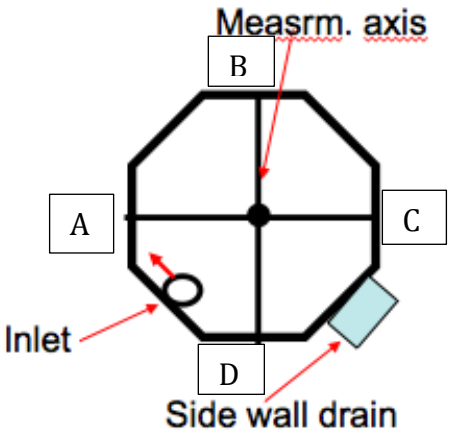

Figure 3.3: Top view of a 3,2 m^3 tank with the inlet, sidewall drain and the measurement axes designated.

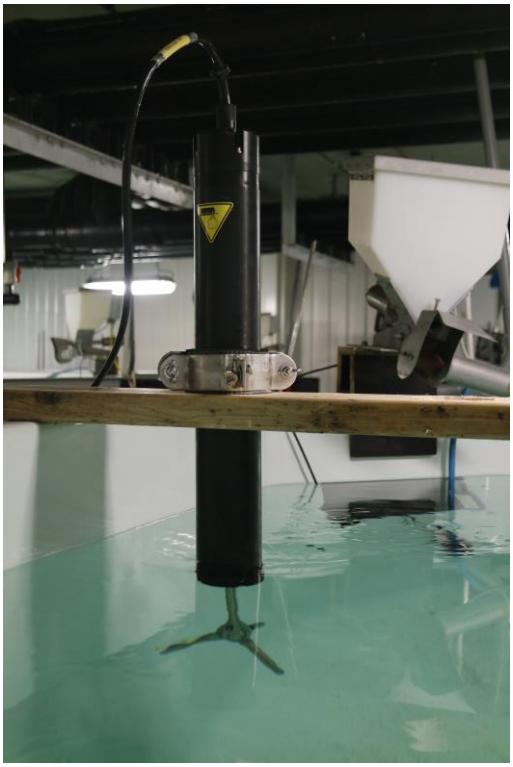

Figure 3.4: The Vector instrument used to measure the water velocity in an empty tank.

3.1.1.3 Influence of feed pellets on velocity measurements

To test if the presence of feed pellets has a direct influence on acoustic velocity measurements feeding regimes were started in the empty tanks. Each rearing unit contains an automatic feeding machine positioned on the side of the tank. The feeding machines are filled with feed pellets while a rotating paddle wheel scatters the pellets over the entire tank surface. A central computer in the research hall where specific feeding regimes can be set operates all feeding machines. The feed pellets in tank slowly sink to the bottom where they leave the tank through the outlet at the bottom of the tank. For this experiment continuous feeding was enabled. Meaning pellets were continuously added to the tank ensuring presence of feed pellets during all of the measurements. Tank profiles were created for all four of the tanks using the same measurement plan as described in 3.1.1.2.

Figure 3.5: Feeding machine attached to the side of a 3,2 m3 rearing unit at the Nofima centre for recirculation.

3.1.1.4 Influence of fish presence on velocity measurements

In order to test in what capacity fish presence influences the water velocity in the rearing units and how the instrument performs at different fish densities post-smolts were added to the four rearing units. 90 kg/m^3 post-smolts were added to tanks 105 and 106 set at a flow of 140 L/min while 25 kg/m^3 were added to tanks 102 and 103 set at a flow of 40 L/min. These proportions roughly correspond to the mass specific water use of 1,5 L/min/m^3 a ratio used in salmon rearing for setting inlet flows, which should ensure optimal training regimes. Tank profiles were created for all four of the tanks using the same measurement plan as describes in 3.1.1.2.

Figure 3.6: 3,2 m3 rearing unit containing 25 kg/m3 of post smolt.

Figure 3.7: 3,2 m3 rearing unit containing 90 kg/m3 of post smolt.

3.1.1.5 Influence of fish presence in combination with feed pellets on velocity measurements

While feed pellets may or may not have a direct influence, pellets in combination with fish presence could influence the measurements in a different way. Feeding regimes may influence fish movement as fish move to catch pellets floating in the water. The continuous feeding regime described in 3.1.1.3 was enabled to ensure feed pellets were distributed throughout the entire tank while the tanks were being measured as described in 3.1.1.2.

3.1.1 0,5 m^3 rearing units

Four 0,5 m^3 tanks present at the Nofima centre for recirculation were measured in order to test if the same changes occur at a different tank scale and if a smaller scale might cause problems for acoustic velocity measurements. The 0,5 m^3 tanks have an integrated flow meter positioned on the inlet tube so the flow of all four tanks was easily calibrated to a flow of 25 L/min. Two of the tanks were filled with flow through salt water as in the tests done in the 3,2 m^3 tanks while the other two were connected to the recirculation system in order to test the influence of water quality. In each tank the water velocity was measured at two locations, both located in the centre of the tank at depths of 25 and 80 cm. Measurements took 5 minutes and used the same deployment settings as described in 3.1.1.2. All four tanks were measured empty while tanks 301 and 303 were also measured after 10 fish were added.

3.1.2 Commercial scale

The Vector instrument was tested in commercial scale rearing units during two sampling trips at a commercial aquaculture site in Lensvik owned by Lerøy seafood. The main objective for this project was to test the operation efficiency at larger scale rearing units. There exists no equipment for mounting the instrument; therefore wooden beams, rope and a ladder present at the site were used. All measurements were done using the same deployment settings as during the measurements at the Nofima centre for recirculation as measurements showed correlation values above 80%.

Figure 3.8: Acoustic velocity measurements in commercial scale tanks in Lensvik.

On the first trip a tank profile was made of one of the tanks. A ladder was placed over the entire tank to which the instrument was attached with a steel pole, which allowed the instrument to be lowered to the bottom of the tank. Nine measurement locations were evenly distributed over one axis. All locations were measured as described in 3.1.1.2. During the second sampling trip the water velocity was measured in six tanks. As the tank profile method using a ladder proved to be too time consuming measurements were done at three locations. These locations were situated located 50 cm out from the tank edge at depths of 50, 100 and 150 cm.

Figure 3.9: A ladder being used in order to create a tank profile displaying water velocities in commercial scale rearing units at Lensvik.

3.1.3 Data processing and statistical comparison

All data recorded were automatically stored on the internal Vector memory. After importing the data files to the computer the Explore V software was used to analyse the results. This programme was used to remove bad measurements from the time series and determine the average velocity (cm/s). Once uploaded, the programme displays the three water velocity data sets independently (Stream wise, vertical and horizontal), in addition to the correlation values. The Explore V software allows the removing of inconsistent data point by adding filters (see figure 3.10), for example to remove velocity spikes caused by fish presence. During data processing a correlation and spike filter was used to ensure fish presence does not influence the measurement and all data point have a correlation above 80%. Furthermore all time series were cut back to 5 minutes so all measurements have exactly the same sampling time. After editing the data set the average velocities for each velocity vector are calculated and can be used to calculate the "real" stream wise velocity. As the instrument measures water velocity along three vectors it might occur that the x-axis is not positioned optimally (stream wise), in this case the real stream wise velocity will need to be calculated using the Pythagoras equation. As the water current flow in salmon rearing units is circular there will be little to no vertical flow, therefore the "real" stream wise water velocity was calculated by combining the stream wise and horizontal measurement data sets using the Pythagoras equation. After the data processing described above the different tanks and set-us were tested for significance making use of T-tests and ANOVA tests using Microsoft Excel and the programme stat-plus, in order to test which factors influence the water velocity and if this can be reliably measured using acoustics.

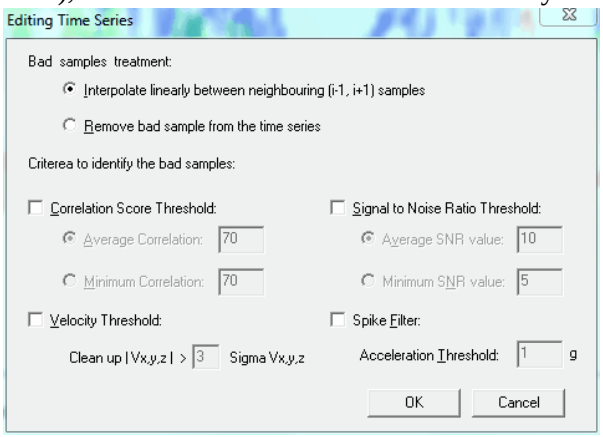

Figure 3.10: Explore V software; editing time series menu.

3.2 TSS

The method 2540 D (APHA, 1999) is used as a standard method for measuring TSS by filtrating water samples with GF/C filters and drying these filters at 103-105 °C. The weight of the filter before and after filtrating is used to calculate the TSS. There are however indications that the method is unreliable when measuring TSS in brackish and salt water samples, which are common when Atlantic salmon post-smolt is concerned, as the salt adheres to both the filter and the particles. It is possible to rinse the filters using deionized water, but the optimal volume of rinsing water and the role the temperature of the rinsing water plays in this process are not known at the moment. In the following experiments these variables will be tested against the standard method, in order to find the optimal method for measuring TSS in salt and brackish water.

3.2.1 Standard method for measuring Total suspended solids (2540 D.)

Described underneath is the standard method 2540D (APHA, 1999), for measuring TSS in water samples, which was used as a basis for the following experiments. This method was used in making a standard stock solutions used in the following experiments.

Figure 3.11: Filtration apparatus used for filtrating the test samples.

Whatman Glass microfiber filters (GF/C) were prepared by using a vacuum apparatus to pre-wash the filters using three successive 20 mL volumes of deionized water. The filters were placed in aluminium dishes and dried in an oven at a temperature between 103 and 105 °C. After drying the filter for one hour the filters were stored in a desiccator to allow the temperature to balance as hot objects may influence the measurement. Prior to filtration the sample was stirred in order to homogenise the solution. After filtration the filters were washed using three successive washes of 10mL volumes of deionized water, after which the filters were left to dry in the oven for one hour. The filters were then stored and cooled in the desiccator before being weighed. After weighing the TSS was calculate using the following equation:

$$mg\ total\ suspended\frac{solids}{Litre} = (A - B) \times \frac{1000}{sample\ volume\ (ml)}$$

A = weight of filter + dried residue (mg)
B = weight of filter (mg)

3.2.2 Preparation of stock solutions

Figure 3.12: Preparation of stock solution. Feed pellets were dissolved during 24 hours using a magnetic stirrer.

In order to compare the results from different experiments a standard solution is used. As one of the main sources of TSS in aquaculture rearing units comes from uneaten or partly dissolved feed pellets a stock solution was used made by dissolving feed pellets designed specifically for Atlantic salmon by Skretting. By using feed pellets the lab results represent actual measurements more closely, as the salt will adhere to the particles in the same way as it does in the rearing units. This stock solution was developed by dissolving known amounts of feed pellets in water while also being able to measure consistent values. To represent measurements done in RAS, TSS concentration of 20 mg/L or lower are desired as these concentrations are most common in culture units for Atlantic salmon (Terjesen, et al., 2012); (Vinci, Summerfelt, Creaser, & Ken, 2004); (Wolters, Masters, Vinci, & Sumerfelt, 2009).

To test the reliability of this stock solution four 2-Litre fresh water stock solutions were prepared by dissolving different amounts of feed pellets in each beaker: 0,5; 0,3 and 0,5 grams; all weighed using an analytical balance. Using larger amounts of pellets did not result in homogenous stock solutions. The pellets were left to dissolve for 24 hours while being stirred using a magnetic stirrer that also homogenises the solution. The stock solutions were divided into samples with differing volumes to perform replicate measurements and test if the sample volume influences the measurement. From each stock solution three 250 mL and one 1000 mL sample was made (See appendix 2 for an overview of all samples), after which the standard method described in 3.2.1 was used to analyse all samples. After this test the 250 mL samples for further testing was chosen, as the filters were not able to filtrate the larger sample efficiently. And 0,3 grams of pellets were used to prepare stock solutions as this amount of feed gave TSS close to the desired 20 mg/L while also producing consistent measurements.

3.2.3 Effect of salinity on the standard TSS method

To show the effect of salinity on TSS measurements, the standard method was tested at different salinities. Four 2-litre stock solutions were prepared as described in 3.2.2. By adding salt the salinity of three of the stock solutions was increased to 12, 22 and 32 ppt, while fresh water was used for the remaining stock as a blank. While salinities vary over the four stock solutions, identical amounts of feed pellets were added, meaning the measured TSS should be equal in each solution. The standard method was used to measure the TSS for each stock in triplicates, after which statistical comparison using T-tests shows if the measurements do indeed differ significantly.

3.2.4 Test 1: Effect of the post-filtration rinsing water volume on TSS measurements in brackish and salt water

The first test aimed at testing different volumes of post-filtration rinsing water. While the standard method dictates to use three successive washes of 10mL deionized water, this may not be enough to wash salt particles of the filter. Four stock solutions with salinities of 0, 12, 22 and 32 ppt were prepared to measure the TSS in triplicate using the standard method. However instead of using the prescribed 10 mL washing volume 100, 250 and 500mL washing volumes were used. The different volumes were tested in triplicate for each of the stock solutions. T-tests were used to test for significant differences, by comparing the results to the control (stock at 0ppt). The results of this test determine the volume of rinsing water needed to perform reliable measurements in salt water which will also be used in the further two tests.

3.2.5 Test 2: The effect of temperature of post-rinsing water on TSS measurements in brackish and salt water

Where the results of test 1 have determined the effect of increased volumes of rinsing water, test 2 explores if the temperature of this rinsing water can affect the reliability of TSS measurements. The method of this test is identical to the method described in 3.2.4 only the rinsing water volume has already been determined and instead of volume different rinsing water temperatures were tested.

3.2.6 Test 3: The effect of TSS concentration on TSS measurements in brackish and salt water

The focus of the last test is to take the variables determined in the previous two tests and test the efficiency of this optimized method at salinities of 0, 12, 22 and 32ppt and at different TSS levels. Using the method described in 3.2.2 three stock solution were prepared for each salinity. Each of these stock solutions contained a different amount of TSS by adding either 0,1; 0,3 or 0,5 grams of feed pellets. All stock solutions were measured in triplicate as described in 3.1.1 using the rinsing water volumes and temperatures found in 3.2.4 and 3.2.5. Measuring all samples and mutually comparing the results to the control (0ppt) using statistics confirmed the efficiency of the improved method.

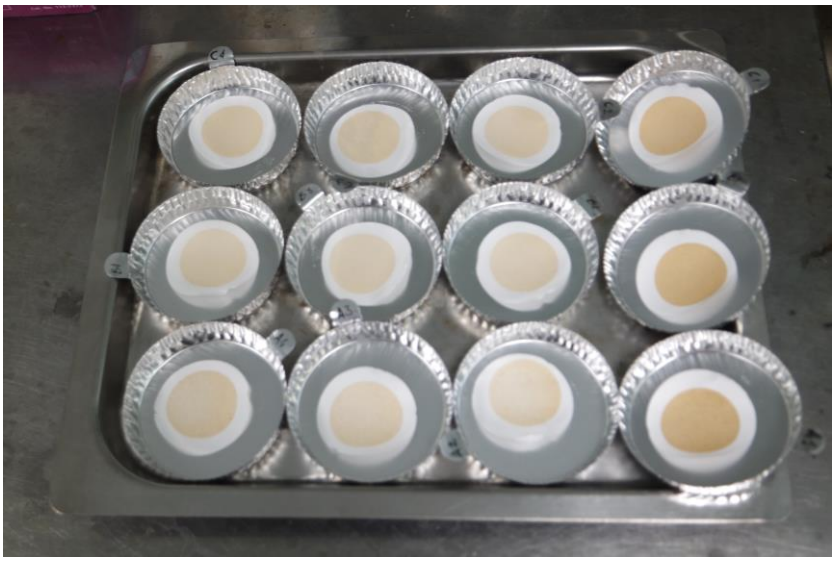

Figure 3.13: Whatman glass microfiber filters (GF/C) used for filtration.

4. Results

4.1 Velocity measurements

4.1.1 3,2 m^3 tanks

Tank 105 & 106 **Water flow:** **140 L/min**
Fish density: **90 kg/m^3**

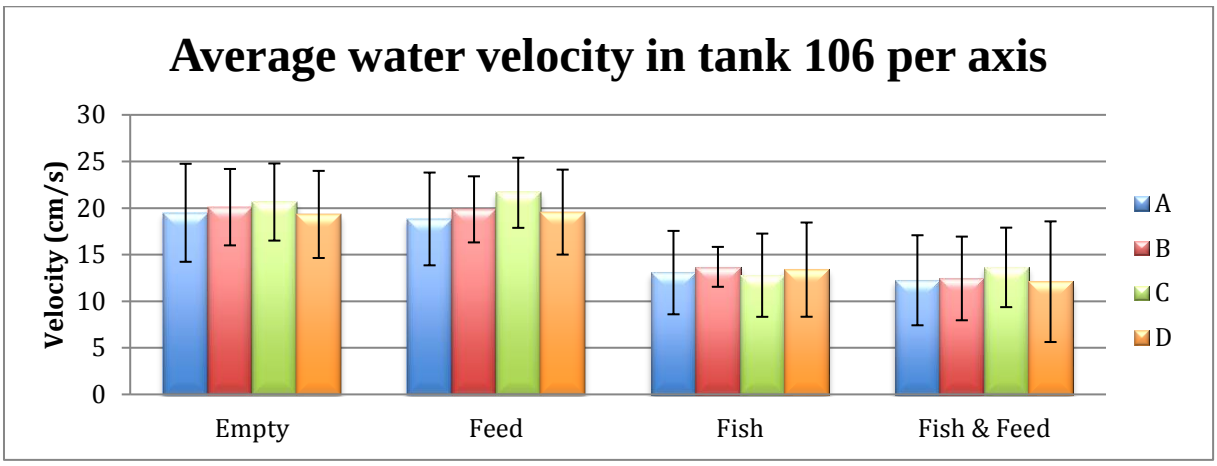

Figure 4.1: Average water velocity measured in tank 106 over the different axes, at each of the four tank set-ups.

Figure 4.1 shows the average water velocities over the different axes (A, B, C and D) to be fairly consistent, varying up to 0.89 %. However, the figure also shows high standard deviations for each axis. These high deviations for all axes can be explained by the fact that the measured water velocity decreases an average of 47% when the measurement location moves closer to the tank centre, as shown in Figure 4.2. This would suggest that, although the water velocity varies over each axis, it should not matter which axis is being measured to determine the average velocity in the entire tank. Figure 4.2 also shows that the measured water velocity only decreases when moving towards the tank centre but that the depth of the measurement location only has a minimal effect, differing up to 9%. Statistical comparison of the three data sets using ANOVA-tests gives a p-value of 0,87, meaning there is no difference in the water velocities at the different depths.

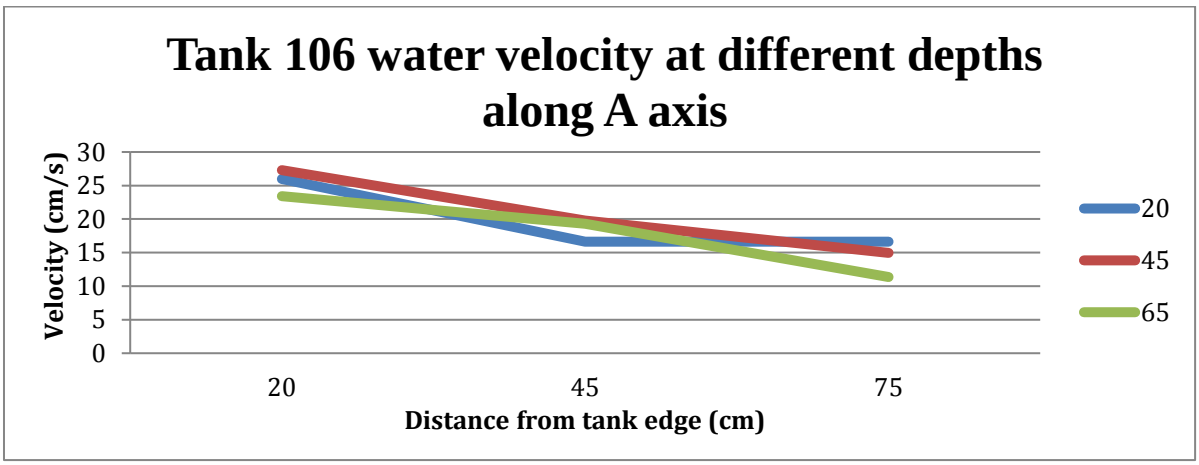

Figure 4.2: Water velocity measured at different depths along one axis, showing the depth has no effect but that water velocity decreases when moving closer to the centre of the tank.

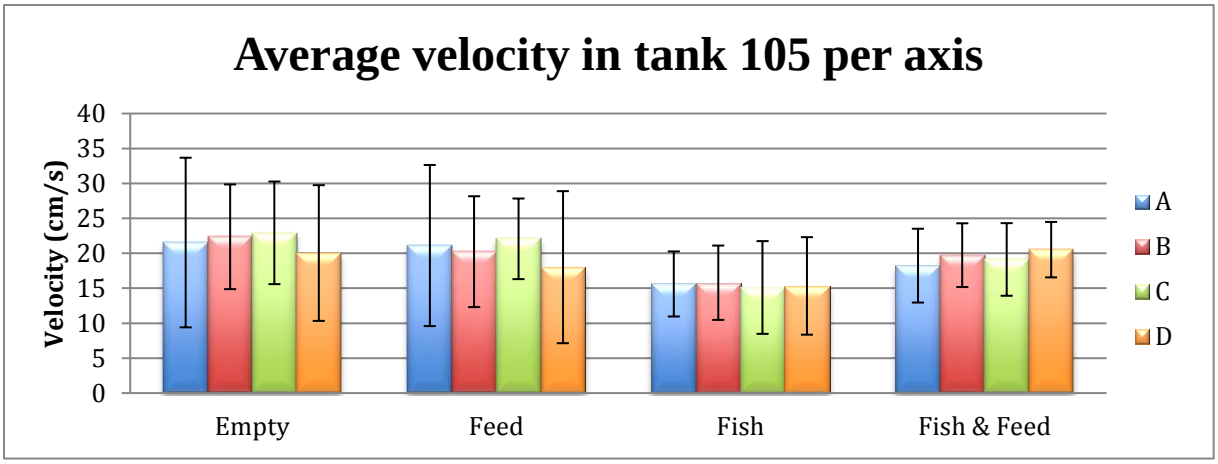

Figure 4.3: Average water velocity measured in tank 105 over the different axes, at each of the four tank set-ups.

The graph for tank 105 (Fig 4.3) looks similar to the graph for tank 106 (Fig 4.1) in regards to the high standard deviations and the decrease of 28,62% in water velocity in the set-up containing fish. At first sight the only difference between the two graphs is the 3,94 cm/s increase in velocity between the fish and feed set-up. Statistics confirm this difference between the fish and fish & feed set-up with the T-test giving a p-value of 0,002. However, the presence of feed pellets does not seem to make an impact in the empty tank set-up as statistical analysis shows a p-value of 0,53 when comparing the two data sets. Statistical comparison of the velocity measured in tank 106 shows that there was no significant difference in velocity between the empty tank and tank with feed set-up ($p = 0,89$) nor between the tank with fish and the tank with fish and feed ($p = 0,55$). Furthermore, as figure 4.1 does suggest, statistical comparison confirms that the datasets of the empty set-up and fish set-up differ ($p = 8,389E^{-9}$); this is also the case for tank 105 ($p = 0,00086$). While T-tests have been used to test for significance between different tank set-ups the axes in each set up have also been tested for significance using ANOVA tests. The ANOVA test makes is possible to compare more data sets at once, necessary when comparing the four axes. The p-values of these ANOVA tests show that there is no significant difference between the measured water velocities at the different axes. This is the case in all tank set-ups for both tanks 105 and 106. Statistical comparisons between the two tanks show that there is no significant difference in the empty set-up ($p = 0,28$) or the fish set-up ($p = 0,06$).

Tank 102 & 103 **Water flow:** **40 L/min**
Fish density: **25 kg/m^3**

Figure 4.4 shows the average water velocities over the different axes to be fairly consistent, as was the case with tanks 105 and 106, and shows high standard deviations as well. These high deviations for all the axes can again be explained by the fact that the velocities measured at the different locations vary an average of 52%, as shown in figure 4.5. The water velocity does not decrease as much in tank 102 (19,25%) compared to tank 105 (28,62%) and tank 106 (33,38%) set at a higher flow and containing higher fish densities. Using statistics to compare the feed set-up to the fish and fish & feed set-ups shows that there is indeed no significant difference, with T-tests resulting in p-values of 0,32 and 0,48. Furthermore, when using the T-test to compare the feed set-up to the empty set-up the p-value of 0,068 shows there is no significant difference. However, this does not mean that the measurements of the empty set-up are statistically similar to the fish and fish & feed set-up as the p-values of 0,0013 and 0,0021 shows there is a significant difference.

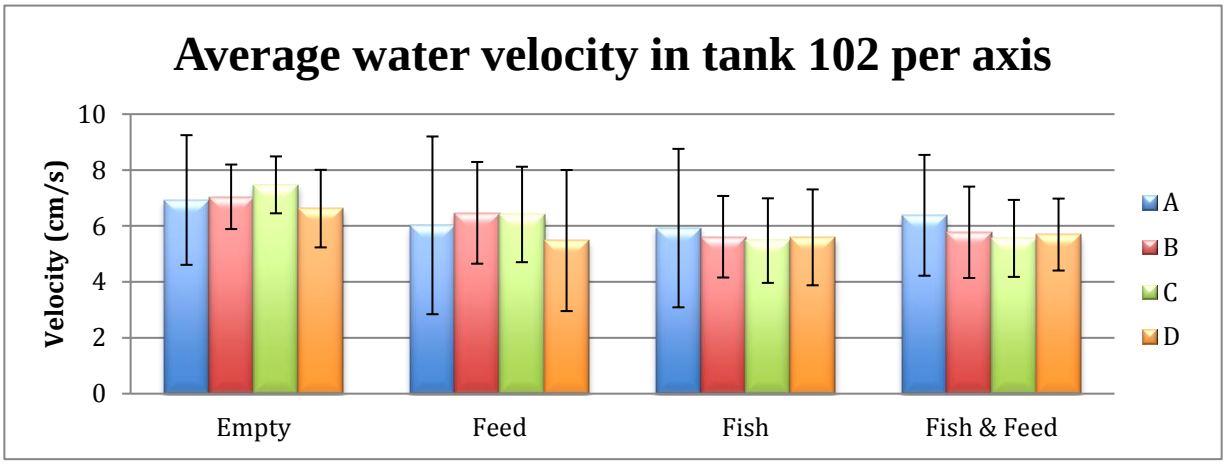

Figure 4.4: Average water velocity measured in tank 102 over the different axes, at each of the four tank set-ups.

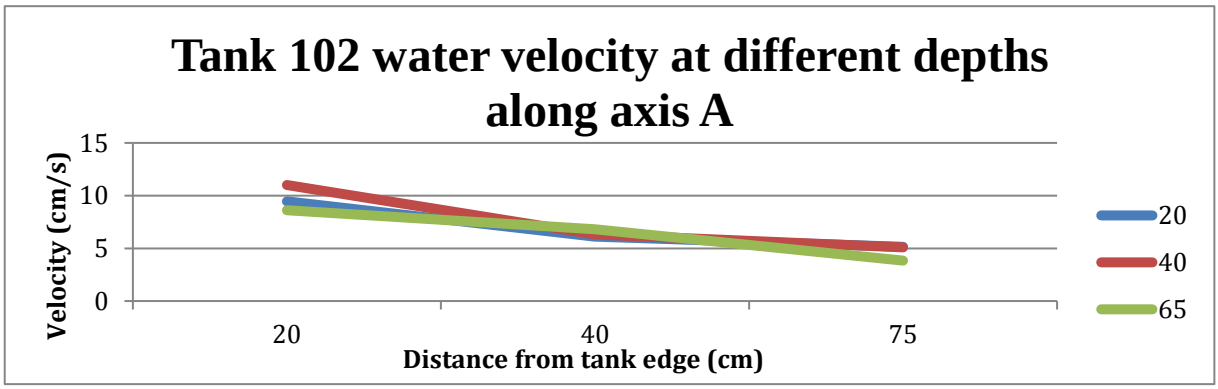

Figure 4.5: Water velocity measured at different depths along one axis, showing the depth has no effect but that water velocity decreases when moving closer to the centre of the tank.

Unlike in tank 102, figure 4.6 shows a decrease of in water velocity of 30,86% similar to the decrease in tank 105 and 106. Statistical analysis of the data sets again show the lack of impact the presence of feed pellets has on the measurement. T-tests comparing the empty set-up ($p = 0,79$) and set-up containing fish ($p = 0,61$) to the variant containing feed-pellets show no significant difference. As shown above there is a significant difference between the empty set-up and the set-up containing fish in tank 102 ($p = 0,0013$), the same is the case in tank 103 ($p = 4,47069E^{-5}$). Using ANOVA tests to compare the results measured at the different axes for significance shows that there is no significant difference between the axes in each of the different set-ups. This is the case for both tanks 102 and 103. Comparison of the two tanks also shows there is no significant difference in the empty set-up ($p = 0,09$) and the set-up containing fish ($p = 0,007$).

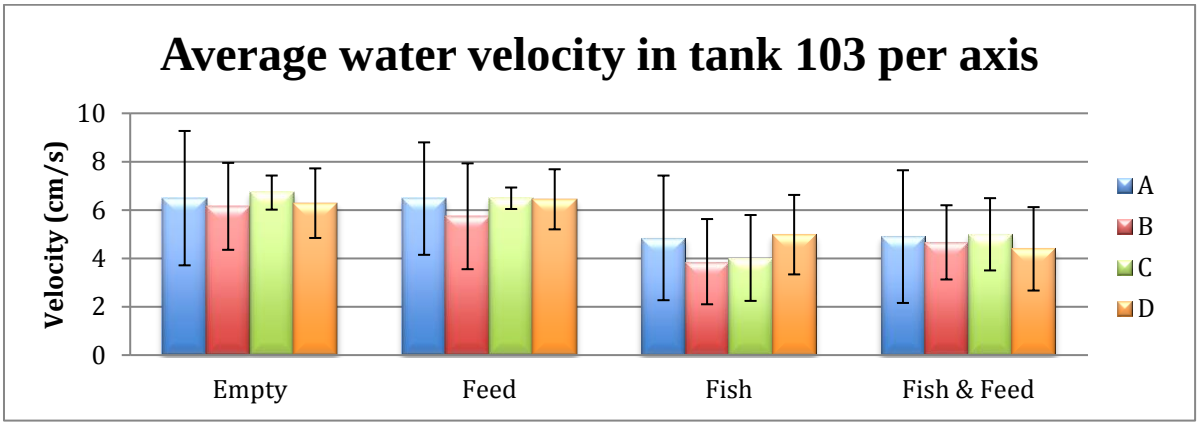

Figure 4.6: Average water velocity measured in tank 103 over the different axes, at each of the four tank set-ups.

4.1.2 Water velocity decrease

Figures 4.7 and 4.8 display the decrease in water velocity caused by the presence of post-smolts (90 kg/m^3) in rearing units 105 and 106; set at a water flow of 140 L/min. Both figures show the average water velocity, measured before and after the post-smolts were added, in each of the tanks axes. The water velocity decrease appears to be consistent at each of the axes, what can be expected as statistics has shown that measurements at different axes do not significantly differ from each other. The average water velocity in both tanks decreases approximately 28,62% in tank 105 and 33,38% in tank 106.

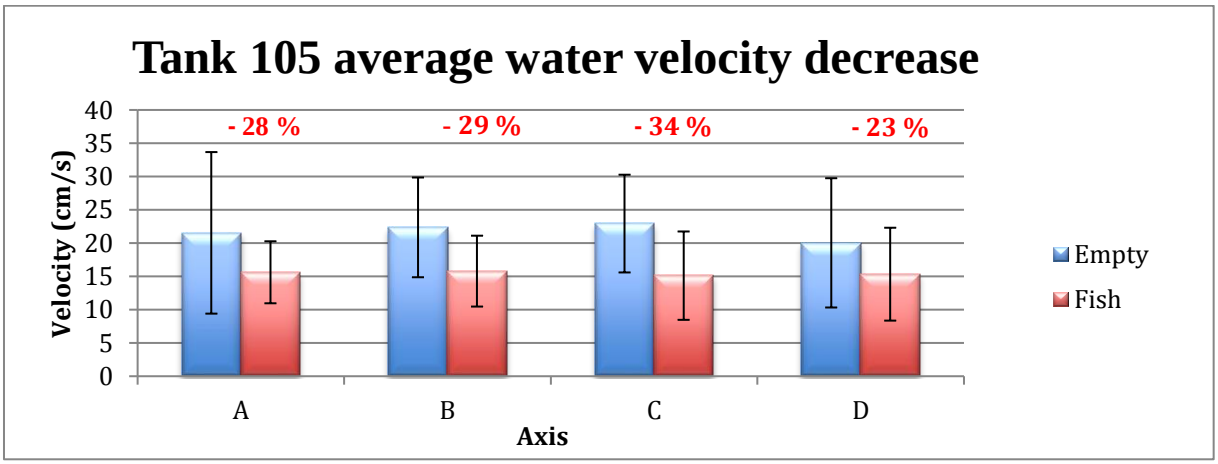

Figure 4.7: Average water velocity decrease in each axis in tank 105 caused by fish presence in the tank.

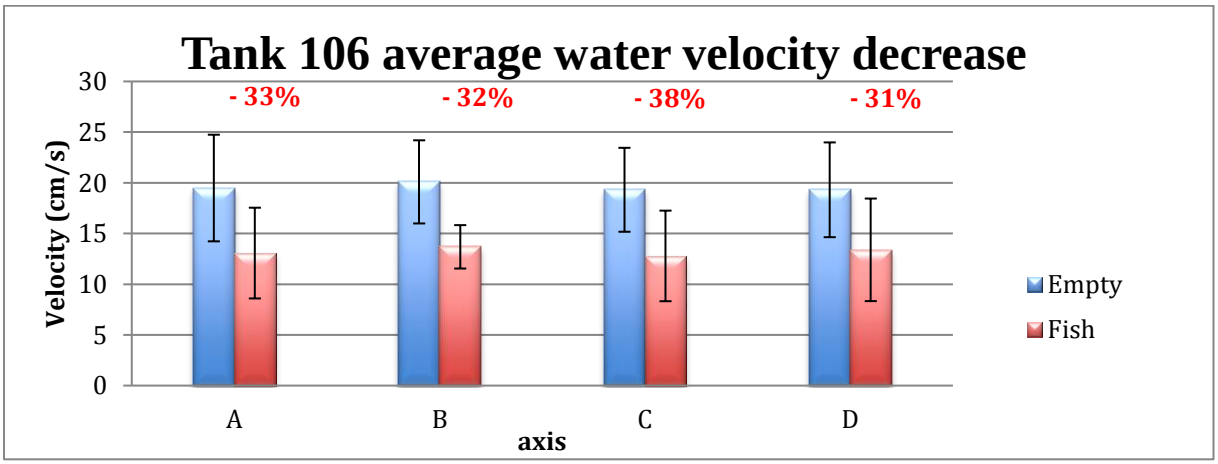

Figure 4.8: Average water velocity decrease in each axis in tank 106 caused by fish presence in the tank.

Figures 4.9 and 4.10 display the decrease in water velocity caused by the presence of post-smolts (25 kg/m^3) in rearing units 102 (19,25%) and 103 (30,86%); set at a water flow of 40 L/min. As shown in figure 4.4 the measurements in tank 102 deviate from the measurements in other tanks. This can also be seen in figure 4.9, as the average velocity decrease is significantly lower compared to the decrease in the other tanks. The total average water velocity decrease of 30,86% in tank 103 resembles the situation in tank 105 and 106. This similar decrease in both situations suggests there is a correlation between the mass specific water use and the water velocity decrease. As a similar decrease occurs at the same mass specific water use under different water flows and fish densities.

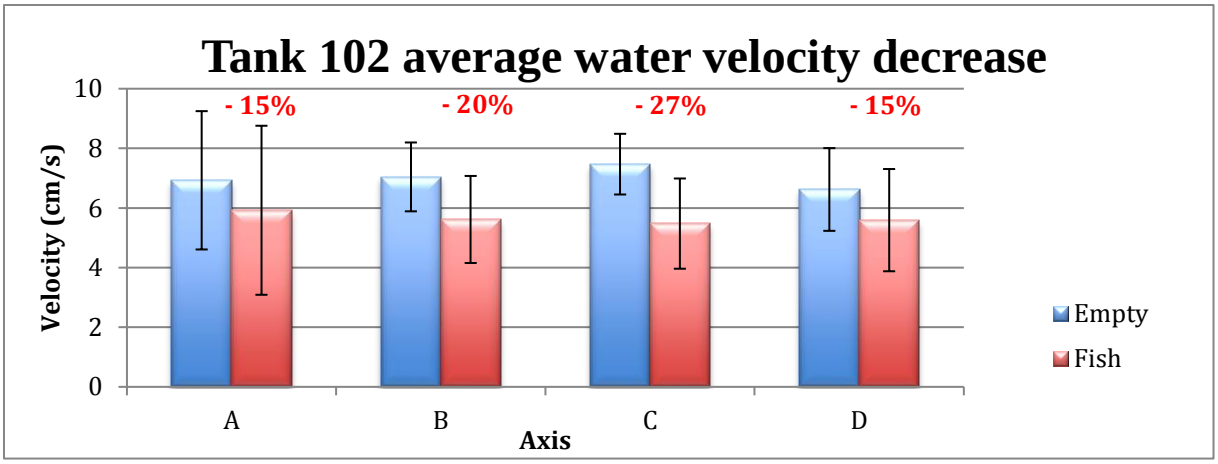

Figure 4.9: Average water velocity decrease in each axis in tank 102 caused by fish presence in the tank.

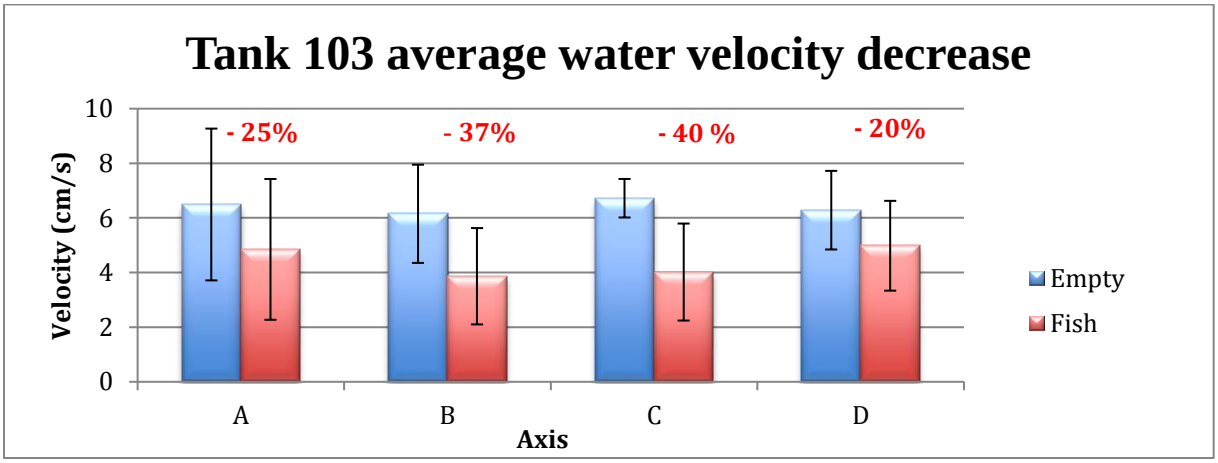

Figure 4.10: Average water velocity decrease in each axis in tank 103 caused by fish presence in the tank.

4.1.3 0,5 m^3 tanks

Figure 4.11 displays the average velocity of the two locations measured in each of the four 0,5 m^3 tanks at the Nofima centre for recirculation. Tanks 301 and 302 are connected to the recirculation system. Tanks 303 and 304 were connected to the flow through system, just as the

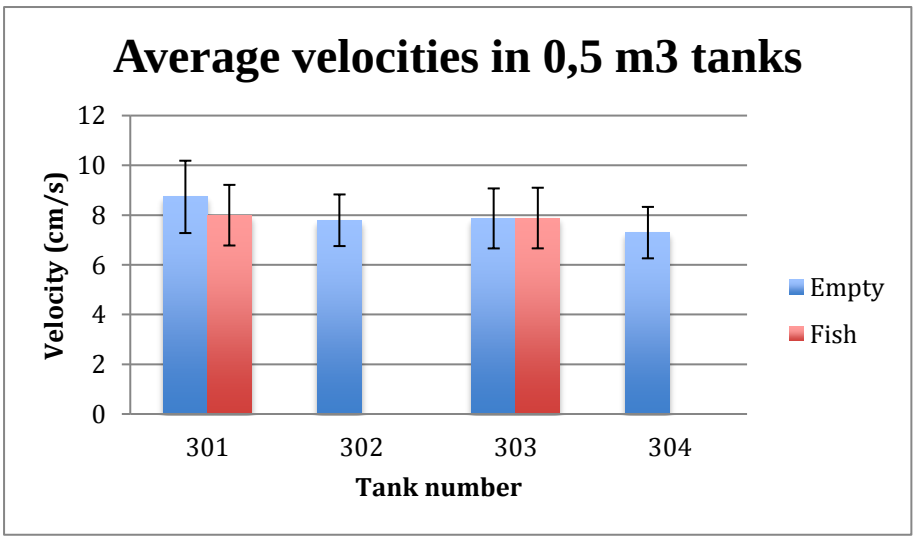

Figure 4.11: Average velocities measured in four 0,5 m^3 tanks. Tanks 301 and 302 were connected to the recirculation system, where tanks 303 and 304 were connected to the flow through system. Tanks 301 and303 were measured both empty and containing fish.

3,2 m^3 tanks, receiving relatively cleaner water than the RAS system. Velocity was also measured in two of the tanks while fish were present in the tank. Where the 3,2 m^3 tanks showed a clear velocity decrease the 0,5 m^3 show no significant decrease in water velocity when fish were introduced. This is also confirmed by statistical analyses, which shows there is no significant difference between the set-ups with or without fish. Furthermore, there is also no significant difference between the tanks connected to the RAS and the two tanks using flow through water. Suggesting the difference in amount of particles present in the water does not influence the reliability of the measurement.

4.1.4 Commercial scale

On the first sampling at the commercial site four out of six rearing units were measured, as two of the tanks still had to be stocked with fish, and part of a tank profile was created. On the second sampling trip all six of the rearing units present in the hall were measured. The results from the first sampling were compared to the results from the seconds sampling trip to test for any changes over time, caused by fish growth or redistribution. Table 4.1 displays the p-values, which show that there are no significant differences between the average water velocities measured during the first and second sampling. Tanks 83, 84, 86 and 87 display similar water velocities. While the velocity measured in tank 85 is lower than average and the velocity in tank 88 is higher than average (Fig 4.12). This is probably the result of fish redistribution, as the inlet flow was probably not adjusted accordingly.

Table 4.1: Results from T-test comparing data from the first and second sampling at Leroy.

Tank number	P-value
83	0,057
84	0,879
86	0,931
87	0,321

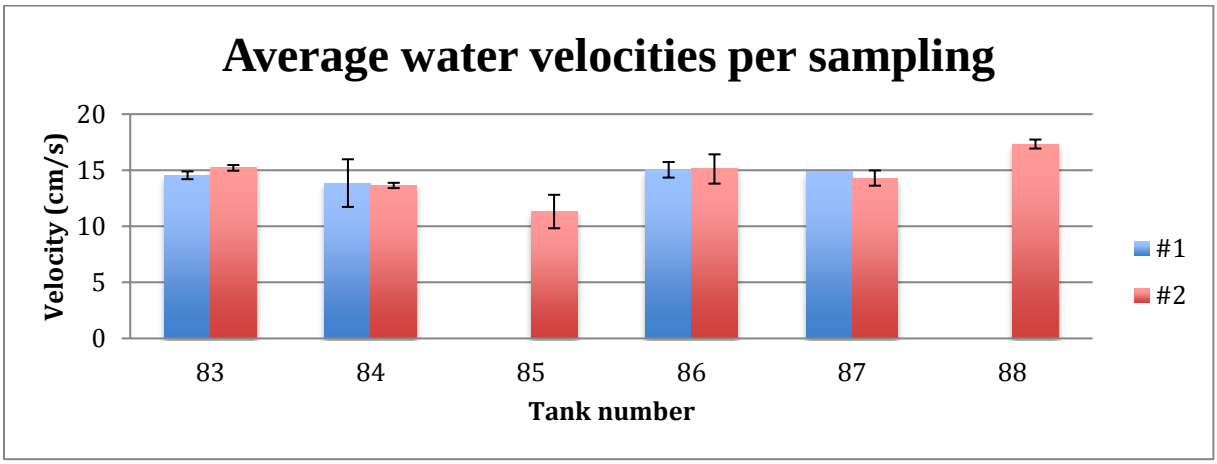

Figure 4.12: Average water velocities measured in commercial scale rearing units at Leroy in Lensvik. The graph displays data from 2 sampling trips.

4.2 TSS

4.2.1 Stock solution

Figure 4.13 shows the TSS concentration of three stock solutions, made from different amounts of fish feed, measured using the standard method. The concentrations of the three stock solutions are averages of four replicate samples. Because of the lower standard deviations an amount of 0,3g of fish feed was used to make the stock solution during further testing. In further testing of the standard

method high deviations between stock replicates were recorded, as can be seen in figure 4.14, assumingly caused by particles in the stock solution. Compared to the fish feed dog feed dissolves easier and gave more stable TSS results at a lower TSS level compared to the fish feed (Fig: 4.14). Although dog feed gave the more stable measurements in the end fish feed was used in preparation of the stock solutions for the final tests, as this is more representable for measurements in aquaculture. Further testing of the stock, the results of which are shown in figure 4.15, indicate the possibility of producing identical stock solutions. Statistical comparison shows this as well as the p-value of 0,98 indicates no significant difference between the three stock solutions. However, the high standard deviation indicates large variances between the independent samples.

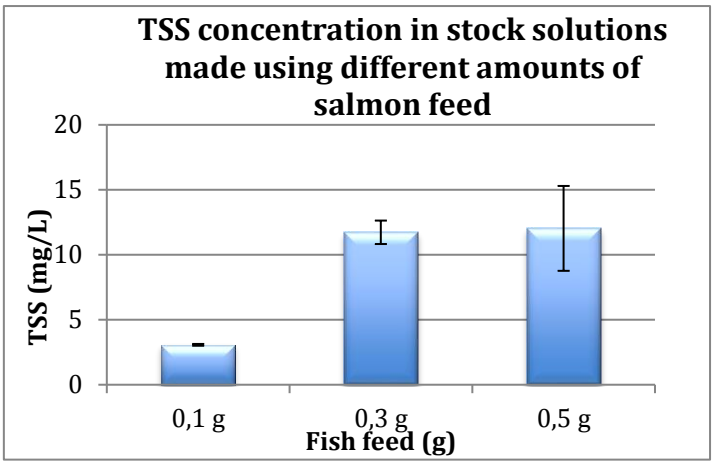

Figure 4.13: TSS in stock solutions made using different amounts of salmon feed measured using the standard method.

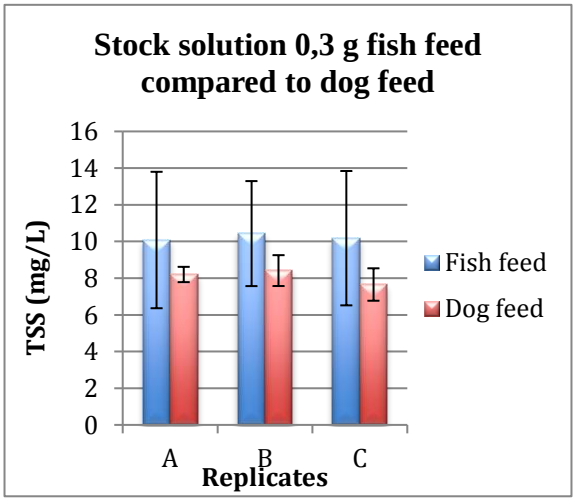

Figure 4.14: Stock solution made of dissolved feed pellets compared to stock solutions made by using dog feed. The stock using dog feed shows lower standard deviations as the pellets are easier to dissolve.

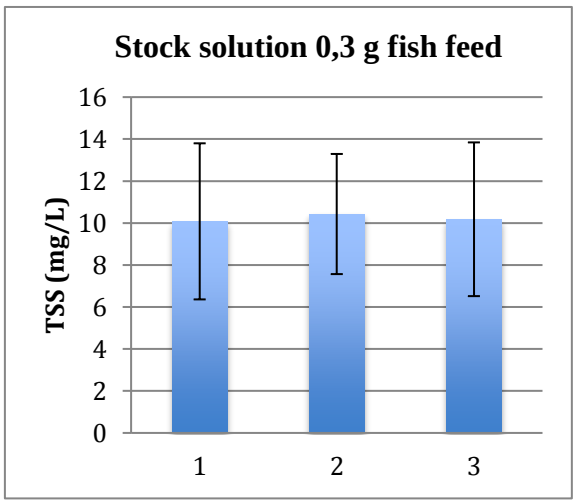

Figure 4.15: Three stock solutions each containing 0,3g of dissolved fish feed pellets. Average TSS content was determined by analysing four samples poured from the stock solution.

4.2.2 Test results

Figure 4.16 shows a reduction in the measured TSS values when the amount of rinsing water is increased. While the measurement method appears to have an effect on the TSS content the salinity appears to only have a minor influence, as the TSS content differs only 0,4 mg/L between the 0 ppt and 32 ppt stock solution. This may however be caused by variation in TSS contents over the samples, as shown in figure 4.17. For some reason the first samples poured from the stock solution contain a higher TSS content than the last samples poured. Figure 4.16 does however show that in the case of the varying methods the TSS content increases when the salinity is increased. Except in the case of the 300mL rinsing water at 32 degrees, meaning this method may provide a viable alternative to the standard method when measuring TSS in different salinities.

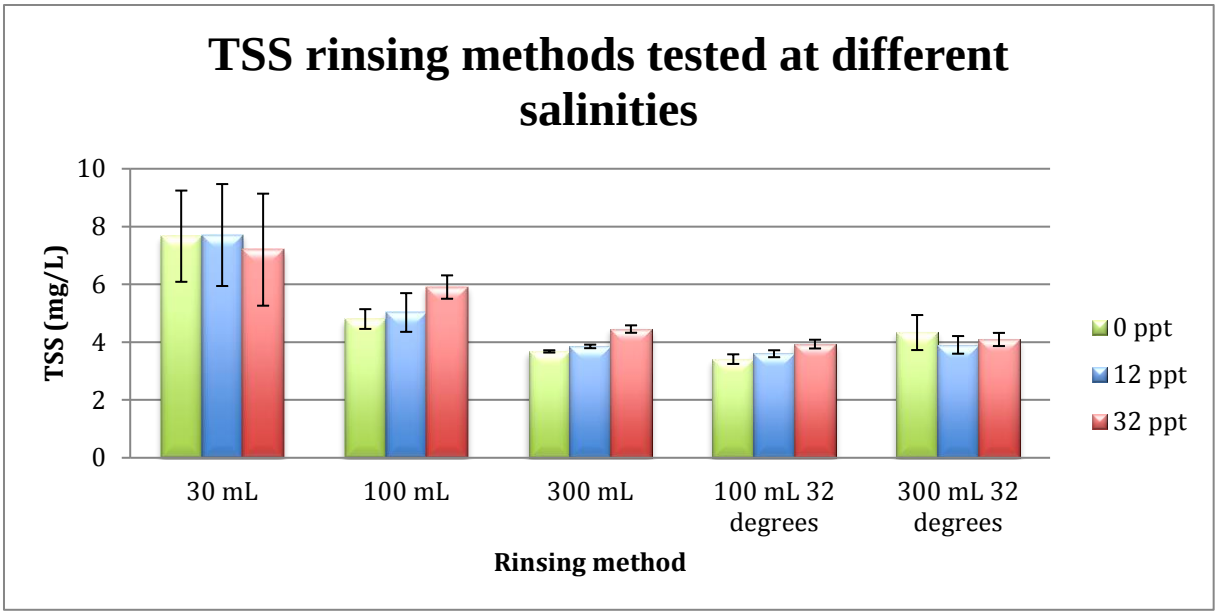

Figure 4.16: TSS measurements testing the reliability of the different methods at increasing salinities.

While in most cases the results look relatively stable statistical comparison was applied to test for similarities and significant differences, see appendix four for all statistical results. Again there was no significant difference between the three stock solutions (p-value: 0,82915), but just as in 4.2.1 the stock solutions displayed large standard deviations. Except for the 300 mL rinsing method there different rinsing methods do not significantly vary when the salinity increases. There is also no significant difference in the standard rinsing method, which would suggest this method is already able to reliably measure TSS at increased salinities. When testing the reliability of the different rinsing methods over the varying salinities all tests show low p-values, meaning the rinsing methods have a significant impact on the TSS measurement. This could however also be caused by the apparent regression of TSS concentrations over the samples as shown in figure 4.17. This view is also contradicted by the fact that when comparing each method separately over the three salinities none of the methods, exempting the 300mL and 100 mL at 32 degrees method, show significant differences. Which would mean that the type of method used does not affect the reliability at increasing salinities.

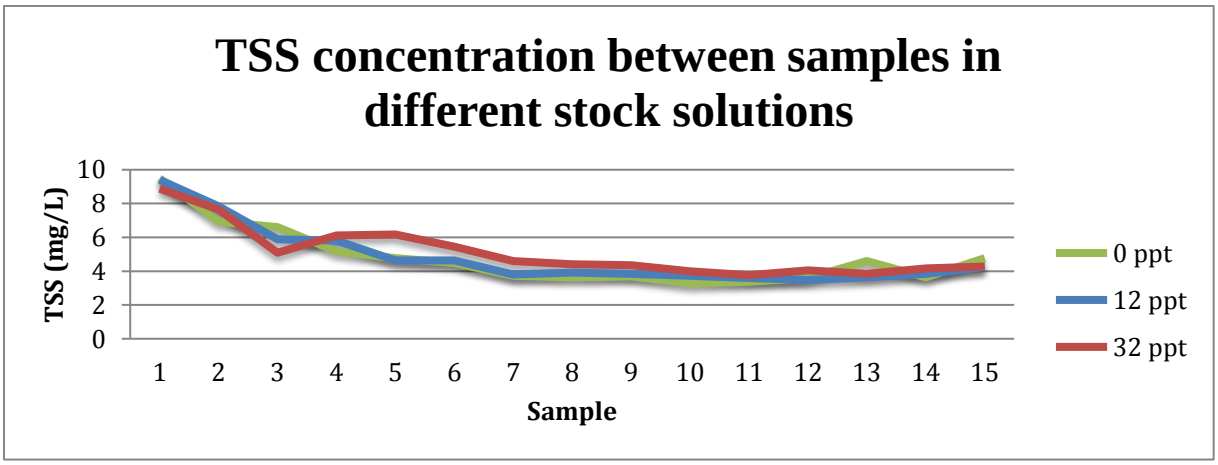

Figure 4.17: Measured regression of TSS concentration over the 15 samples.

5. Discussion

5.1 Water velocity measurements

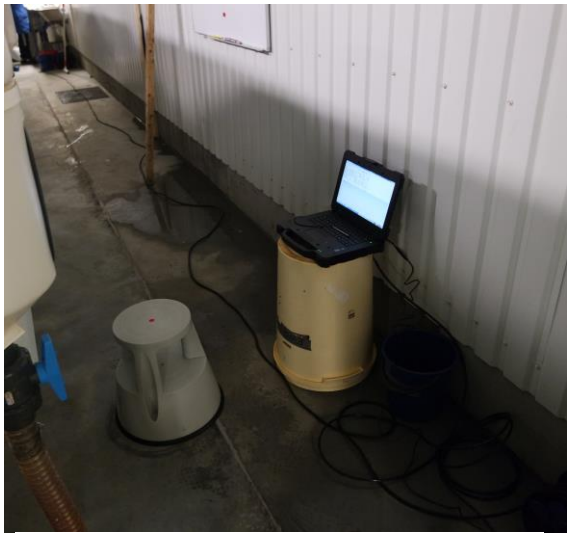

Figure 5.1: Computer attached to the Vector instrument during measurements running the accompanying software. This computer was used to operate the instrument and monitor the measurements.

While the Vector instrument required some training to be used accurately and efficiently, these skills were quickly learned with help from the NORTEK presentation. The instrument was designed with turbulence and wave measurements in mind (Nortek) and therefore has numerous settings and options not used in the straightforward vertical water current velocity measurements. This meant that while operation of the instrument seems difficult, it is actually a straightforward procedure that can be easily managed and monitored by leaving a computer attached to the instrument during measurements. The same goes for the Explore V software used to analyse the measurement data, which offers a wealth of options to edit the data. Most of these options regard turbulence measurements and the basic data filtration was sufficient to analyse the velocity results. The correlation of 80% may have even been a bit strict according to NORTEK as this may have filtered out some good data points as well (see appendix 5). Noise pollution is another factor that needs to be taken into account when using acoustics to measure the velocity. Both aquaculture research and commercial sites can experience noise caused by for example the water treatment or feeding facilities. While beforehand there was concern this could cause a problem there were never any indications of data inconsistencies caused by noise pollution. Special care has to be taken while importing data from the instrument to the computer as some data sets have gone missing during importing.

Water velocity results from the 3,2 m^3 rearing units have largely been according to expectations. Being similar between the duplicate tanks and decreasing when moving closer to the centre and bottom of the tank. While there were no difficulties measuring the pre-determined measurement locations moving any closer to the tank edges would have caused interference. This interference was easy to spot while monitoring the measurement, as the velocity reading would spike constantly which also caused the correlation to drop. The impact of fish presence, decreasing the water velocity with about 30% was larger than expected and surprisingly appears to show a correlation with the mass specific water use. Tank 102 differs from the rest of the tanks both in average velocity decrease as in the statistical comparison to tank 103. This could be the cause of in variance in the inlet flow or because some of the velocity data from tank 103 are missing. These results were missing because of a malfunction during data importing. The difference in water quality between flow through and RAS, which was also tested in these tanks, had no impact on the acoustic velocity measurements. This means that the difference in amount of particles present in the water does not influence significantly influence the instruments reliability, therefore the Vector instrument can be reliably used in the centre for recirculation.

The instrument was procured with the intention to measure water velocities both at the Nofima centre for recirculation as commercial sites. Positioning of the instrument does not cause difficulties at the centre for recirculation as the small tank scales and walkways over the larger scale tanks allows for easy installation. Commercial sites my cause problems when using the Vector as tank design and accessibility differ from site to site. As seen in figures 3.9 and 3.10 wooden beams, rope and ladders were used in order to position the instrument correctly. This improvisation is time consuming and causes limitations on the places able to measure. While using the ladder to be able to measure locations throughout the tank only nine locations were measured during an entire sampling day. When using a propeller to measure water velocities Nofima research technicians make use of a simple construction consisting of a wooden beam fastened to the tank edge. This allows for the propeller to be positioned some distance from the tank edge. This approach is not as easy where the Vector is concerned, as the instrument is substantially heavier. While some movement of the instrument during measurements can be compensated using the Explore V software, tilts less than 5 degrees should be the aim (Nortek A.S., 2013). Therefore it is desirable to design a construction, which can be easily attached to the tank edges while also being robust enough to hold the Vector. Pictures of the site being measured will also help in preparing for any difficulties.

5.2 TSS

The creation of a reliable stock solution proved to be the main hindrance during the testing of alternative methods for measuring TSS. A reliable stock solution was necessary in order to compare the different variations on the standard method. While the average TSS concentrations between stock solutions were often not similar and did not differ significantly from each other, these averages were always accompanied by large standard deviations. The fish feed pellets proved too difficult to dissolve properly in order to create a homogenous stock solution. This makes it difficult to provide a solid reliable answer using the results from the testing. As there exists no stock solution for measuring TSS testing should be repeated using a more stable stock solution in order to increase the credibility of the results. This could be accomplished by optimising the process of dissolving the feed pellets.

While not being reliable enough to make outright conclusions the results do suggest the alternative methods that were tested do not increase reliability at increased salinities. As shown in figure 4.17 the TSS concentration gradually decreases over the samples. The order shown is the order in which the samples were poured and analysed. This figure can be interpreted in two ways. Either the first samples poured from each stock solution contain a higher TSS concentration than subsequent samples or the salt adhering to the particles causes this higher concentration. This would confirm the hypotheses that salt can adhere to the solids present in the water disturbing TSS measurements (Hakanson, 2005). This view is however contradicted by the fact that the standard method measures statistically the same TSS concentration at each of the three salinities. If the standard method would not be able to reliably measure TSS at different salinities the measured concentrations would increase when the salinity increases which is not the case, as can be seen in figure 4.16. As stated above the use of a more stable stock solution in further testing could confirm these assumptions.

6. Conclusion

6.1 Acoustic water velocity measurements

In the 3,2 m^3 rearing units fish presence has shown to have a significant impact on the water velocity causing average velocity decreases of up to 33,38%. The results suggest a correlation between this decrease and the mass specific water use (L/min/kg). This makes it possible to predict velocity decreases and adjust the inlet flow accordingly. This significant velocity decrease did however not occur in the 0,5 m^3 rearing units. Fish presence proved to be the only factor with a significant impact on the velocity and acoustic measurements. Statistics have shown that the presence of feed pellets, both in empty tanks as in combination with fish presence, have no significant impact. This means acoustic velocity measurements can be done regardless of feeding taking place. The four 0,5 m^3 tanks, in which the impact of differences in water quality were researched, have shown that differences in water quality between flow through and RAS are not significant enough to impact acoustic velocity measurements.

During the presentation by Nortek the advice was given to change as few settings as possible and look only to the deployment settings menu. This advice proved to be valid as slight changes in sampling rate, salinity and coordinates system resulted in average data correlations of above 80%. No problems were encountered in measuring the predetermined measurement locations. However, moving any closer to the tank edges will cause interference to the measurement. While the measured velocity varies between the measurement locations, the average velocities in each tank axis do not differ from each other. While a difference was expected as the water velocity supposedly decreases when moving farther away from the tank inlet. Statistical comparison has however shown that there is no significant difference, and thus measurements can take place at only one axis and are not influenced by the inlet pipe orientation. The measured water velocity varies between most of the measurement locations, the water velocity being the highest along the tanks edges while slowly decreasing where the locations move closer to the centre and bottom of the tank. The water velocity measured in location 5, located at the centre of each axis, is closest to that of the overall tank average. Meaning that in order to measure the average water velocity in the 3,2 m^3 rearing units only one location has to be measured, situated 45cm from the tank edge at a depth of 50cm.

6.2 TSS

As mentioned in the discussion the results from the TSS testing are not reliable enough to make credible conclusions, nonetheless the results suggest the following. The results displayed in figure 4.16 suggest that the salinity does not influence the reliability of the standard method for measuring TSS (2540 D.) as the method measures similar concentrations at three different salinities. This same figure shows that the alternative rinsing methods measure significantly lower TSS concentrations, but also measures similar concentrations at the different salinities. If this decrease in the measured concentration is caused by inconsistencies between samples, as described 5.2, the TSS results show that alternative rinsing water volumes and temperatures of rinsing water have no effect on the reliability of TSS measurements at increased salinities.

6.3 Recommendations

6.3.1 Water velocity measurements

Monitoring in the 3,2 m^3 rearing units at the Nofima centre for recirculation can happen fast and efficiently by measuring the centre of the tank axis which is the most accessible. Measuring this axis for 5 minutes and editing this data set to filter out any potential errors provides accurate velocity measurements under any circumstances encountered in the centre for recirculation. This recommended method is further described in appendix 5. Vector is easy to operate in the different tank sizes present at the research station and the instrument does not experience interference from the different water qualities in use at the station. Vector also functions accordingly at commercial scale sites, although proper equipment has to be designed to be able to stably position the instrument on the tank edge. This will enable the fast and efficient measurements needed during sampling trips.

6.3.2 TSS

The alternative rinsing water methods tested during this project probably have no significant impact on the accuracy of TSS measurements in salt water. The standard method might even be used to perform accurate TSS measurements regardless of salinity. Further testing using a more stable stock solution is required to confirm these findings. This improved stock solution could possibly be created by prolonging the dissolving process at increased temperatures.

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Appendix

Appendix 1: TSS measurements method

Table 1: Samples to be measured to create the standard solution for TSS measurements and determine if sample volume influences the measurement.

Amount of feed pellets (g)	Sample volume (mL)	Replicates
20	250	3
	1000	1
30	250	3
	1000	1
40	250	3
	1000	1
50	250	3
	1000	1

Table 2: Testing a known TSS concentration using the standard method at different salinities.

Salinity (ppt)	Sample volume of given TSS concentration (mL)	Temperature of the rinsing water (°C)	Volume of the rinsing water (mL)	Number of replicates
0	To be determined in 3.2.2	Room temp.	10 (3x)	3
12	To be determined in 3.2.2	Room temp.	10 (3x)	3
22	To be determined in 3.2.2	Room temp.	10 (3x)	3
32	To be determined in 3.2.2	Room temp.	10 (3x)	3

Table 3: Test 1. Variable salinity (0,12,22 and 32 ppt.) and volume of the rinsing water (50,100 and 200 mL)

Salinity (ppt)	Sample volume of given TSS concentration (mL)	Temperature of the rinsing water (°C)	Volume of the rinsing water (mL)	Number of replicates
0	To be determined in 3.2.2	Room temp.	100	3
	To be determined in 3.2.2	Room temp.	250	3
	To be determined in 3.2.2	Room temp.	500	3
12	To be determined in 3.2.2	Room temp.	100	3
	To be determined in 3.2.2	Room temp.	250	3
	To be determined in 3.2.2	Room temp.	500	3
22	To be determined in 3.2.2	Room temp.	100	3
	To be determined in 3.2.2	Room temp.	250	3
	To be determined in 3.2.2	Room temp.	500	3
32	To be determined in 3.2.2	Room temp.	100	3
	To be determined in 3.2.2	Room temp.	250	3
	To be determined in 3.2.2	Room temp.	500	3

Table 4: Test 2. Variable salinities (0,12,22 and 32 ppt.) and temperatures (4,20 and 37 °C)

Salinity (ppt)	Sample volume of given TSS concentration (mL)	Temperature of the rinsing water (°C)	Volume of the rinsing water (mL)	Number of replicates
0	Determined in 3.2.2	4	From test 1	3
	Determined in 3.2.2	20	From test 1	3
	Determined in 3.2.2	37	From test 1	3
12	Determined in 3.2.2	4	From test 1	3
	Determined in 3.2.2	20	From test 1	3
	Determined in 3.2.2	37	From test 1	3
22	Determined in 3.2.2	4	From test 1	3
	Determined in 3.2.2	20	From test 1	3
	Determined in 3.2.2	37	From test 1	3
32	Determined in 3.2.2	4	From test 1	3
	Determined in 3.2.2	20	From test 1	3
	Determined in 3.2.2	37	From test 1	3

Table 5: Test 3. Variable salinity (0,12,22 and 32 ppt.) and TSS concentration in the water samples

Salinity (ppt)	Sample Volume (mL)	Concentration of TSS in the sample (mg/L)	Temperature of the rinsing water	Volume of the rinsing water (mL)	Number of replicates
0	Determined in 3.2.2	Concentration 1	From test 2	From test 1	3
		Concentration 2	From test 2	From test 1	3
		Concentration 3	From test 2	From test 1	3
12	Determined in 3.2.2	Concentration 1	From test 2	From test 1	3
		Concentration 2	From test 2	From test 1	3
		Concentration 3	From test 2	From test 1	3
22	Determined in 3.2.2	Concentration 1	From test 2	From test 1	3
		Concentration 2	From test 2	From test 1	3
		Concentration 3	From test 2	From test 1	3
32	Determined in 3.2.2	Concentration 1	From test 2	From test 1	3
		Concentration 2	From test 2	From test 1	3
		Concentration 3	From test 2	From test 1	3

Appendix 2: Water velocity results

TANK 102 Velocity Measurements

Tank Axis	Empty			Feed			Fish			Fish & Feed		
	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)
A1	9,42	0,81	9,45	7,66	0,05	7,66	9,25	0,37	9,26	9,06	0,63	9,08
A2	11	0,36	11,01	11	0,7	11,02	10,35	0,32	10,35	9,8	0,33	9,81
A3	8,56	0,94	8,61	10,89	0,04	10,89	8,83	0,68	8,86	8,26	0,26	8,26
A4	5,84	1,78	6,11	5,03	0,36	5,04	5,07	0,53	5,09	5,37	0,99	5,46
A5	6,11	1,57	6,31	5,48	0,08	5,48	5,21	0,33	5,22	5,65	0,45	5,67
A6	6,69	1,2	6,79	4,96	0,24	4,97	4,98	0,35	4,99	6,22	0,45	6,24
A7	5,05	0,97	5,14	3,49	0,11	3,49	3,42	0,15	3,42	4,74	0,18	4,74
A8	4,8	1,7	5,09	2,88	1,29	3,16	3,33	0,15	3,33	4,26	1,04	4,39
A9	3,69	1,05	3,84	2,46	0,35	2,48	2,7	0,63	2,77	3,44	1,57	3,78
Average			**6,93**			**6,02**			**5,92**			**6,38**
B1	8,43	0,46	8,44	8,77	0,68	8,79	7,81	0,19	7,81	8,51	0,34	8,52
B2	8,57	0,04	8,57	8,73	0,01	8,73	6,86	0,37	6,87	7,48	0,53	7,49
B3	8,25	0,28	8,25	8,45	0,51	8,47	7,45	0,11	7,45	7,23	0,45	7,24
B4	6,79	1,09	6,88	6,54	0,13	6,54	5,66	0,39	5,67	5,85	0,28	5,85
B5	6,18	0,32	6,19	6,21	1,22	6,33	5,36	0,38	5,37	5,22	0,39	5,23
B6	5,53	0,86	5,59	5,57	0,51	5,59	4,7	0,3	4,71	4,86	0,18	4,86
B7	6,88	0,79	6,93	4,73	0,93	4,82	4,48	0,1	4,48	3,57	0,65	3,62
B8	6,66	1,83	6,91	4,94	0,58	4,97	4,49	0,47	4,51	4,6	0,77	4,66
B9	5,02	2,53	5,62	3,95	0,42	3,97	3,62	0,42	3,64	4,44	0,3	4,45
Average			**7,04**			**6,47**			**5,61**			**5,77**
C1	9,12	0,04	9,12	8,82	0,77	8,85	7,46	1,12	7,54	7,67	1,32	7,78
C2	8,35	0,47	8,36	7,85	1,41	7,98	7,29	1,09	7,37	6,89	0,58	6,91
C3	8,24	0,08	8,24	7,92	0,63	7,95	6,02	0,08	6,02	6,21	0,63	6,24
C4	7,81	0,82	7,85	7,21	0,05	7,21	5,79	0,24	5,79	6,24	1,08	6,33
C5	7,67	0,89	7,72	7,15	0,02	7,15	6,1	1,34	6,25	6,09	0,91	6,16
C6	6,24	1,51	6,42	5,74	1,39	5,91	5,17	1,06	5,28	5,04	1,08	5,15
C7	5,96	0,35	5,97	4,33	0,54	4,36	2,97	0,7	3,05	3,74	0,93	3,85
C8	7,18	0,4	7,19	4,67	0,25	4,68	4,22	0,54	4,25	4,36	0,48	4,39
C9	6,73	0,12	6,73	4,39	0,48	4,42	4,03	0,28	4,04	3,93	0,4	3,95
Average			**7,47**			**6,41**			**5,48**			**5,56**
D1	8,4	0,53	8,42	9,4	0,27	9,40	8,05	0,2	8,05	6,75	0,58	6,77
D2	8,1	0,88	8,15	8,79	0,07	8,79	7,99	0,07	7,99	7,41	0,14	7,41
D3	7,73	0,93	7,79	8,05	0,03	8,05	7,37	0,02	7,37	6,84	0,42	6,85
D4	6,65	0,91	6,71	5,26	0,41	5,28	5,37	0,49	5,39	5,49	0,1	5,49
D5	7,4	0,25	7,40	5,97	0,39	5,98	6,19	0,59	6,22	6,79	0,67	6,82
D6	7,62	0,66	7,65	6,58	0,77	6,62	6	0,3	6,01	6,14	0,15	6,14
D7	4,63	1,29	4,81	2,54	1	2,73	3,58	0,5	3,61	3,98	1,18	4,15
D8	5,06	1,3	5,22	3,08	0,98	3,23	3,85	0,23	3,86	4,73	0,07	4,73
D9	5,16	0,87	5,23	3,11	0,41	3,14	4,28	0,23	4,29	3,93	0,17	3,93
Average			**6,62**			**5,48**			**5,59**			**5,69**
Tank Average	**7,02**			**6,09**			**5,65**			**5,85**		

Empty

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	62,35356	6,92817	5,38027
B	9	63,38262	7,04251	1,33284
C	9	67,61066	7,5123	1,0354
D	9	61,37834	6,81982	1,92554

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	2,51062	3	0,83687	0,34603	0,79222	3,77316
Within Groups	77,39235	32	2,41851			
Total	79,90297	35				

Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	54,19396	6,02155	10,11018
B	9	58,22176	6,46908	3,31152
C	9	58,49669	6,49963	2,91448
D	9	53,22661	5,91407	6,37201

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	2,45759	3	0,8192	0,1443	0,93258	3,77316
Within Groups	181,66551	32	5,67705			
Total	184,12309	35				

Fish

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	53,30803	5,92311	8,03562
B	9	50,52946	5,61438	2,12942
C	9	49,59864	5,51096	2,28986
D	9	52,78846	5,86538	2,94056

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	1,05262	3	0,35087	0,09116	0,96438	3,77316
Within Groups	123,16358	32	3,84886			
Total	124,2162	35				

Fish & Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	57,42603	6,38067	4,67108
B	9	51,95693	5,77299	2,6716
C	9	50,77434	5,64159	1,89728
D	9	52,31023	5,81225	1,65727

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	2,89472	3	0,96491	0,35418	0,78641	3,77316
Within Groups	87,17783	32	2,72431			
Total	90,07255	35				

Tank 103 Velocity Measurements

Tank Axis	Empty			Feed			Fish			Fish & Feed		
	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)
A1	8,56	0,69	8,59	8,91	0,29	8,91	7,12	1,14	7,21	7,83	0,67	7,86
A2	10,66	0,36	10,67	8,93	0,28	8,93	9,24	0,49	9,25	8,9	0,48	8,91
A3	10,42	0,44	10,43	9,55	0,31	9,56	8,04	0,07	8,04	8,38	1,17	8,46
A4	4,92	0,09	4,92	3,58	0,36	3,59	3,75	0,49	3,78	4,03	0,13	4,03
A5	5,62	1,2	5,75	5,69	0,13	5,69	3,61	0,18	3,61	4,09	0,18	4,09
A6	6,41	1,4	6,56	5,92	0,23	5,92	3,53	0,22	3,54	3,63	0,29	3,64
A7	3,93	1,3	4,11	4,54	0,51	4,57	2,99	0,39	3,02	2,67	0,5	2,72
A8	3,79	1,25	3,99	4,59	0,13	4,59	2,42	0,06	2,42	2,61	0,04	2,61
A9	3,34	0,68	3,41	-	-	-	1,38	2,39	2,76	1,78	0,13	1,78
Average			**6,49**			**6,47**			**4,85**			**4,9**
B1	8,29	1,31	8,39	7,76	0,73	7,79	6,31	0,94	6,38	6,41	0,36	6,42
B2	8,24	2,02	8,48	7,6	0,2	7,60	5,97	0,68	6,01	6,61	0,03	6,61
B3	8,08	0,06	8,08	7,76	0,41	7,77	4,5	0,33	4,51	6,04	0,45	6,06
B4	5,89	2,53	6,41	-	-	-	4,35	0,77	4,42	4,94	0,12	4,94
B5	5,53	1,67	5,78	-	-	-	3,42	0,15	3,42	4,48	0,17	4,48
B6	5,05	1,57	5,29	-	-	-	-	-	-	3,91	0,03	3,91
B7	4,03	0,62	4,08	3,41	1,86	3,88	2,14	0,15	2,15	2,62	0,35	2,64
B8	4,91	0,24	4,92	4,07	0,69	4,13	1,77	0,17	1,78	3,32	0,96	3,46
B9	3,89	0,62	3,94	3,26	0,28	3,27	2,15	0,66	2,25	2,66	0,4	2,69
Average			**6,15**			**5,74**			**3,86**			**4,66**
C1	7,8	1,11	7,88	-	-	-	6,53	0,45	6,55	7,03	0,93	7,09
C2	7,3	0,09	7,30	-	-	-	5,63	0,68	5,67	6,65	0,95	6,72
C3	7,05	0,19	7,05	-	-	-	-	-	-	4,12	0,13	4,12
C4	6,47	2,2	6,83	6,69	1,01	6,77	3,81	0,63	3,86	5,62	0,02	5,62
C5	6,65	0,68	6,68	6,64	1,04	6,72	4,86	0,08	4,86	5,63	0,89	5,69
C6	5,83	0,36	5,84	5,95	0,54	5,97	4,76	1,25	4,92	4,93	0,83	4,99
C7	6,67	1,07	6,76	-	-	-	1,74	0,12	1,74	3,32	0,71	3,39
C8	6,56	0,77	6,61	-	-	-	2	0,28	2,02	3,45	0,42	3,48
C9	5,35	1,44	5,54	-	-	-	2,24	1,15	2,52	2,97	0,15	2,97
Average			**6,72**			**6,49**			**4,02**			**4,99**
D1	7,95	1,7	8,13	7,83	1,32	7,94	7,21	0,26	7,21	6,3	0,71	6,34
D2	7,58	1,23	7,68	7,67	0,92	7,72	6,95	0,39	6,96	6,44	0,69	6,48
D3	7,17	0,16	7,17	7,4	0,57	7,42	6,56	0,18	6,56	5,64	0,34	5,65
D4	6,5	0,11	6,50	5,89	1,83	6,17	4,68	0,14	4,68	4,25	0,32	4,26
D5	6,6	1,02	6,69	6,81	0,71	6,85	5,14	0,62	5,18	5,33	0,1	5,33
D6	6,92	0,25	6,92	7,07	0,33	7,08	4,59	0,51	4,62	4,5	0,16	4,50
D7	4,18	1,01	4,30	4,58	1,28	4,76	3,72	0,6	3,77	1,93	0,32	1,96
D8	4,38	0,08	4,38	4,94	0,09	4,94	2,93	0,3	2,95	2,83	0,28	2,84
D9	4,69	0,94	4,78	5,09	0,48	5,11	2,89	0,21	2,89	2,12	0,56	2,19
Average			**6,28**			**6,44**			**4,98**			**4,39**
Tank Average	**6,41**			**6,29**			**4,43**			**4,74**		

Empty

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	58,42204	6,49134	7,72242
B	9	55,36484	6,15165	3,23246
C	9	60,49201	6,72133	0,49781
D	9	56,54875	6,28319	2,07048

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	1,6772	3	0,55907	0,16537	0,91892	3,77316
Within Groups	108,18543	32	3,38079			
Total	109,86262	35				

Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	8	51,77854	6,47232	5,40885
B	6	34,45208	5,74201	4,78932
C	3	19,46122	6,48707	0,19759
D	9	57,98864	6,44318	1,54502

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	2,39459	3	0,7982	0,23551	0,87064	4,02762
Within Groups	74,56389	22	3,38927			
Total	76,95848	25				

Fish

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	43,63306	4,84812	6,64564
B	8	30,91365	3,86421	3,10879
C	8	32,14178	4,01772	3,15507
D	9	44,8267	4,98074	2,70321

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	8,20047	3	2,73349	0,69122	0,56458	3,80923
Within Groups	118,63778	30	3,95459			
Total	126,83825	33				

Fish & Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	44,11191	4,90132	7,53024
B	9	41,2109	4,57899	2,35792
C	9	44,09447	4,89939	2,23534
D	9	39,55567	4,39507	2,97511

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	1,68975	3	0,56325	0,14922	0,92943	3,77316
Within Groups	120,78891	32	3,77465			
Total	122,47866	35				

Tank 105 Velocity Measurements

Tank Axis	Empty			Feed			Fish			Fish & Feed		
	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)
A1	29,89	2,04	29,96	27,09	3,53	27,32	20,69	2,02	20,79	20,3	4,13	20,72
A2	41,29	2,07	41,34	38,79	0,9	38,80	18	1,48	18,06	14,32	2,91	14,61
A3	37,27	1,33	37,29	37,73	0,16	37,73	22	4,34	22,42	29,67	0,55	29,68
A4	18,1	3,33	18,40	18,53	0,73	18,54	17,74	1,45	17,79	19,5	3,4	19,79
A5	20,34	2,53	20,49	21,42	1,57	21,48	15,51	2,02	15,64	18,6	3,1	18,86
A6	17,33	1,48	17,39	16,49	3,97	16,96	15,12	0,67	15,13	15,31	2,74	15,55
A7	11,63	0,58	11,64	11,86	2,71	12,17	10,33	4,97	11,46	17,54	5,67	18,43
A8	10,75	1,02	10,79	11,06	1,05	11,11	9,63	1,65	9,77	14,34	6,51	15,75
A9	6,09	2,33	6,52	5,87	0,7	5,91	9,37	1,25	9,45	9,94	3,99	10,71
Average			**21,54**			**21,11**			**15,61**			**18,23**
B1	31,47	0,72	31,48	30,56	0,17	30,56	25,04	0,48	25,04	26,03	2,57	26,16
B2	31,71	3,96	31,96	29,26	2,55	29,37	18,44	2,81	18,65	24,76	3,02	24,94
B3	30,78	1,32	30,81	30,9	0,02	30,90	19,66	1,71	19,73	21,06	5,22	21,69
B4	23,07	4,03	23,42	19,36	3,04	19,59	18,6	0,26	18,60	21,99	4,77	22,50
B5	20,74	5,03	21,34	15,84	1,99	15,96	16,24	1,34	16,29	17,21	1,29	17,26
B6	17,76	4,5	18,32	16,57	0,96	16,59	12,99	1,92	13,13	12,41	0,46	12,42
B7	15,53	2,95	15,81	14,21	1,94	14,34	11,45	1,9	11,61	19,19	0,58	19,19
B8	15,34	0,53	12,35	14,54	0,11	14,54	11,2	0,14	11,20	18,33	4	18,76
B9	12,33	3,33	12,77	9,5	3,77	10,22	7,8	0,69	7,83	14,42	2,63	14,66
Average			**22,36**			**20,23**			**15,79**			**19,73**
C1	33,38	2,11	33,45	29,51	4,73	29,89	26,39	5,13	26,88	23,07	2,54	23,21
C2	28,92	6,76	29,69	26,09	1,45	26,13	21,06	2,85	21,25	13,73	2	13,87
C3	26,39	4,26	26,73	25,15	1,72	25,21	17,74	1,12	17,78	11,46	0,57	11,47
C4	27	2,93	27,16	27,42	0,16	27,42	14,69	0,02	14,69	27,39	1,15	27,41
C5	25,02	2,13	25,11	24,14	0,66	24,15	16,32	3,41	16,67	21,71	3,42	21,97
C6	20,56	4,22	20,98	18,97	2,76	19,17	14,55	2,8	14,82	16,05	4,96	16,79
C7	11,54	1,74	11,67	12,26	5,29	13,35	5,3	0,45	5,32	23,05	3,08	23,25
C8	14,22	0,15	14,22	15,28	2,21	15,44	8,14	0,97	8,19	18,45	2,77	18,66
C9	17,22	2,06	17,34	17,84	1,39	17,89	10,27	1,39	10,36	15,1	3,11	15,42
Average			**22,93**			**22,07**			**15,11**			**19,12**
D1	33,37	1,99	33,43	33,52	1,93	33,58	27,48	2,06	27,56	25,66	1,09	25,68
D2	31,65	0,46	31,65	30,84	3,29	31,01	22,94	0,08	22,94	24,25	1,81	24,32
D3	29,66	0,43	29,66	28,18	1,73	28,23	19,56	1,32	19,60	24,39	0,81	24,40
D4	17,65	0,42	17,65	14,56	1,87	14,68	15,35	2,02	15,48	20,49	1,7	20,56
D5	18,61	2,73	18,81	17,21	4,24	17,72	14,15	3,11	14,49	15,75	1,09	15,78
D6	20,88	0,18	20,88	17,34	2,22	17,48	13,67	0,03	13,67	14,06	1,56	14,15
D7	8,13	3,03	8,68	2,42	2,95	3,82	6,59	2,26	6,97	17,66	5,28	18,43
D8	9,44	0,28	9,44	5,17	2,21	5,62	8	1,28	8,10	21,66	1,57	21,72
D9	9,99	1,64	10,12	8,46	5,3	9,98	8,62	3,12	9,17	19,63	1	19,66
Average			**20,04**			**18,01**			**15,33**			**20,52**
Tank Average	**21,72**			**20,36**			**15,46**			**19,40**		

Empty

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	193,85195	21,53911	147,27432
B	9	201,25327	22,36147	56,13696
C	9	206,36945	22,92994	53,89094
D	9	180,33484	20,0372	94,29948

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	42,65935	3	14,21978	0,16177	0,92128	3,77316
Within Groups	2.812,81364	32	87,90043			
Total	2.855,473	35				

Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	190,01979	21,11331	132,83344
B	9	182,09385	20,23265	62,89244
C	9	198,65055	22,07228	33,27512
D	9	162,13052	18,0145	118,34243

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	81,1526	3	27,05087	0,31152	0,81689	3,77316
Within Groups	2.778,74744	32	86,83586			
Total	2.859,90004	35				

Fish

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	140,53485	15,61498	21,68445
B	9	142,09774	15,78864	28,31839
C	9	135,971	15,10789	44,04121
D	9	137,97762	15,33085	48,66829

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	2,45415	3	0,81805	0,02293	0,9952	3,77316
Within Groups	1.141,69876	32	35,67809			
Total	1.144,15291	35				

Fish & Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	164,10076	18,23342	27,87435
B	9	177,59355	19,73262	20,81826
C	9	172,07785	19,11976	27,008
D	9	184,70309	20,52257	15,71481

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	25,29196	3	8,43065	0,36889	0,77594	3,77316
Within Groups	731,32333	32	22,85385			
Total	756,61529	35				

Tank 106 Velocity Measurements

Tank Axis	Empty			Feed			Fish			Fish & Feed		
	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)
A1	25,73	3,55	25,97	22,58	1,49	22,63	18,11	0,11	18,11	18,28	1,17	18,32
A2	27,17	2,57	27,29	23,77	0,81	23,78	19,93	0,46	19,94	18,95	0,84	18,97
A3	23,11	3,75	23,41	26,37	0,43	26,37	17,95	0,01	17,95	17,1	1,36	17,15
A4	16,62	0,54	16,63	16,71	3,94	17,17	12,36	0,76	12,38	11,79	0,77	11,82
A5	19,78	0,66	19,79	17,56	0,88	17,58	11,7	0,12	11,70	10,23	1,21	10,30
A6	19,31	0,14	19,31	17,48	3,54	17,83	11,31	1,26	11,38	11,03	1,32	11,11
A7	16,32	3,3	16,65	17,49	3,93	17,93	9,39	0,37	9,39	9,68	1,18	9,75
A8	14,91	1,25	14,96	16,76	2,61	16,96	9,05	1,7	9,21	7,01	0,99	7,08
A9	11,31	1,07	11,36	9,09	1,4	9,19	7,52	0,82	7,56	5,71	0,48	5,73
Average			**19,49**			**18,83**			**13,07**			**12,25**
B1	24,98	0,96	24,99	25,28	2,14	25,37	18,38	0,58	18,39	20,78	1,01	20,80
B2	24,8	1,08	24,82	-	-	-	15,29	1,42	15,36	17,7	2,05	17,82
B3	23	0,46	23,00	22,41	4,61	22,88	12,87	1,95	13,02	13,95	1,09	13,99
B4	22,06	0,4	22,06	21,8	1,56	21,86	13,07	1,71	13,18	12,76	0,83	12,79
B5	20,76	2,51	20,91	20,04	1,63	20,11	14,12	0,23	14,12	11,65	0,88	11,68
B6	15,84	1,03	15,87	16,73	1,1	16,77	11,71	2,1	11,89	10,21	1,17	10,28
B7	17,36	1,18	17,40	17,59	2,5	17,77	13,35	0,61	13,36	7,5	1,14	7,59
B8	18,55	0,98	18,58	19,78	0,49	19,79	12,75	0,74	12,77	8,03	0,12	8,03
B9	13,11	1,43	13,19	14,07	2,7	14,33	11,09	0,34	11,09	9,02	0,2	9,02
Average			**20,09**			**19,86**			**13,69**			**12,44**
C1	27,78	0,74	27,79	27,59	2,02	27,66	20,62	0,35	20,62	21,5	0,1	21,50
C2	24,55	0,04	24,55	25,59	0,85	25,60	16,98	0,78	16,99	17,08	0,27	17,08
C3	22,52	1,19	22,55	24,68	1,5	24,73	14,36	0,27	14,36	13,53	0,06	13,53
C4	-	-	-	22,44	3,68	22,74	14,29	0,59	14,30	15,95	1,45	16,01
C5	20,36	0,79	20,38	22,26	2,63	22,41	12,56	1,07	12,61	15,05	0,19	15,05
C6	16,06	0,17	16,06	17,09	0,67	17,10	11,54	1,56	11,64	12,18	0,81	12,21
C7	16,95	0,93	16,98	18,94	0,96	18,96	4,45	3,31	5,55	8,84	0	8,84
C8	19,85	3,24	20,11	18,54	0,14	18,54	8,28	3,51	8,99	9,54	0,12	9,54
C9	16,61	2,15	16,75	18,01	1,53	18,07	9,62	2,86	10,04	8,83	1,19	8,91
Average			**20,65**			**21,64**			**12,79**			**13,63**
D1	-	-	-	20,14	0	20,14	21,24	0,9	21,26	22,75	2,31	22,87
D2	24,85	1,21	24,88	26,29	0,57	26,29	19,89	1,13	19,92	20,32	0,81	20,34
D3	25,52	0,52	25,53	25,16	2,71	25,31	16,42	0,05	16,42	16,93	1,14	16,97
D4	20,92	4,67	21,43	18,74	2,07	18,85	11,5	0,27	11,50	9,04	1,46	9,16
D5	20,41	0,37	20,41	-	-	-	13,61	1,45	13,69	10,17	1,23	10,24
D6	19,4	1,21	19,44	21,04	0,74	21,05	13,67	0,24	13,67	11,35	1,39	11,43
D7	14,8	2,44	14,99	14,8	0,84	14,82	7,61	1,36	7,73	6,77	0,24	6,77
D8	14,37	1,23	14,42	14,55	0,54	14,56	8,23	2,33	8,55	6,07	0,44	6,09
D9	13,23	2,07	13,39	15,17	3,02	15,47	7,74	0,5	7,76	4,92	0,76	4,98
Average			**19,31**			**19,56**			**13,39**			**12,09**
Tank Average	**19,88**			**19,97**			**13,23**			**12,60**		

Empty

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	175,38069	19,48674	27,65564
B	9	180,8385	20,09317	16,81397
C	8	165,16428	20,64553	17,13574
D	8	154,50399	19,313	21,84252

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	9,06105	3	3,02035	0,14415	0,93262	3,80923
Within Groups	628,60472	30	20,95349			
Total	637,66577	33				

Feed

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
A	9	169,4568	18,82853	24,78559
B	8	158,85728	19,85716	12,58578
C	9	195,83092	21,75899	14,1579
D	8	156,50021	19,56253	20,80419

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	41,87949	3	13,95983	0,76804	0,52097	3,80923
Within Groups	545,27774	30	18,17592			
Total	587,15723	33				

Fish

Summary

Groups	Sample size	Sum	Mean	Variance
A	9	117,62972	13,06997	20,03327
B	9	123,1925	13,68806	4,5817
C	9	115,11147	12,79016	19,95507
D	9	120,50368	13,3893	25,58263

ANOVA

Source of Variation	SS	df	MS	F	p-level	F crit
Between Groups	4,08762	3	1,36254	0,07769	0,97161	3,77316
Within Groups	561,22139	32	17,53817			
Total	565,30901	35				

Fish & Feed

Summary

Groups	Sample size	Sum	Mean	Variance
A	9	110,2265	12,24739	23,34688
B	9	112,0016	12,44462	20,16946
C	9	122,67696	13,63077	18,19384
D	9	108,84603	12,094	41,90749

ANOVA

Source of Variation	SS	df	MS	F	p-level	F crit
Between Groups	13,20239	3	4,4008	0,16989	0,91593	3,77316
Within Groups	828,94133	32	25,90442			
Total	842,14371	35				

Table 6: Water velocity decrease in percentages after adding fish to the tanks, displayed for each tank axis as well as the tank average.

Tank number	Water velocity decrease in percentages for each axis				Total average decrease (%)
	A	B	C	D	Tank
106	32,93	31,87	38,05	30,67	33,38
105	27,5	29,39	34,11	23,49	28,62
102	14,51	20,28	26,7	15,53	19,25
103	25,31	37,18	40,22	20,73	30,86

0,5 m³ tanks water velocity measurements

	RAS						Flow-through					
	Tank 301			Tank 302			Tank 303			Tank 304		
Measurement location	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)
Empty												
A	9,75	0,42	9,76	8,52	0,28	8,52	8,71	0,36	8,72	8,01	0,48	8,02
B	7,68	0,59	7,70	6,91	1,43	7,06	6,96	0,85	7,01	6,53	0,65	6,56
Tank Average			**8,73**			**7,79**			**7,86**			**7,29**
Containing fish												
A	9,07	0,34	9,08				8,72	0,62	8,74			
B	6,91	0,14	6,91				6,98	0,73	7,02			
Tank Average			**7,99**						**7,88**			

LEROY first sampling

Tank 84 Water velocity measurements

Measurement location. Length from the tank edge x depth (cm)	x	y	Velocity (cm/s)
50 x 50	13,89	7	15,55
50 x 100	13,52	5,32	14,53
50 x 150	11,47	0,2	11,47
Average			**13,85**
200 x 50	15,89	4,43	16,49
200 x 100	14,59	4,13	15,16
200 x 150	16,74	1,18	16,78
Average			**16,15**
300 x 50	11,35	4,36	12,16
300x 100	10,17	3,1	10,63
300 x 150	14,77	2,87	15,05
Average			**12,61**

Measurement location. Length from the tank edge x depth (cm)	Tank 83			Tank 86			Tank 87		
	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)	x	y	Velocity (cm/s)
50 x 50	13,83	3,27	14,21	13,75	2,83	14,02	15,37	0,35	15,37
50 x 100	14,72	2,34	14,90	15,21	2,33	15,39	13,84	2,65	14,09
50 x 150	14,32	2,46	14,53	15,64	1,13	15,68	15,1	1,72	15,19
Average			**14,55**			**15,04**			**14,89**

Analysis of Variance (One-Way)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
Variable #1	3	49,83656	16,61219	8,78614
Variable #2	3	41,55494	13,85165	4,51068
Variable #3	3	45,10641	15,03547	0,7674
Variable #4	3	44,66305	14,88768	0,4833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	11,68287	3	3,89429	1,07078	0,4143	5,90138
Within Groups	29,09506	8	3,63688			
Total	40,77793	11				

LEROY second sampling

		Measurement location Length from tank edge x depth (cm)			
		50 x 50	50 x 100	50 x 150	50 x 200
Tank 83	X	15,12	14,1	15,16	14,64
	Y	0,51	5,91	3,28	2,81
	Velocity (cm/s)	15,13	15,29	15,51	14,91
	Tank Average	**15,21**			
Tank 84	X	13,26	13,72	13,83	13,46
	Y	1,97	1,79	0,75	0,38
	Velocity (cm/s)	13,41	13,84	13,85	13,47
	Tank Average	**13,64**			
Tank 85	X	11,1	9,17	11,35	11,98
	Y	1,79	1,12	4,56	3,73
	Velocity (cm/s)	11,24	9,24	12,23	12,55
	Tank Average	**11,32**			
Tank 86	X	13,04	15,15	16,01	15,87
	Y	2,3	1,19	1,99	0,06
	Velocity (cm/s)	13,24	15,19	16,13	15,87
	Tank Average	**15,11**			
Tank 87	X	13,41	14,13	14,57	15
	Y	0,24	1,32	0,57	0,67
	Velocity (cm/s)	13,41	14,19	14,58	15,01
	Tank Average	**14,29**			
Tank 88	X	17,74	16,56	17,07	16,82
	Y	0,06	2,71	3,64	4,3
	Velocity (cm/s)	17,74	16,78	17,45	17,36
	Tank Average	**17,33**			

Analysis of Variance (One-Way)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
Variable #1	4	60,8351	15,20878	0,06497
Variable #2	4	54,5575	13,63937	0,05608
Variable #3	4	45,26056	11,31514	2,22578
Variable #4	4	60,44126	15,11032	1,70811
Variable #5	4	57,19977	14,29994	0,46342
Variable #6	4	69,33511	17,33378	0,1622

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	79,31098	5	15,8622	20,33375	0,00	3,58606
Within Groups	14,04166	18	0,78009			
Total	93,35263	23				

Appendix 3: TSS results

Test-Results

0 ppt					
Rinsing method	Filter #	Pre-filtration	Post-filtration	Difference	TSS (mg/L)
10 mL	1	2,3684	2,3921	0,0237	**9,48**
	2	2,3557	2,373	0,0173	**6,92**
	3	2,3528	2,3693	0,0165	**6,6**
100 mL	4	2,38	2,3929	0,0129	**5,16**
	5	2,3633	2,3752	0,0119	**4,76**
	6	2,3633	2,3745	0,0112	**4,48**
300 mL	7	2,3646	2,3729	0,0093	**3,72**
	8	2,3716	2,3807	0,0091	**3,64**
	9	2,3654	2,3746	0,0092	**3,68**
100 mL 32 degrees	10	2,3649	2,3731	0,0082	**3,28**
	11	2,366	2,3744	0,0084	**3,36**
	12	2,3663	2,3753	0,009	**3,6**
300 mL 32 degrees	13	2,3713	2,3828	0,0115	**4,6**
	14	2,3583	2,3674	0,0091	**3,64**
	15	2,3537	2,3656	0,0119	**4,76**

12 ppt					
Rinsing method	Filter #	Pre-filtration	Post-filtration	Difference	TSS (mg/L)
10 mL	16	2,3512	2,3747	0,0235	**9,4**
	17	2,3377	2,3573	0,0196	**7,84**
	18	2,3412	2,3559	0,0147	**5,88**
100 mL	19	2,3413	2,3558	0,0145	**5,8**
	20	2,3389	2,3505	0,0116	**4,64**
	21	2,3168	2,3284	0,0116	**4,64**
300 mL	22	2,3495	2,359	0,0095	**3,8**
	23	2,3585	2,3683	0,0098	**3,92**
	24	2,3258	2,3354	0,0096	**3,84**
100 mL 32 degrees	25	2,3414	2,3507	0,0093	**3,72**
	26	2,3513	2,3603	0,009	**3,6**
	27	2,3342	2,3429	0,0087	**3,48**
300 mL 32 degrees	28	2,3502	2,3593	0,0091	**3,64**
	29	2,3426	2,3522	0,0096	**3,84**
	30	2,3541	2,3647	0,0106	**4,24**

32 ppt					
Rinsing method	Filter #	Pre-filtration	Post-filtration	Difference	TSS (mg/L)
10 mL	31	2,3301	2,3523	0,0222	8,88
	32	2,3496	2,3687	0,0191	7,64
	33	2,3478	2,3605	0,0127	5,08
100 mL	34	2,3636	2,3789	0,0153	6,12
	35	2,3555	2,3709	0,0154	6,16
	36	2,3495	2,3631	0,0136	5,44
300 mL	37	2,3447	2,3562	0,0115	4,6
	38	2,3428	2,3538	0,011	4,4
	39	2,3617	2,3726	0,0109	4,36
100 mL 32 degrees	40	2,373	2,383	0,01	4
	41	2,3344	2,3438	0,0094	3,76
	42	2,3145	2,3246	0,0101	4,04
300 mL 32 degrees	43	2,3578	2,3674	0,0096	3,84
	44	2,3495	2,3599	0,0104	4,16
	45	2,3336	2,3443	0,0107	4,28

Comparison between stock solutions

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*Stdev.*	*CV*
0 ppt	15	71,68	4,77867	2,91723	1,707989071	35,7419588
12 ppt	15	72,28	4,81867	3,01711	1,736983702	36,04697777
32 pt	15	76,76	5,11733	2,25542	1,501805897	29,34743155

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	1,02748	2	0,51374	0,18819	0,82915	4,30012
Within Groups	114,65664	42	2,72992			
Total	115,68412	44				

Standard method

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
0 ppt	3	23,	7,66667	2,49173	1,578522516	20,58941517
12 ppt	3	23,12	7,70667	3,11093	1,763783811	22,88645824
32 ppt	3	21,6	7,2	3,7552	1,937833842	26,91435892

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	0,47609	2	0,23804	0,07631	0,92741	8,05209
Within Groups	18,71573	6	3,11929			
Total	19,19182	8				

100 mL

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
0 ppt	3	14,4	4,8	0,1168	0,34176015	7,120003121
12 ppt	3	15,08	5,02667	0,44853	0,669726312	13,32345892
32 ppt	3	17,72	5,90667	0,16373	0,404639757	6,850556362

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	2,05049	2	1,02524	4,21873	0,07178	8,05209
Within Groups	1,45813	6	0,24302			
Total	3,50862	8				

100 mL (32 degrees)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
Variable #1	3	10,24	3,41333	0,02773	0,16653328	4,878909451
Variable #2	3	10,8	3,6	0,0144	0,12	3,333333333
Variable #3	3	11,8	3,93333	0,02293	0,151437556	3,850110616

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	0,41636	2	0,20818	9,59836	0,0135	8,05209
Within Groups	0,13013	6	0,02169			
Total	0,54649	8				

300 ml

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
Variable #1	3	11,04	3,68	0,0016	0,04	1,086956522
Variable #2	3	11,56	3,85333	0,00373	0,061101009	1,58566633
Variable #3	3	13,36	4,45333	0,01653	0,12858201	2,887320587

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	0,98809	2	0,49404	67,78049	0,00008	8,05209
Within Groups	0,04373	6	0,00729			
Total	1,03182	8				

300 mL (32 degrees)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
Variable #1	3	13,	4,33333	0,36693	0,605750224	13,97886207
Variable #2	3	11,72	3,90667	0,09333	0,305505046	7,82008837
Variable #3	3	12,28	4,09333	0,05173	0,227449628	5,556591531

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	0,27449	2	0,13724	0,80417	0,49044	8,05209
Within Groups	1,024	6	0,17067			
Total	1,29849	8				

0 ppt - 30,100,300 mL

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
30 mL	3	23,	7,66667	2,49173	1,578522516	20,58941517
100 mL	3	14,4	4,8	0,1168	0,34176015	7,120003121
300 mL	3	11,04	3,68	0,0016	0,04	1,086956522

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	25,36569	2	12,68284	14,57724	0,00497	8,05209
Within Groups	5,22027	6	0,87004			
Total	30,58596	8				

12 ppt - 30,100,300 mL

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
30 mL	3	23,12	7,70667	3,11093	1,763783811	22,88645824
100 mL	3	15,08	5,02667	0,44853	0,669726312	13,32345892
300 mL	3	11,56	3,85333	0,00373	0,061101009	1,585667702

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	23,40729	2	11,70364	9,85376	0,01271	8,05209
Within Groups	7,1264	6	1,18773			
Total	30,53369	8				

32 ppt - 30,100,300 mL

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*	*stdev.*	*CV*
30 mL	3	21,6	7,2	3,7552	1,937833842	26,91435892
100 mL	3	17,72	5,90667	0,16373	0,404639757	6,850556362
300 mL	3	13,36	4,45333	0,01653	0,12858201	2,887322748

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	11,32907	2	5,66453	4,31806	0,06889	8,05209
Within Groups	7,87093	6	1,31182			
Total	19,2	8				

Reliability stock solution

Stock 0,3g					
Stock	Sample Volume	Pre-filtration	Post-filtration	Difference	TSS (mg/L)
1	250 mL	2,3503	2,3743	0,024	**9,6**
		2,3462	2,3679	0,0217	**8,68**
		2,3463	2,3621	0,0158	**6,32**
		2,3344	2,3643	0,0277	**11,08**
2		2,3235	2,3516	0,0281	**11,24**
		2,3565	2,3856	0,0291	**11,64**
		2,3401	2,3759	0,0358	**14,32**
		2,3365	2,361	0,0245	**9,8**
3		2,3186	2,3427	0,0241	**9,64**
		2,3604	2,3913	0,0309	**12,36**
		2,3342	2,3666	0,0324	**12,96**
		2,334	2,3557	0,0217	**8,68**

Analysis of Variance (One-Way)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
Variable #1	4	35,68	8,92	3,98187
Variable #2	4	47,	11,75	3,55987
Variable #3	4	43,64	10,91	4,29693

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	16,89947	2	8,44973	2,14122	0,17352	6,234
Within Groups	35,516	9	3,94622			
Total	52,41547	11				

Stock solution dog feed

Stock 0,3g					
Stock	Sample Volume	Pre-filtration	Post-filtration	Difference	TSS (mg/L)
1	250 mL	2,3514	2,3853	0,0339	**6,78**
		2,3451	2,3644	0,0193	**7,72**
		2,3441	2,3653	0,0212	**8,48**
		2,3344	2,3554	0,021	**8,4**
2		2,324	2,3591	0,0351	**7,02**
		2,355	2,374	0,019	**7,6**
		2,3388	2,3597	0,0209	**8,36**
		2,3377	2,3609	0,0232	**9,28**
3		2,3187	2,3542	0,0355	**7,1**
		2,3578	2,3746	0,0168	**6,72**
		2,3334	2,3528	0,0194	**7,76**
		2,335	2,3562	0,0212	**8,48**

Analysis of Variance (One-Way)

Summary

Groups	*Sample size*	*Sum*	*Mean*	*Variance*
Variable #1	4	31,38	7,845	0,62037
Variable #2	4	32,26	8,065	0,95717
Variable #3	4	30,06	7,515	0,5985

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*p-level*	*F crit*
Between Groups	0,61307	2	0,30653	0,4226	0,6677	6,234
Within Groups	6,5281	9	0,72534			
Total	7,14117	11				

Appendix 4: Nortek mail

Hi Lauran

My apologies for not getting back to you sooner. Your email has been transferred a bit back and forth (as you are probably aware of, since I accidentally included your address in one of them)

1) At first I used the function: editing series. Here I chose to remove the bad samples (minimum correlation score threshold:80 & spike filter: 1g). Secondly I tried digital filtration (Tukey's cos-filter, low pas). For both methods I chose to see the histograms afterwards. This also shows the average velocities, these differ a little bit between the methods. The digital filtration gives a lower variance so I guess this is the best method for analyzing the data, but is it?

It is difficult to give a general recommendation regarding filtering method, but you can look at the two options this way:
-Editing Time Series is for quality control.
-Digital filtering is used if you want to look at for example high-frequency or low-frequency data, or something in between. You will need to know what you are looking for to decide on what filter type to use.

By the way, the threshold of 80 is relatively stright, it is possible that you are screening out good data.
I have attached the ExploreV manual if you want the details about digital filtration and what they are used for.

2) Furthermore, when calculating the real velocity with the use of Pythagoras I should use the stream wise velocity and the transverse velocity right?

You then have the water current in X,Y and Z which can be simply transformed in to a resultant current speed using pythagoras. Perhaps these two forum postings are useful: http://www.nortek-as.com/en/knowledge-center/forum/velocimeters/30181013?b_start=0#515208851 & http://www.nortek-as.com/en/knowledge-center/forum/current-profilers-and-current-meters/579860281

Also check out our Comprehensive Manual if you have collected data using beam coordinates (download from here:http://www.nortek-as.com/en/support/manuals)

Let me know if there are any uncertainties

Best regards
Elin

Appendix 5: Recommended method for acoustic velocity measurements using Vector

The following method should be applied when monitoring water current velocities in the 3,2 m^3 rearing units in research hall 1 and 2 at the Nofima centre for recirculation in Sunndalsora using the Vector instrument.

Positioning

1. Put the wooden beam over the centre of the tank, making sure the centre of the hole through the beam is situated 45cm from the tank edge.
2. Lower the instrument through the hole and fasten it using the clamps. The instrument should be submerged for 40cm. As the instrument measures a location 10cm underneath the transmitter, the actual measurement location is situated 50cm underneath the water surface.

Calibration

1. Connect the instrument to the computer with the accompanying cable; making sure the water lock is sealed tight.
2. Open the deployment settings menu in the Vector software program.
3. Set the salinity value equal to the salinity measured in the water being measured.
4. Set the sampling rate to 8 Hz.
5. Start measuring to test if the right deployment settings are in use. The average correlation has to be above 70 % and tilt may not be above 5 degrees.

Measurement

1. Start the measurement using manual deployment and name the data set.
2. Measure the water velocity at the location for 5 minutes.
3. Stop the measurement and save the data set.

Analysis

1. Import the data sets from the instruments internal memory.
2. Open the data sets in Explore V to edit the data.
3. Cut the series to 5 minutes.
4. Open the editing time series menu and apply the spike filter and a correlation threshold of 70%.
5. Calculate the stream wise velocity from the x and y vector using the Pythagoras equation.