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Jarmo Makkonen (ed.)

Technical Solutions in the Management of Environmental Effects of Aquaculture

The Scandinavian Association of Agricultural Scientists Seminar no. 258

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Abstract

The Scandinavian Association of Agricultural Scientists held Seminar No. 258, September 13-15, 1995, at Hotel Rantasipi, Oulu. The theme of the seminar was technical solutions in the management of the environmental effects of aquaculture. The seminar was organized by the Aquaculture Section of the Finnish Game and Fisheries Research Institute. Altogether 36 participants attended the seminar consisting of eleven presentations.

This paper includes all presentations, abstracts and appendices containing the programme and names participants at the meeting.

Key words

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Tähän julkaisuun on koottu kaikki pidetyt esitelmät tai abstraktit sekä liitteiksi seminaarin ohjelma ja osallistujalista.

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Contents

OPENING ADDRESS: AQUACULTURE IN FINLAND

KAI WESTMAN

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It gives me great pleasure to welcome you on behalf of the Finnish Game and Fisheries Research Institute to Finland and to this NJF Seminar on Technical Solutions in Management of the Environmental Effects of Aquaculture.

As the seminar is held in Finland I thought it would be advisable to give you a few facts about the aquaculture in this country. Early attempts in aquaculture were made during the 1850s but as a specialised industry aquaculture was first begun only during the 1960s when the rainbow trout was introduced for the second time and factory-made feeds became available. In addition to the rearing of rainbow trout for human consumption, the rearing of juveniles of many fish species both in farms and natural food ponds for stocking also increased rapidly. During the early 1970s experiments for farming rainbow trout in net cages in the coastal areas were begun.

According to data collected by the Finnish Game and Fisheries Research Institute food-fish farming in Finland expanded by about 15 % per year during the 1980s, attaining a peak in 1991 when over 19 000 tonnes of rainbow trout were produced (Fig. 1). Since then production has slightly decreased to 17 000 tonnes in 1994, which was over 10 % of the total domestic fish production. About 80 % of food fish are reared in net cages in the Baltic and the rest in earthen ponds in inland farms. The dominant food fish product is the large rainbow trout (1-3 kg), of which Finland is currently the largest producer in Europe. The percentage of rainbow trout in domestic fish consumption is about 25 %, most of which is marketed as fresh fish, while about 40 % is processed. The main forms of processing are filleting and smoking. The bulk of rainbow trout are consumed in Finland and only about 6-11 % are exported; a significant export commodity is rainbow trout roe.

About 20 fish species with 80 different strains and two crayfish species are reared in Finland for restocking. Atlantic salmon, brown trout and Arctic char are the most important species reared in fish farms (total production about 10-12 million mostly 1-2-year-old, 50-150-g individuals yearly) while coregonids, pike-perch and grayling are the dominant species in natural-food pond production (total production about 40-45 million 1-summer-old, 5-15 g juveniles; Table 1). As a whole aquaculture plays an important role in fishing, as the catches of salmon and trout are based almost totally on stockings and similarly a large proportion of coregonid and pike-perch catches originates from reared juveniles.

The total number of aquaculture farms was slightly below 800 in 1994. Of these, about 200 were in coastal and 550 in inland areas including about 340 natural-food pond enterprises (about 850 ponds, total area 9970 hectares); about 100 additional farms produce crayfish juveniles. Most aquaculture farms are small - the average production is about 30 tonnes - and run by the owners.

The value percentage of aquaculture has continuously increased since 1980 to about 68 % of commercial fisheries production and 81 % of export in 1992 (Fig. 2). The number of employees in the aquaculture sector has been estimated to be equivalent to about 2000 man-years. In general, the development of aquaculture and the management of fish stocks with reared juveniles have been the greatest changes occurring in Finnish fisheries during the last few decades.

The nutrient load caused by fish farming grew steadily during the 1980s, mainly due to the increase in production. The load is now decreasing, however, mainly as a result of reduced specific load.

In recent years we have seen a strongly increased public concern over environmental protection. Many conflicts between fish farming and other interests have occurred, especially in the archipelago areas, concerning nutrient load. Increasing demands also occur to reduce the environmental impact of fish farming. If these and other environmental problems cannot be solved and the nutrient load reduced, especially in net-cage farming, no possibilities would exist for increasing aquaculture production - on the contrary I fear that demands to decrease the production will grow continually stronger.

Bearing this in mind the topic of this NJF seminar is most important and appropriate. I would like to mention that at the VI Meeting of Directors of Fishery Research Organisations in the European Union, Arcachon, May 1995, environmental and site problems were pointed out as the main constraints on the development of aquaculture in the Northern countries. That so many distinguished experts, representing seven nationalities, have gathered here is a clear indication of the need for and the wide interest in the management of environmental effects of aquaculture. The exchange of information on an international basis is an absolute necessity for promoting the sound development of aquaculture in our countries.

I hope you will enjoy your visit to Oulu and to Kainuu Fisheries Research and Aquaculture Station and have a pleasant stay in Finland.

Table 1. Aquaculture in Finland. Volume figures 1993.

CAPACITY			
Number of active farms		744	units
	Cage volume	1,5	mill. m^3
	Area of tanks/raceways	0,9	mill. m^2
	Natural food pond area	9 970	hectares
PRODUCTION			
Market size (1-3 kg) trout			
	In the Baltic Sea	13 760	tons
	In inland waters	3 750	tons
Salmonid parr and smolts			
	Atlantic salmon	5,9	mill. indiv.
	Brown trout	6,3	mill. indiv.
	Arctic charr	0,3	mill. indiv.
Juveniles of other species			
	Coregonids	35,9	mill. indiv.
	Grayling	2,5	mill. indiv.
	Pike-perch	6,7	mill. indiv.
	Other fish species	1,6	mill. indiv.
	Crayfish	0,4	mill. indiv.

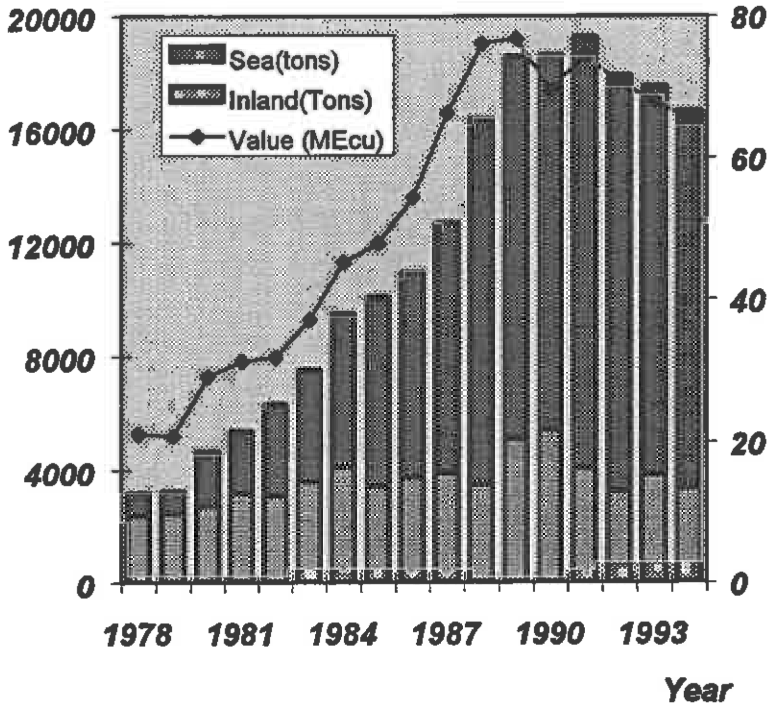

Figure 1. Aquaculture in Finland. Food fish production (amount and value).

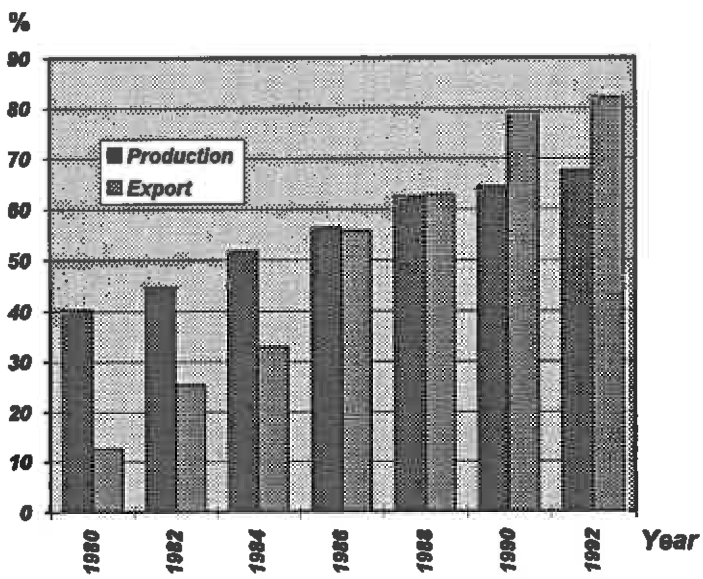

Figure 2. Aquaculture in Finland. The role in the finnish fisheries industry. The value share of the aquaculture of commercial fisheries production and export in 1980-1992.

SITE SELECTION VERSUS PROPER FARMING TECHNOLOGIES WITH RESPECT TO THE ENVIRONMENTAL IMPACTS OF AQUACULTURE, A REVIEW

LARS HÅKANSON

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Norbyvägen 18 B, S-75236 Uppsala, Sweden

The review presentation summarised the following five papers:

FISKODLING SOM MILJÖVÅRD?
Can emissions from fish farms be used as a remedial measure for lakes?
Lars Håkanson, Lennart Carlsson och Torbjörn Johansson. Inst. för geovetenskap, Uppsala univ., Norbyv. 18 B, 75236 Uppsala, Sverige. Vatten 51: 112-124. Lund 1995.

VILDFISKENS BETYDELSE FÖR SPRIDNINGEN AV FOSFOR FRÅN FISKODLINGAR
The importance of wild fish to the distribution of phosphorus from fish farms
Kristian Borum, Vetrepharm A/S, Brande, Danmark, Torbjörn Johansson och Lars Håkanson Inst. för geovetenskap, Uppsala univ., Norbyv. 18 B, 75236 Uppsala, Sverige. Vatten 51: 125-134. Lund 1995.

VAR TAR EMISSIONER FRÅN FISKODLING VÄGEN?
Where are the emissions from fish farms in lakes?
Lars Håkanson och Johan Persson. Inst. för geovetenskap, Uppsala univ., Norbyv. 18 B, 75236 Uppsala, Sverige. Vatten 51: 00-00. Lund 1995.

FOSFORFLÖDEN OCH EUTROFIERINGSEFFEKTER - KALIBRERINGAR OCH SIMULERINGAR MED LEEDS-MODELLEN I SJÖN SÖDRA BULLAREN
Flows and effects of phosphorus-calibrations and simulations using the LEEDS-model (Lake Eutrophication, Effect-Dose-Sensitivity model) in Lake S. Bullaren, Sweden
Lars Håkanson och Lennart Carlsson. Inst. för geovetenskap, Uppsala univ., Norbyv. 18 B, 75236 Uppsala, Sverige. Vatten 51: 00-00. Lund 1995.

EN KRITISK GENOMGÅNG AV METODER OCH BEDÖMNINGS-UNDERLAG FÖR ÖVERGÖDNINGSEFFEKTER AV FISKODLING I SJÖAR - SAMMANSTÄLLNING OCH ÖVERSIKT
A critical Review of Methods to Calculate Eutrophication Effects of Emissions from Fish Farms in Lakes
Lars Håkanson och Torbjörn Johansson. Inst. för geovetenskap, Uppsala univ., Norbyv. 18 B, 75236 Uppsala, Sverige. Vatten 51: 00-00. Lund 1995.

DECISION ANALYSIS - A SET OF TOOLS TO DESIGN ENVIRONMENTALLY SUSTAINABLE AQUACULTURE

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ABSTRACT

Environmental impacts, like eutrophication are among the most serious factors limiting the growth and development of aquaculture industry. In addition to this the communication between fish farmers and environmental authorities is often far from optimal. For these reasons it seems importing to search for methods which facilitate the analysis of interactions between environmental management and economy and improve the communication. In the paper, a set of such methods is suggested. We will discuss about the decision analysis as a tool for designing sustainable development of aquaculture.

Decision analysis is a group of methods to formulate and examine various decision problems. It will enable use to model and compare the consequences of different decision alternatives. By using the approach we will be able to deal with uncertainties. Also, the value of additional information, like improved monitoring, or the usefulness of certain environmental measure can be evaluated.

A characteristic feature of decision modelling is that rather than single measures attention is paid to goals and criteria that often are incompatible. Furthermore, decision analysis will enable the discussion between different groups with different and inconsistent targets. Main conflicts between interests can be pointed out and analysed in details.

In the paper a preliminary model is development for analysing a goal oriented environment protection programme for Finnish aquaculture. The model is applied to point out the relevant measures for environmental policy of aquaculture in the country.

Keywords: Mariculture, Environmental impacts, Environmental policy, Decision analysis

AUTOCHTHONOUS AND ALLOCHTHONOUS FOOD RESOURCES IN RAINBOW TROUT CAGE CULTURE: CONSEQUENCES FOR NUTRIENT LOADS INTO THE WATER

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ABSTRACT

The nutrient loads into the water from rainbow trout cage culture using either autochthonous Baltic herring or allochthonous artificial dry pellets were estimated and compared. Herring-feeding showed lead to nitrogen and phosphorus loads into the water which are twice as high as feeding on commercial dry pellets. This was also confirmed by direct measurements of the ammonia and phosphate excretion. The net nutrient loads into the Baltic using herring-feeding were negative, *i.e.* nutrients were removed from the Baltic by fish farming.

Attempts to reduce the total loadings were made. Increasing feeding frequencies resulted in increased nutrient loads irrespective of diets. Because the main reason for high nitrogen loads from herring was thought to be the high protein-to-energy ratio, herring was enriched with fish oil. Dietary fat level had a more pronounced effect in reducing the expected nutrients loads in dry pellets than herring. However, the reduction within the herring, was about 18 % on average for nitrogen and 25 % for phosphorus loads. Dietary water content *per se* did not affect the nutrient loads as was shown in an experiment on carefully formulated moist pellets.

Variability in body nutrients contents was larger than expected and the phosphorus content tended to slightly increase with increasing body size. Nutrient retention efficiencies were related to the growth of the fish as well as the dietary contents of nutrient. Year-to-year variation in nutrient loads into the water was large and one of the main reasons for this difference in growth of the fish between the various years.

ENVIRONMENTAL PARAMETERS AND MEASURING METHODOLOGY FOR CAGE FARMING, FARM MANAGEMENT AND TECHNOLOGICAL SOLUTIONS TO MINIMIZE THE WASTE FROM AQUACULTURE - A REVIEW

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ABSTRACT

Various methods have been used to describe the environmental effect from fish farming in cages. This review gives a brief description of how some of the methods can be used in the calculation of carrying capacity of a farm site, evaluate the possibility of diseases and be useful in the daily maintenance of the farm. Various technological solutions to minimise the waste from aquaculture is also presented.

A proper management of fish farms can be carried out by using new feeding methods based on physiological and behavioural mechanism that control the appetite of the fish. Overfeeding can be registered by using a hydroaccustic system for monitoring feeding and feeding control, and waste feed can be sampled by use of specific designed sampling mechanism, the "LiftUp" system. The system is particular useful when antibiotics is used in disease treatment. Good husbandry practice and management of fish farms can only be carried out when all steps in the farming process are well planned. This includes buying high quality fingerlings/smolt, use of vaccines, selection of high quality feed, keeping records of daily maintenance and feeding, site location and surveillance of the environmental conditions. If these operations are followed carefully, there will be few environmental problems both at the farm and in the surroundings.

WASTE PHOSPHORUS AND SOLIDS FLOW IN AQUACULTURE SYSTEM - A PRACTICAL STUDY

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ABSTRACT

According to the new licence given by the Water Rights Court for Eastern Finland, the Saimaa Fisheries Research and Aquaculture was obliged to follow up the effluent treatment phases and to take into consideration the possible improvements that may diminish the sludge and nutrients (phosphorus) in the outflow.

In summer 1994, the solid and phosphorus flows in the functionally different parts of the fish farm, and the efficiency of the different water treatment technologies were studied.

On the basis of the results, basins' self-cleaning capacity and swirl separators' efficiency in the different parts of fish farm, as well as the waste treatment efficiency of sludge collection plant and settlement ponds were calculated and analysed. The total phosphorus loading from the whole process was calculated on the basis of the results from the different parts of the fish farm.

Basins' self-cleaning capacity had a connection with basin size. In the juvenile and the brood stock halls, the self-cleaning capacity was high, about 80 % of the total phosphorus and 83-94 % of suspended solids. The same values for the large basins in the outdoor area were much lower, 11-28 % and 5-32 %. Swirl separator with constant flow was clearly more effective than separators with pulsating inflow; the total phosphorus catch 50 % and suspended solids catch over 70 %, whereas pulsating inflow lowered the levels remarkably. The settlement ponds were effective on suspended solids: about 98 % of inflow solids were left in the ponds, but only about 8 % of the phosphorus. In the sludge collection plant with liming and sedimentation silo, phosphorus removal was excellent (over 98 % cleaning efficiency).

1. INTRODUCTION

Saimaa Fisheries Research and Aquaculture (formerly Central Fish Culture and Fisheries Research Station for Eastern Finland) is one of the fish farms and research stations of the Finnish Game and Fisheries Research Institute. The farmed species are salmonids, coregonids and grayling, but nowadays also pike perch and crayfish. The farm mainly produces fish eggs, fry and also some fingerlings. Therefore, of the maximum allowed biomass (33 tn), the major part consists of brood stock. Saimaa

Aquaculture was built in 1981-1989 and the technological solutions were planned and built according to the knowledge of modern aquaculture technology of the time.

According to the new license given by the Water Rights Court for Eastern Finland, the fish farm was obliged to follow up the effluent treatment phases and take into consideration the possible improvements that may diminish the amount of sludge and nutrients (phosphorus) in the outflow.

In summer 1994, the solids and phosphorus flows in the functionally different parts of the fish farm, and the efficiency of different water treatment technologies were studied. This paper summarises the results published in Finnish in the Report Series of the Finnish Game and Fisheries Research Institute by Pursiainen and Makkonen (1995).

2. PROCESS DESCRIPTION

2.1 Water flow in general

Incoming water from two sources, Lake Ylä-Enonvesi and Lake Pahkajärvi flows into the use of aquaculture through a tunnel and pipelines. The total amount of water varies from 670 l/s in winter to 870 l/s in summer. The water is distributed into the basins in the hatchery, juvenile hall and brood stock hall mainly along open throughs. The upper outdoor concrete basin area gets only primary water through pipelines. The lower outdoor area with concrete basins and raceways, and also some earthen ponds uses secondary watering; the water distribution is arranged along tubelines or a channel from a cascade that aerates the water coming from upper parts of the fish farm. By using various sludge collection systems and separate basin structures (described below), a minor part of the water is handled separately, but the whole outflow goes through the earthen settlement ponds.

2.2 Production facilities

There are many different types and sizes of basins in Saimaa Aquaculture, most of them designed to be self-cleaning. In Table 1, the types, numbers and areas of basins are given, as well as the fish biomass, feeds, feeding method and water usage during the study period (Table 1). The total fish rearing basin area in the whole fish farm is 8 832 m^2 and the fish biomass during the study period about 24 tn.

Table 1. Types and numbers of basins with their area (m^2), and fish biomass (kg), feeding (kg/day), feeding method (automatic or manual) and water usage (l/sec.) during the study period. SS1 - SS5 are the swirl separators.

STUDY AREAS	BASINS		FISH	FEEDING		WATER
Type of basins	Num.	m^2	kg	kg/day	A/M**	l/sec.
HATCHERY						13.1
Round, fibreglass (type B)	16	3.3	79.9	2.1	A	
JUVENILE HALL (SS1)						88.1
Round, fibreglass (type A)	29	2.1	119.8	3.6		
Round, fibreglass (type B)	60	3.3	1 331.4	20.2	A	
Round, fibreglass (type E)	15	3.3	682.2	18.9	A	
Round, fibreglass (type H)	10	12.7	878.2	19.2	A	
BROOD STOCK HALL (SS4)						144.6
Round, fibreglass/concrete (type I)	18	28	1 023.9	29.0	A+M	
Round, fibreglass/concrete (type J)	13	63	2 014.1	16.5	M	
UPPER OUTDOOR AREA (SS2)						194.7
Round, concrete (type J)	18	63	3 213.0	13.9/0.5*	A+M	
Round, concrete (type K)	6	113	4 004.0	12.4/2.8*	M	
UPPER OUTDOOR AREA (SS3)						227.3
Round, concrete (type K)	20	113	7 748.8	15.6/8.5*	M	
LOWER OUTDOOR AREA						662.3
Round, concrete (type J) (SS5)	13	63	14.0	-	A+M	
Raceway, concrete (types M, N)	4/6	150/75	397.1	3.9/0.2*	A+M	
Earthen (type P)	3	360	2 227.1	9.4/7.9*	A+M	
SETTLEMENT PONDS						740.5
Earthen, settlement (type T)	3	1 240	no	no	no	
Earthen, sedimentation (type T4)	1	820	no	no	no	

* fresh feed (smelt)

** automatic (A) / manual (M) feeding

2.3 Waste water and sludge flows from rearing facilities

Water outflow from the hatchery self-cleaning basins (type B, cf. Table 1) goes via throughs and a tubeline directly to the settlement ponds (type T, cf. Table 1). Hatchery basins do not have a sludge separation system.

The whole outflow from the small basins (type A, cf. Table 1) in the juvenile hall, as well as the surface outflow from the deep basins (types E and H, cf. Table 1) also pass via throughs and a tubeline directly to the settlement ponds. In type E and H basins, there are sludge pockets in the middle, from which the sludge is pumped daily to the swirl separator nr 1 (SS1). All outflow from type B basins goes through the swirl separator nr 1 (SS1).

In the brood stock hall all basins (types I and J, cf. Table 1) have two outlets, one from the surface and the other from the sludge pocket in the middle of the bottom. The water from the surface outlet flows to the cascade to be aerated and further used on the lower outdoor area. The sludge pockets are emptied every workday to the swirl separator nr 4 (SS4).

The basins (types J and K, cf. Table 1) on the upper outdoor area are also equipped with two outlets, one from the surface to the cascade and the other from the sludge pocket. The sludge pockets are emptied every workday to the swirl separators nr 2 (SS2) and nr 3 (SS3).

On the lower outdoor area, the round concrete basins (type J, cf. Table 1) function in the same manner as the basins in the upper outdoor area, but the surface outlet leads to the settlement ponds. The concrete raceways (basins type M and N, cf. Table 1) and earthen ponds (type P, cf. Table 1) have a common outlet channel that conveys the flow straight to the settlement ponds.

2.4 Swirl separators, settlement ponds and sludge collection plant

There are five swirl separators in Saimaa Aquaculture. Swirl separator nr 1 (SS 1, ∅ 4.0 m, max Q 67 l/s) operates on the basis of the constant current from the juvenile hall. The swirl separators nr 4 (SS4, ∅ 2.5 m, max Q 25 l/s) of the brood stock hall, nr 3 (SS3, ∅ 2.5 m, max Q 22 l/s) and nr 4 (SS4, ∅ 2.5 m, max Q 23 l/s), of the upper outdoor area, and nr 5 (SS5, ∅ 2.5 m, max Q 11 l/s) of the lower outdoor area, receive pulses from the effluent water in the sludge pockets of each basin.

From the swirl separators nr 1 - 3 (SS1 - SS4) the overflow goes to the cascade for aeration and is used on the lower outdoor area. Swirl separators nr 4 (SS4) of the brood stock hall and nr 5 (SS5) on the lower outdoor area has such position that their overflow goes to the washing water channel (see below). The sludge from the bottom of the swirl separators is pumped into the sludge collection plant.

Because of the position of the fish farm, the washing and rinsing waters from the basins in the brood stock hall and in the outdoor areas are drained or pumped into the collection channel. From this channel, the water is pumped forward to the sludge sedimentation pond type T4 (cf. Table 1) after adding some 250 g/m3 of lime into the water to activate the sedimentation. During the study period, the liming was in a testing phase and not automatic. Therefore, this purification method is not carefully analysed in this paper.

The fish farm has three flow-through settlement ponds type T (cf. Table 1), which collect all the water from the fish farm. These ponds are drained every year after the production period and the sludge is transported to be used as fertilizers on local agricultural land.

The sludge water from the bottom of swirl separators is pumped every workday to the sludge collection plant. The sludge is stabilized automatically by liming and settled in a steel/concrete silo. The clarified water from the surface is pumped into the washing water channel, and the sludge transported weekly to be used as agricultural fertilizers.

3. METHODS

The study focused on suspended solids and phosphorus (total phosphorus, or filtered samples) loads from different parts in the fish farm. The results are given as the increase of the content of suspended solids or phosphorus compared to the incoming water, and as the total loading amounts per day.

Sampling period was from July 25 to September 22, when feeding levels usually are at their maximum. In August, the water temperature was exceptionally high and, therefore, feeding levels low. This caused difficulties in sampling and analyzing and made it difficult to compare the results between the studied parts of the fish farm.

Automatic samplers were used when possible. Each area was sampled within one week from Monday afternoon to Thursday afternoon, i.e. three samples on successive days were taken for analysis.

During the sampling period, the number of fish was very low in the round concrete basins in the lower outdoor area. Therefore, no sampling was done, and the efficiency of the swirl separator nr 5 (SS5) could not be studied.

The efficiency of the sludge collection plant was followed during the whole study period by weekly sampling. Samples were taken from the limed sedimented sludge and from the clarified overflow water.

4. RESULTS

Table 2 shows the average phosphorus and suspended solids contents in inflow and outflow of each of the studied areas, and the loads either to the cascade or to the settlement ponds, and finally to the receiving water, Sahalampi bay, which is located below the fish farm.

Table 2. Inflow and outflow mean contents of phosphorus (µg/l) and suspended solid (mg/l) and the total amounts of phosphorus (g/day) and suspended solids (kg/day) during sample periods from the different parts of the fish farm.

STUDIED AREA	PHOSPHORUS total		PHOSPHORUS filtered		SUSPENDED SOLIDS	
	µg/l	g/day	µg/l	g/day	mg/l	kg/day
HATCHERY						
Inflow	16.5	10.7	14.1	9.5	1.6	1.0
Outflow	24.6	27.8	12.3	13.9	1.5	1.7
Load to settlement ponds		**17.1**		**4.4**		**0.7**
JUVENILE HALL (SS1)						
Inflow	16.5	41.8	14.1	37.7	1.6	3.9
Outflow	23.1	99.1	14.7	63.1	1.5	6.3
Load to settlement ponds		**57.3**		**25.4**		**2.4**
BROOD STOCK HALL (SS4)						
Inflow	14.7	114.0	9.0	71.1	1.7	12.0
Outflow	12.9	155.6	5.1	61.5	1.1	13.3
Load to cascade		**41.6**		**-9.6**		**1.3**
UPPER OUTDOOR AREA (SS2)						
Inflow	9.9	166.5	6.3	106.0	0.9	15.7
Outflow	12.3	202.6	4.8	79.0	1.2	19.8
Load to cascade		**36.1**		**-27.0**		**4.1**
UPPER OUTDOOR AREA (SS3)						
Inflow	11.1	218.0	8.4	165.0	0.7	13.1
Outflow	12.6	244.1	6.6	127.8	0.8	14.9
Load to cascade		**26.1**		**-37.2**		**1.8**
LOWER OUTDOOR AREA						
Inflow	14.6	835.5	8.2	467.3	0.8	45.8
Outflow	16.2	927.0	9.0	515.0	0.9	51.5
Load to settlement ponds		**91.5**		**47.7**		**5.7**

In Table 3, the average phosphorus and suspended solids contents in the inflow and outflow of the studied swirl separators are given, as well as the loadings either to the cascade or to the washing water channel.

Table 3. Mean contents of phosphorus (µg/l) and suspended solids (mg/l) and amounts of phosphorus (g/day) and suspended solids (kg/day) in swirl separators.

SWIRL SEPARATOR SS nr	PHOSPHORUS total		PHOSPHORUS filtered		SUSPENDED SOLIDS	
	µg/l	g/day	µg/l	g/day	mg/l	kg/day
SS1						
Inflow	70.9	235.2	27.9	92.4	4.6	15.1
Overflow	40.4	134.7	18.0	60.0	1.9	6.4
Load to cascade		**101.1**		**29.4**		**3.3**
SS4						
Inflow	432.2	186.7	130.9	56.6	45.3	19.6
Overflow	311.2	134.4	67.3	29.1	20.3	8.7
Load to wash. channel		**131.7**		**27.4**		**8.4**
SS2						
Inflow	50.0	17.7	14.4	5.1	6.2	2.2
Overflow	36.8	13.0	12.6	4.5	2.5	0.9
Load to cascade		**9.5**		**2.3**		**0.6**
SS3						
Inflow	23.1	6.2	10.5	2.8	1.0	0.3
Outflow	26.1	7.0	10.8	2.9	1.3	0.4
Load to cascade		**4.0**		**0.7**		**0.2**

Table 4 shows the results of the sampling of the settlement ponds. It should be remembered that the outflow from the sedimentation pond (T4) is included in the values given, because the overflow of that pond goes through the same channel to the receiving water.

Table 4. Mean contents of phosphorus (µg/l) and suspended solids (mg/l) and amounts of phosphorus (g/day) and suspended solids (kg/day) in settlement ponds.

SETTLEMENT PONDS	PHOSPHORUS total		PHOSPHORUS filtered		SUSPENDED SOLIDS	
	µg/l	g/day	µg/l	g/day	mg/l	kg/day
Inflow	20.0	1 277.4	9.3	592.9	1.1	70.3
Outflow	19.2	1 228.4	10.2	652.6	0.9	57.6
Load to Sahalampi		**-49.0**		**59.7**		**-12.7**

The results of the two months' weekly follow-up of the sludge collection plant are given in Table 5.

Table 5. The average amount of limed sedimented sludge (m^3/week) and its mean content (mg/l) and amount (g/week) of phosphorus and the sludge dry matter concentration (DM mg/l). The clarified overflow phosphorus content (mg/l) and load (g/week) in the sludge collection plant is also given.

SLUDGE COLLECTION PLANT	SLUDGE				OVERFLOW	
	m^3/week	P mg/l	P g/week	DM mg/l	P mg/l	P g/week
Weekly averages	4.14	761	3 139.1	15.3	1.1	52.5

5. ANALYSIS OF THE WASTE FLOWS

5.1 Basins' self-cleaning capacity

Basins' self-cleaning capacity in the different studied parts of the fish farm is analysed and presented in Table 6. The self-cleaning capacity is given as percentages (%) of phosphorus and suspended solids taken from the sludge pockets of the basins compared to the total outflow phosphorus and suspended solids.

Table 6. Total loads of phosphorus and suspended solids (g/day) in different parts of the fish farm and the share of it that remained in the swirl separators (g/day), and self-cleaning capacity (%) calculated according to those figures. SS are the swirl separators of each area.

	STUDY AREA (loader)					
	Hatchery	Juvenile hall (SS1)	Brood stock hall (SS4)	Upper outd. area (SS2)	Upper outd. area (SS3)	Lower outdoor area
Total load (g/day)						
Phosphorus, total	17.1	258.8	225.6	50.3	29.3	91.5
Phosphorus, filtered	4.4	87.3	45.3	-24.0	-36.6	47.7
Suspended solid	0.7	14.4	20.6	6.0	1.9	5.7
Load to swirl separators (g/day)						
Phosphorus, total	0.0	201.6	184.0	14.2	3.2	0.0
Phosphorus, filtered	0.0	61.8	54.9	2.2	0.6	0.0
Suspended solid	0.0	12.0	19.3	1.9	0.1	0.0
Basin self cleaning capacity (%)						
Phosphorus, total	0.0	77.9	81.6	28.2	10.9	0.0
Phosphorus, filtered	0.0	70.8	121.2	-*	-*	0.0
Suspended solid	0.0	83.3	93.7	31.7	5.3	0.0

* P not filtered -efficiencies not valid, because the load from basins was negative

5.2 Swirl separator efficiency

Swirl separator efficiencies to remove suspended solids and phosphorus from their inflow is analysed and presented in Table 7. The efficiencies are given as percentages (%) of the differences between inflow and outflow phosphorus and amounts of suspended solids.

Table 7. Nutrient and suspended solids removal efficiency in the studied swirl separators. The amounts of incoming total phosphorus and phosphorus from filtered samples as well as suspended solids are given (Inflow/Outflow (g/day)), and efficiency counted as percentages (%) between given values. SS are the swirl separators of each area.

LOADS Area and SS number	Inflow g/day	Overflow g/day	Settlement g/day	Efficiency %
Phosphorus, total				
Juvenile hall (SS 1)	201.6	101.1	100.5	49.9
Brood stock hall (SS4)	184.0	131.7	52.3	28.4
Upper outdoor area (SS2)	14.2	9.5	4.7	33.1
Upper outdoor area (SS3)	3.2	4.0	-0.8	-25.0
Phosphorus, filtered				
Juvenile hall (SS 1)	61,8	29.4	32.4	52.4
Brood stock hall (SS4)	54.9	27.4	27.5	50.1
Upper outdoor area (SS2)	2.9	2.3	0.6	20.7
Upper outdoor area (SS3)	0.6	0.7	-0.1	-16.7
Suspended solids				
Juvenile hall (SS 1)	12 000	3 300	8 700	72.5
Brood stock hall (SS4)	19 300	8 400	10 900	56.5
Upper outdoor area (SS2)	1 900	600	1 300	68.4
Upper outdoor area (SS3)	100	200	-100	-100.0

5.3 Sludge removal efficiency

Settlement pond nutrient and suspended solids removal efficiency was calculated from the differences between incoming and outflowing load (Table 8). In the outflow, there are also nutrients and solids from the sedimentation pond (T4), which represent only a very small part of the totals.

Table 8. Nutrient and suspended solids removal efficiency of the flow through settlement ponds. The amounts of incoming total phosphorus and phosphorus from filtered samples as well as suspended solids are given, and efficiency counted as percentages (%) between given values.

LOADS	Inflow g/day	Outflow g/day	Settlement g/day	Efficiency %
Phosphorus, total	631.2	582.2	49.0	7.8
Phosphorus, filtered	118.1	177.8	-59.7	-50.6
Suspended solids	13 000	3 000	12 700	97.7

Sludge collection plant efficiency was very good, according to the results given in the Table 5. Of the inflow phosphorus (3 139.1 g/week) only 52.5 g was pumped into the washing water channel. The efficiency was as high as 98.3 %.

In autumn, when the sedimentation pond (T4) was drained and the sedimented sludge (160 m^3) removed, the amount of the total phosphorus in the sludge was only 4.5 kg. The dry matter concentration in the sludge was 0.48 %. At the same time, the vegetation that was grown during the summer in the flow through settlement ponds was harvested. The amount of removed vegetation was 13 tons, containing 3.5 kg of phosphorus.

5.4 Waste phosphorus flow in the fish farm

The analysis of the whole process is done dealing with the total waste phosphorus in the aquaculture process. Generally speaking, it can be noticed from the results and the analysis, that the total phosphorus is related to the amount of suspended solids, and therefore it can be used in this context. Total phosphorus is also the most important negative factor in fish farm effluents in Finland.

The phosphorus load from fish farm basins and ponds flows into the internal processes in the fish farm, i.e. to swirl separators, cascade, washing water collection channel, settlement ponds and the sludge collection plant. The loading to the receiving water comes only from the settlement ponds.

According to the principle explained, the phosphorus loading to the receiving water was calculated in relation to the phosphorus load leaving the basins and ponds. To make the figures of the purification processes comparable, the phosphorus loads from a certain studied area were in these calculations given the value 100 (Table 9).

Table 9. Relative total phosphorus flow in the fish farm and the load to lake from each studied area. The phosphorus in the effluents of the basins has been given the value 100.

	STUDIED AREA (loader)					
PHOSPHORUS FLOW	Hatchery	Juvenile hall (SS1)	Brood stock hall (SS4)	Upper (SS2) outd. area	Upper (SS3) outd. area	Lower outdoor area
Effluent	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Load catch via swirl separators into sludge collection plant	0.0	38.2	22.8	9.2	-2.7	0.0
Load remaining in settlement ponds	7.8	4.8	6.0	7.1	8.0	7.8
Total of the caught loading	7.8	43.0	28.8	16.3	5.3	7.8
Load to lake	**92.2**	**57.0**	**71.2**	**83.7**	**94.7**	**92.2**

The calculated loading effect in Table 9 does not describe the real situation, they only give relative figures of the outflow loading from each area. The fish biomasses as well as feeding differ greatly from one area to another. Therefore, to get some idea of the real share of the loading from different parts of the fish farm, the figures given in Table 10 are related to fish biomass.

Table 10. Loading influence in percentages (%) related to fish biomass.

STUDIED AREA	Relative loading to the lake	Fish biomass kg	Relative loading × biomass	Share of the total loading (%)
Hatchery	92.2	79.9	7 366.8	0.37
Juvenile hall (SS1)	57.0	3 011.6	171 661.2	8.67
Brood stock hall (SS4)	71.2	3 113.7	221 695.4	11.19
Upper outdoor area (SS2)	83.7	7 217.0	604 062.9	30.50
Upper outdoor area (SS3)	94.7	7 748.8	733 811.4	37.05
Lower outdoor area	92.2	2 624.2	241 951.2	12.22

6. DISCUSSION AND CONCLUSIONS

The summer 1994 was exceptionally warm, and the feeding levels very low especially during the sampling period on the upper outdoor area (swirl separator nr SS3). Therefore, the results regarding that particular area are not completely reliable. In the juvenile hall, there are two different basin structures and three outlet solutions, which makes it difficult to get exact information on the self-cleaning capacity of those basins. The lower outdoor area with round concrete basins and swirl separator SS5 was not studied because of its low fish biomass. This would have been of interest, because it re-uses the water from the upper part of the farm that already contains some nutrient and suspended solids loading.

The self-cleaning capacity of the basins varies greatly in different areas, as can be seen from the summary Table 11.

Table 11. Basins' self-cleaning capacity (%) compared to the basin surface area (m^2).

STUDIED AREA	Basin area (m^2)	Phosphorus, total (%)	Suspended solids (%)
Juvenile hall	2.1 - 12.7	78	83
Brood stock hall	28 - 63	82	94
Upper outdoor area (SS2)	63 - 113	28	32
Upper outdoor area (SS3)	113	11	5

It can clearly be seen from Table 11, that self-cleaning capacity depends on the basin surface area; the bigger the basin, the lower the share of relative load that can be separated from the main outflow. In the juvenile hall, there are several different types of basin outlets and structures, which undoubtedly affects the results. It should also be noticed, that there is a big difference between brood stock hall and upper outdoor area. Some of the brood stock hall basins are small (28 m^2) and shallow (0.5 m), some deeper (c. 1.4 m), whereas all outdoor basins are about 1.5 m deep. In shallow basins there is, of course, greater water velocity than in the deeper ones, which increases the sludge transportation to the sludge pocket. However difference is so big between these two areas, that it seems obvious that direct sunshine and algae growth explain to some extent the poorer results under the open sky basins compared to the sheltered basins.

Swirl separator efficiency on phosphorus and suspended solids clearly depends on the self-cleaning capacity of the basins. Another important factor is operation principle, i.e., constant or pulsating flow, as can be seen from summary Table 12.

Table 12. Swirl separator efficiency in removing phosphorus and suspended solids of the inflow compared to the operation principle.

AREA AND SWIRL SEPARATOR	Usage principle (inflow)	Phosphorus, total (%)	Suspended solids (%)
Juvenile hall (SS1)	constant + pulses	50	73
Brood stock hall (SS4)	pulsating	28	57
Upper outdoor area (SS2)	pulsating	33	68
Upper outdoor area (SS3)	pulsating	- 25	- 100

It is interesting that there is a constant current from one kind of basins that from the juvenile hall to the swirl separator nr SS1, plus daily pulses from another basin type, and still the efficiency figures remain good. It seems obvious that the stable current circumstances are not disturbed by an additional pulsating inflow.

Settlement pond's efficiency in removing phosphorus was poor, only about 8 percent of the incoming phosphorus. Phosphorus content increased in filtered samples, which is a sign of internal phosphorus dissolving. On the other hand, the removal of suspended solids was very efficient, about 98 percent of the inflow suspended solids.

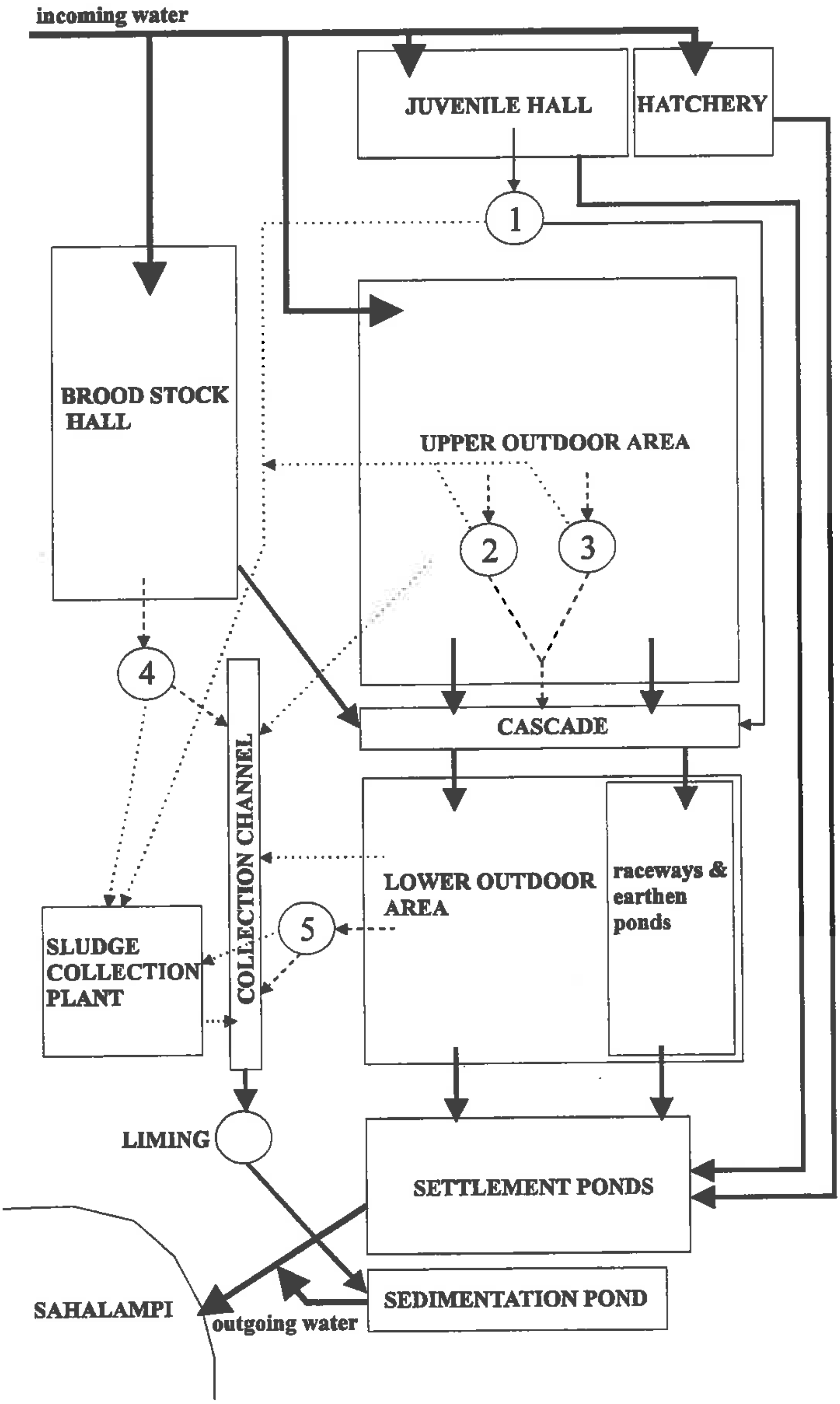
The efficiency of the sludge collection plant comes close to perfection, being 98 percent of the total phosphorus.

7. RECOMMENDATIONS

There are several recommendations that can be given for further development in increasing the waste water treatment and sludge removal in Saimaa Aquaculture; of the results presented, three are the most important.

1) The self-cleaning capacity of bigger basins should be increased. Therefore, the current velocity has to be improved and, at the same time with the internal structures in the basins, develop sludge transportation into the sludge pockets.
2) Mechanical equipment for the removal of sludge from the bottom of the basins is needed, and should be developed in cases where the self-cleaning efficiency remains low. This, however, requires manpower; therefore, the main interest should be the development of the self-cleaning efficiency.
3) Swirl separators should be operating on the principle of constant inflow and the dimensions should be changed to answer those demands. Constant inflow creates stability in the swirl separator, and therefore it can also take pulses from sludge pockets without a disturbance in the separating efficiency.

APPENDIX. Schematic waste water flow in Saimaa Aquaculture



BIOTECHNOLOGICAL INITIATIVES FOR REDUCED ENVIRONMENTAL LOADING IN AQUACULTURE

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ABSTRACT

Aquaculture has experienced significant and sustained growth over the last decade. At present, the industry accounts for approximately 20 million tons, or one fifth of world aquatic produce. Production trends indicate that the aquabusiness will continue to expand, with a concomitant extension in range. Associated with the rapid growth of aquaculture has been an increased interest in the pollution potential of the industry. This has resulted due to the increasing number of reported environmental problems which appear to plague the business: particularly with the rearing of shrimp, but also salmonids. Examples of impact include: loss of coastal wetlands, hypernutrification, sediment biocide accumulation and the introduction of non-native species. These changes have induced: reductions in regional biodiversity; appearance of antibiotic-resistant pathogens; dilutions to native gene pools; and gross impacts on food webs. Often, severe environmental changes have provoked governments to enact legislation to control or eliminate aquaculture impacts. While such directives are often seen as obstructive by producers they are, generally, subtly beneficial to the industry, in that they seek to defend water quality, control disease outbreaks, and maintain gene pools.

Legislation has forced the aquabusiness to seek new methods to control their environmental loadings. An example of positive action taken by the industry, in efforts to enhance effluent quality with respect to nitrogen and phosphorus levels is the use of high energy diets. However, to ensure that the industry does not retrogress, new methods to control and reduce environmental impact must be developed and implemented. In this respect, a number of biotechnologies offer considerable potential. Growth regulators, designer feeds, feed additives, novel food processing technologies, and transgenesis, all present methods for reducing environmental loading of aquaculture. As wee, use of precision feeding techniques combined with contemporary knowledge upon growth will ultimately reduce by-product outputs.

1. Introduction

Issues surrounding the pollution potential of aquaculture have become more prominent over the last decade. And, the diverse ranges of environmental modifications which attend aquaculture developments have received extensive review (*e.g.*, Pillay 1992; Pullin *et al.* 1993). These include the effects of infrastructure development upon terrestrial, estuarine, seascape, and reservoir/lake habitats (McLean *et al.* 1995). By its nature, aquaculture competes for the production potential of agricultural lands and restricts the multi-use capacity of given areas. Coastal structures, such as net pens, may alter water currents, increase the chance of regional siltation and cause navigational risk. Accompanying the visual repercussions of sea-, and land-based operations are increased noise associated with routine activities, and heightened odour levels from mortalities and feeds (Wallace 1993). However, while the preceding impacts are generally obvious, it is perhaps the inconspicuous consequences of aquaculture that are cause for concern; the principal components of which are summarised in table 1.

Table 1. Brief overview of the principal areas of ecological concern with regard to the impact potential of aquaculture upon the environment (summarised from: UNEP 1990; GESAMP 1991; Pillay 1992; McLean *et al*, 1995).

Major Area of Concern	Potential Environmental Impact
Nutrient and organic enrichment	Hypernutrification; reduced biodiversity.
Deterioration of habitats	Loss of coastal wetlands; reduced biodiversity.
Chemical pollution	Bioaccumulations of biocides; resistant bacteria.
Genetic pollution	Dilution of native gene pool; hybridizations.
Disease transfer	Introduction of pathogens into virgin areas.
Miscellaneous impacts	Competition of escapees; impacts on food webs.

Essential to the maintained global growth of the aquabusiness will be the development and deployment of environmentally sound culture techniques (Mayer and McLean 1995). Of high priority in this regard are methods that limit nutrient and organic enrichment. Clearly, implementations of strong management practices, which include effective handling and or control of inputs, inventory and by-products, represent immediate methods for containing pollution events. Further refinements to environmentally sound aquaculture practices may emerge following application of information upon feeding behaviour, nutritional physiology, and the endocrine basis of growth in cultured fish. The following will present an overview of techniques which are either presently employed, or offer high promise in the future, as a means of reducing the environmental loading of aquaculture. Particular attention will be given to methods for optimising feed use.

2. Strategies for reducing the environmental impact of aquaculture

All intensive animal-based culture operations are accompanied by the emission of metabolic by-products and uneaten feed, and it is feed that has generally been assigned the major role in aquaculture pollution events (Pullin *et al.* 1993). While the contributions of metabolic and feed wastes to aquatic pollution are small when compared to domestic, agricultural and industrial sources, their regional effects may nonetheless be significant. For example, organic enrichment from marine cages and ponds have been reported to decrease benthic biodiversity, result in the build-up of anoxic sediments and increase the potential for toxic dinoflagellate bloom events (Gowen and Bradbury 1988; Pullin *et al.* 1993). Developments of strategies that limit feed waste and or enhance the efficiency of feed utilization (FCR), therefore, represent an obvious approach towards limiting the environmental loading of aquaculture.

The major components of nutrient loading to the environment from aquaculture are nitrogen (N) and phosphorous (P). Both these elements are essential for normal fish growth and must be acquired through the diet. Thus, a gross balance for nutrient load will be proportional to the level of N and P in the feed and the FCR (Håkanson *et al.* 1988). This relationship may be expressed by the following equation:

$$\text{Environmental load (N, P)} = \text{FCR} \times \text{feed (N, P)} - \text{fish (N, P)}$$

From the above, it is evident that environmental loadings of N and P may be manipulated with modifications to FCR. This may be accomplished through optimising: a) feeding strategy, b) diet composition and digestibility and or c) manipulation of metabolism.

3. Feed and feeding technologies

Since feed represents the most costly annual input in intensive aquaculture systems (Heen 1993), it is not surprising to find that a considerable literature exists with respect to the development of more efficient methods of feeding cultured inventory (*e.g.*, Teskeredzic *et al.*, 1995). One of the more evident methods to enhance the efficiency of food use is through refinement of feeding strategy. This requires that the actual biomass of the system, and growth potential of the stocked animals, be known. Biomass measurements should include an estimation of size distribution to ensure employment of appropriate sized pellets. Under ideal circumstances, farmed animals should express a degree of size homogeneity. This can only be achieved however, through regular sorting, which results in handling and associated stress, and reduced overall growth performance. Accordingly, efforts have been made to develop automated systems that are able to measure such parameters *in situ* (Løvik 1987; Heyerdahl 1995).

As most animals express rhythmicity in feeding behaviour, élite feed utilization, through precision feeding, would be expected to occur during periods of natural hyperphagia. Automated feeding systems attempt to capitalise on this phenomenon. Such systems have generally been designed for maximal feed dispersion, to ensure against establishment of feeding hierarchies. While the latter may at first glance appear a trivial matter, Thorpe *et al.*, (1990) estimated that at worst, a 40 % loss in feeds could occur due to hierarchy formation in farmed Atlantic salmon. Other devices have been developed to determine the point of satiety and hence optimal timing for feed withdrawal. Examples of such equipment include systems which control feed application. Thus, upon detecting uneated feed pellets in effluent water, a photocell, or receiver, transmits a signal to a PC controller which cuts off an automated feed hopper. The feed hopper releases pellets after a predetermined lag-time. Problems that surround the use of such systems include comparatively high cost, as well as 'tuning' to take account of feed residency time and normal feed waste. Difficulties could also be encountered with respect to hopper cut-off caused by faecal and sloughed biofilm particles.

Dust and small feed particles accompany the packaging, transport and handling of food. Together, these components may comprise 9 % weight of pressed pellets (Seymour and Johnsen 1990), which generally remain uneaten. Such inadvertent waste has been reduced at some facilities with the introduction of repelleting machines wherein, before use, feed is sieved and collected dust and particles repressed before use. Development in feed technology has led to improved digestibility of carbohydrate and optimization of protein utilization with manipulation of dietary lipid content. This strategy has led to a decrease in N and P loading to the environment (Alsted and Jokumsen 1990). An important aspect of diet formulation and environmental control relates to the quality of raw materials used, since this limit too may influence effluent quality. A comparatively recent biotechnology that has been examined as a means of enhancing the efficiency of feed utilization and or reducing reliance upon fish meal products has been the application of various enzymes. In essence, two approaches have been investigated *viz*: dietary supplementation with digestive enzymes and use of phytase. These strategies either optimise nutrient availability by, for example, improving digestibility of raw materials, or act to reduce environmental discharge of N and P. The following provides brief consideration of the implementation of phytase in fish feeds. The importance of this strategy is two-fold in that phytase possesses high potential as a means of reducing environmental discharge of P, while reducing industry dependency upon fish meal-based foodstuffs. For a general discussion of the use of enzymes in preprocessing of animal feeds, the reader is directed to the overview of Wenk (1992).

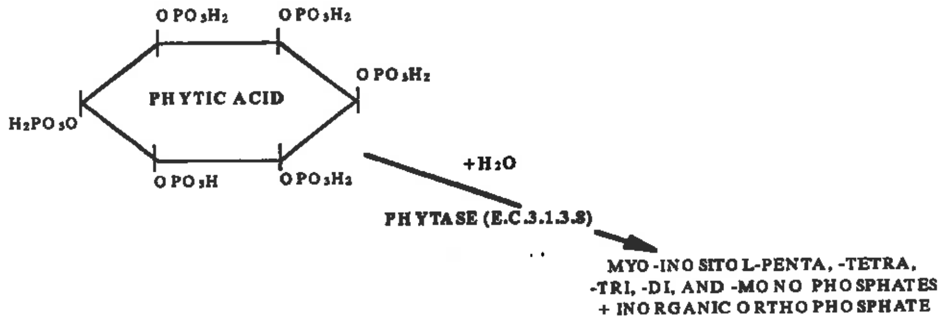

Figure 1. Mechanism underlying the release of phosphorous from phytic acid by the microbial enzyme phytase.

All animals require a source of P, which plays an essential role in skeletal structure and a number of key metabolic pathways. However, conventional aquaculture feeds contain P in excess of biological requirements. Thus comparatively large quantities of P are discharged in fecal and urinary wastes. In contrast, plant proteins contain much less P, of which 60-70 % exists as the hexaphosphate ester of myoinositol, or phytic acid (figure 1). The availability of phytic P is low to monogastric animals that do not contain endogenous enzymes able to release P from the phytic acid core. However, in ruminants, resident bacteria produce phytases that catalyse the conversion of phytate to inositol and inorganic phosphate (figure 1). Genetic recombination techniques have enabled mass production of the enzyme phytase from, among others, *Aspergillus ficuum*. The addition of this enzyme to plant-based feeds makes P available for absorption. A number of recent studies have applied this technology in the production of fish feeds (reviewed in Mayer and McLean 1995) and preliminary results indicate a decreased P output. However, before such biotechnologies can be applied by the industry, the long-term effects of phytase incorporation upon animal production physiology and quality aspects, require detailed study. As well, the economic feasibility of phytase use must be investigated.

4. Endocrine manipulations

Recombinant DNA technology provides the means for producing almost limitless quantities of regulatory peptides. This ability has stimulated renewed interest in the mechanisms that underlie the endocrine regulation of feeding and growth in cultured aquatic organisms; and how such knowledge may be used to beneficially modify production characteristics of aquacultured animals. While a number of factors exert a controlling influence over somatic growth (figure 2), it is growth hormone (GH), which is considered to be the most significant. GH treatment of most temperate species of teleost increases FCE, enhances appetite, and promotes growth (review: McLean and Donaldson 1993). The potential advantage of employing such preparations in aquaculture therefore, might be a reduction in the time required to produce market-sized fish, with a concomitant increased efficiency in the use of water. Moreover, although direct evidence is currently lacking, GH treatment, due to its recorded effect upon FCR, may decrease feed waste and hence reduce the environmental impact potential of aquaculture. Remarkable growth accelerating and FCR effects have also been recorded with another member of the GH family of proteins - placental lactogen (Devlin *et al.* 1994; Shrimpton *et al.* 1995). However, the major technical obstacle that must be overcome before contemplating the application of these biotechnologies to aquaculture will be the development of effective delivery systems for GH; the most elegant of which at present, is seen with transgenic animals (Najamuddin *et al.* 1995).

Many of the actions of GH are mediated by insulin-like growth factors (IGFs; figure 2), gene expression of which is stimulated in the presence of GH. Several studies have provided evidence to support the existence of similar molecules in teleosts (*e.g.*, Wallis and Devlin 1993), while the operation of the antagonistic release-inhibitory peptides GH releasing factor (GHRF, GRF), and somatostatin (SRIF, SST), have also be verified for teleosts in vivo (Harvey 1993). However, while methods of negating the potent release-inhibitory nature of SRIF have been examined in salmonids as an alternate method of enhancing growth (Mayer *et al.* 1995), similar studies with GHRF and IGFs have returned contradictory results. Another method of modifying growth in cultured teleosts may be through potentiating the somatogenic activity of GH following conjugation with monoclonal antibodies (MAb). Work with terrestrial animals indicates that GH-MAb likely acts by decreasing GH clearance rates. However, practical application of such techniques would appear limited due to problems associated with treatment methods and clearance rates. A novel technique of modifying quality characteristics of farmed fish, while enhancing protein deposition and FCR, is with the use of β-adrenergic agonists. Unlike the situation with GH and other bioactives, these compounds do not suffer problems associated with delivery, since they are orally active. Preliminary studies in our laboratory with the β_2-agonist salbutamol indicate promise although future experiments must be undertaken to fully characterise the mechanism of action of this compound in fish. Although fraught with technical difficulties, as well as consumer suspicion with application, artificial endocrine manipulation of feeding and growth of cultured aquatic organisms should be persued vigorously, since these methods provide a strong indication of what might be attainable within selective breeding programmes. In the present context, selective breeding for accelerated growth, enhanced FCR, or digestion capacity (Torrissen *et al.* 1994), would have the additional benefit of reduced environmental loading.

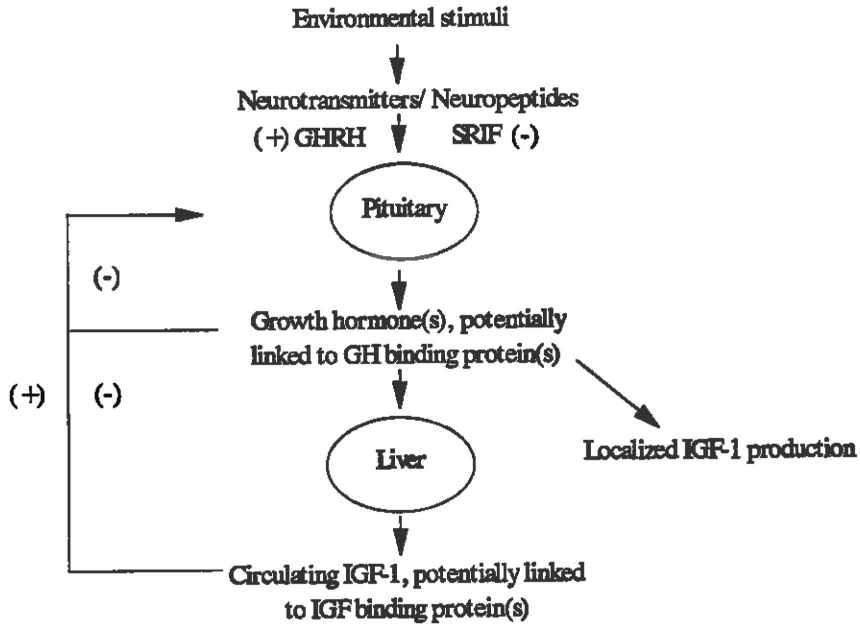

Figure 2. Principle components underlying the endocrine basis of growth in teleosts. With an in-depth knowledge of the mechanism of action of regulating factors, these may be modified to optimize production efficiency and thereby reduce environmental loading.

5. Perspective

Fresh and marine waters suitable for aquaculture are finite resources that often bare the pressure (and deleterious effects), of multi-consumer groups. Over the last decade, aquaculture has borne the brunt of legislation geared towards maintenance of water quality standards. Despite this, the industry has been able to respond positively through the use of high energy diets and with the application of more efficient management and feeding strategies. However, trends suggest that, as the industry achieves or exceeds predetermined legislative goals, new and more stringent objectives appear. To meet these legislative aspirations, the industry must continue to evolve rapidly; perhaps at even greater pace than other food-producing industries. The search for, and application of, new techniques directed towards more environmentally sound operations therefore, must continue. Recirculation technologies represent one step towards zero effluent aquaculture (Skjølstrup *et al.* 1995); however, a number of other strategies, might also be considered including: polyculture; in-line hydroponic systems to maximise by-product and water use, and application of waste waters and sediments for fertilization.

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MINIMIZING THE WASTE FROM KUUSAMO AQUACULTURE

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ABSTRACT

Kuusamo Aquaculture is situated in an environmentally sensitive area, where fish farming can cause local ecological impacts. Solutions to minimize these environmental impacts consists of 1) a license issued by the Water Court which restricts the annual growth, the feed supply and the water inflow, 2) sewage collecting system and use of communal sewage plant, 3) adjustment of feeding, 4) minimizing the negative effects of environmental factors on aquaculture process. The system for the collecting of sludge consist of self cleaning tanks, separate sludge discharge from each tank, separate sewage system using vacuum or gravity to transport sludge from tanks to central collecting point. After clarification the sludge is pumped to the communal sewage plant.

Introduction

Kuusamo Aquaculture is situated in the north-east Finland on the River Kitka in the commune of Kuusamo (Figure 1). The watersheds of Kuusamo are the last ones in natural state in Finland. In this environmentally sensitive area fishfarming can cause local ecological impacts. Solutions to minimize these environmental impacts consist of 1) a license issued by the Water Court which restricts the annual growth, the feed supply and the water inflow, 2) sewage collecting system and the use of communal sewage plant, 3) adjustment of feeding, 4) minimizing the negative effect of environmental factors on aquaculture process.

The objectives and production of Kuusamo aquaculture

The main task of the farm is to act as an genebank of treated brown trout *(Salmo trutta* m. *trutta)*. There are five brood stocks of original and local brown trouts in rearing. Except brown tout rearing the farm grows whitefish *(Coregonus lavaretus s.l.)*, grayling *(Thymallus thymallus)*, artic char *(Salvelinus alpinus)* and landlocked salmon *(Salmo salar* m. *sebago)*. The annual production is 300 000 parr and 150 000 smolts. The egg production is around 1.5 million eggs of trout. In addition 15 million whitefish eggs originating from natural and cultivated broodstocks are hatched in the farm.

Figure 1. Situation of Kuusamo Aquaculture.

The annual growth, feed supply and water inflow

In the license issued by the Water Court the maximal annual growth is 15 000 kg, the feed supply is 18 000 kg and water inflow 200 litres per second.

Rearing facilities

Rearing units of the farm are 12 square 60 m^2 concrete tanks both 16 square 7 m^2 and 16 square 4 m^2 fiber glass tanks with rounded corners. Total area for rearing is 1 033 m^2. All the pools and tanks are situated in the halls.

Sludge collecting system

The system for collecting of sludge consists of self cleaning tanks, separate sludge discharge from each tank and separate sewage system using vacuum or gravity to transport sludge from tanks to the central collecting point (Figures 2 and 3).

From the tanks of the size 4 and 7 m^2 the system uses vacuum to transport sludge to a central collecting point (Figures 2 and 3). After that sludge is pumped to the communal sewage plant. System is controlled by a timer, which opens magnetic valves in the sludge pipes. It's also possible to control the system manually.

In the tanks of the size 60 m^2 the sludge is collected to the sludge discharge openings (Figure 3). From the tank the water runs to a discharge and settling channel from which the clarified water discharge to the river. In this settling channel there are also sludge discharge openings. From the tanks and the channel the system uses gravity to transport sludge to a settling tank. In the tank the sludge is settled and clarified water runs to the river. The settled sludge is pumped to the communal sewage plant. Valves in the sludge discharge system are opened manually once a day. Sludge outlet pipes in the tanks of the size 60 m^2 are used to collect the fish from the tanks, too.

The value of sludge collected from the farm is 350-400 m^3 annually.

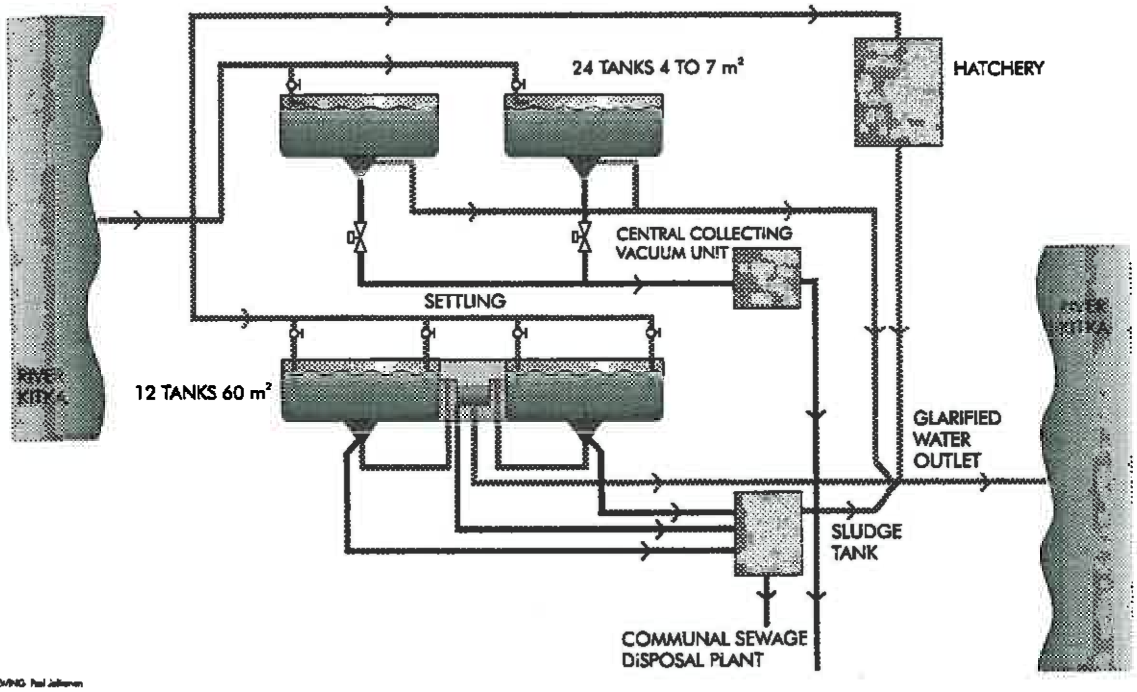

Figure 2. Kuusamo Aquaculture flow diagram.

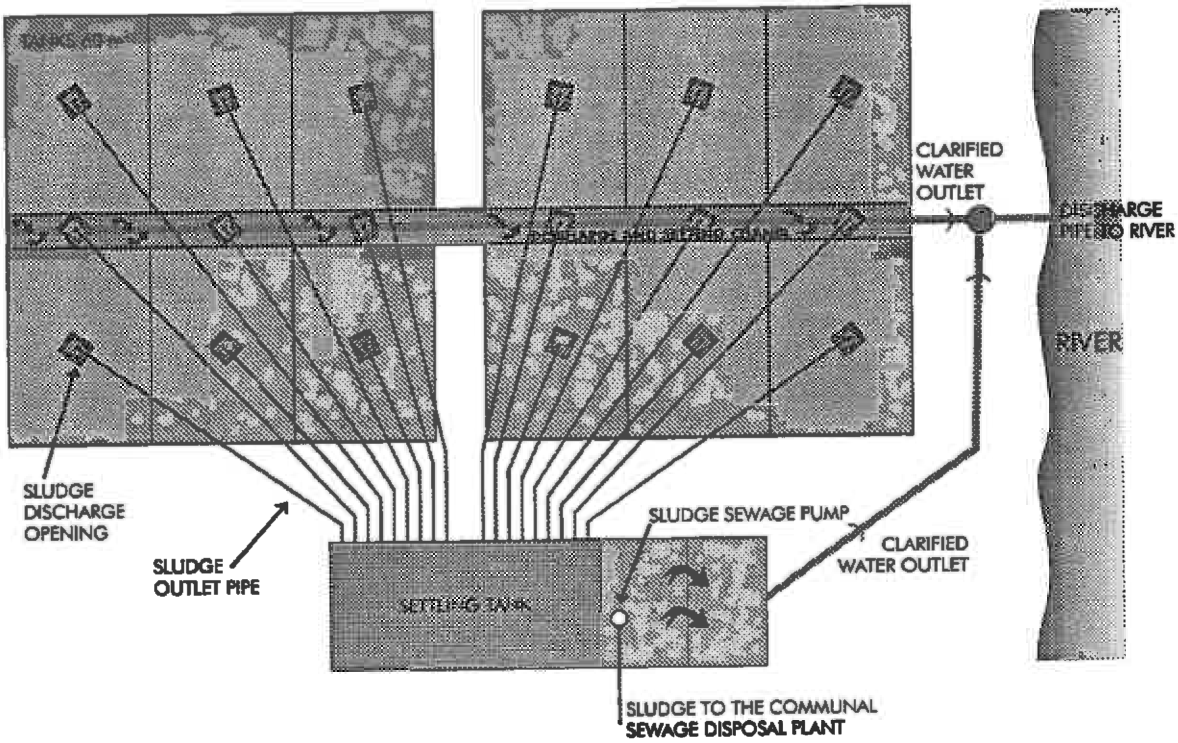

Figure 3. Kuusamo Aquaculture separate sewerage system.

Costs of sludge collecting and processing

Operating costs of sludge collecting and processing are 30 600 FIM annually. Investments are 760 000 FIM. Total costs are 8.66 FIM for 1 kg weight gain of fish (Table 1). Investment and operating costs are low compared to the other settling and filtration methods. Sludge is separated already in the tank, so the processed volume is rather low. Because the sludge volume is low there is no need to separate processing unit and the sludge can be pumped to the communal sewage plant.

Table 1. Annual costs of sludge collecting and processing of Kuusamo aquaculture.

Operating costs FIM		30 600	
	Energy	300	
	Processing	8 300	
	Labour	22 000	
Operating costs FIM/y/kg fish			2.04
Investments FIM		760 000	
	Vacuumsystem	365 000	
	Sludgeoutlet	145 000	
	Separate sewerage system	250 000	
Capital costs	FIM/y/kg fish (10 years pay off., interest 6 %)		6.62
Total costs	FIM/y/kg fish		8.66

Phosphorus reduction

The phosphorus reduction of 4 and 7 m^2 tanks has been investigated in a 9 days trial during the growing season (Vielma 1992). After this trial phosphorus reduction was 21-34 % from the phosphorus not retained to the fish. The efficiency of the whole system is not known. By using higher frequency of sludge collecting it's possible to get the amount of dissolved phosphorus lower.

Feeding system

The farm uses Salmo-feeding system made by Itumic Ltd. The system controls feeding by using mathematical growth model. The System corrects feeding according to the change in water temperature. It's possible to adjust the model according to the data gathered from feeding and growth. The feed coefficient of the whole farm has dropped from over 1.5 to about 1.0 in 90's (see Figure 4).

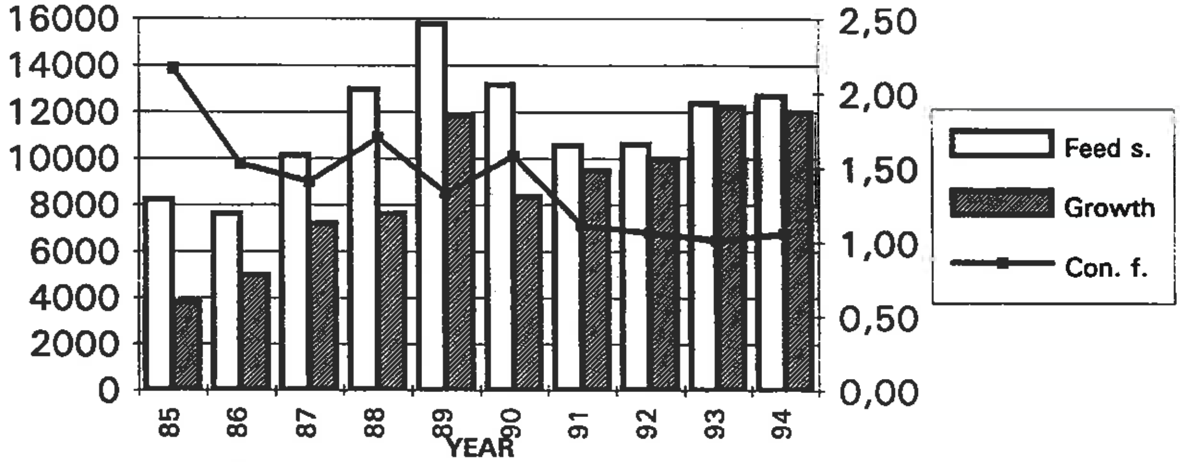

Figure 4. Feed supply, annual growth and conversion factor; years 1985-1994.

Covering the tanks

For minimizing the negative effect of environmental factors on aquaculture process the 60 m^2 tanks that were standing earlier outside were covered with a hall in 1992. The tanks, that were before covered by ice and snow half a year, stay now unfrozen year round. Now fish grow better and use more feed, but the specific load has decreased because of better feed coefficient which has dropped from 1.25 to 1.0.

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BIOFILTERS IN RECIRCULATING AQUACULTURE SYSTEMS: STATE OF THE ART

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ABSTRACT

Increased demand for cultured aquatic animals and growing environmental concern highlights the need for further research to develop sustainable production techniques. Water recirculation systems that typically include oxygenation, screening for particulates, and disinfection. provide a sophisticated approach to environmental protection. Besides the preceding components, recirculation systems employ biofilters. However, biofiltration methods, while being cost-effective, have the draw-backs of expressing long start-up periods and instability over the long-term. The most important biotic factors affecting biofilter performance include: amount of available substrate for nitrifying and heterotrophic bacteria, and predation. A number of physical factors may also influence biofilter performance. These include, but are not limited to: biocides; salinity; light, and pH.

Experience indicates that stable biofilter performance can be achieved where influent water contains constant ammonium levels, high dissolved oxygen content, and low concentrations of degradable organic matter. The amount of degradable organic matter appears to determine the degree of competition between nitrifying and heterotrophic bacteria. Over time, nitrifying bacteria become overlaid by heterotrophs and thus experience a reduction in available oxygen. This may cause a reduction in nitrification rates. As well, predation of nitrifiers by, for example, protozoans, can depress biofilter performance. The influence of light, pH and temperature on biofilter function are reasonably well characterised. However, the effects of biocides, heavy metals and salinity on biofilter efficiency requires further investigation. Recent research illustrates that microbial ecology and biofilm structure, likely play a more important role in overall biofilter performance than previously considered.

1. Introduction

It has been projected that aquaculture will return significant increases in production over the next decade (Csavas 1994). To fulfil such expectations however, the industry will have to adopt sustainable rearing technologies to minimise environmental impact potential (Mayer and McLean 1995). Perhaps one of the most sophisticated methods of controlling aquaculture production environments is through the application of water recirculation. The major problems encountered in using such systems relate to the maintenance of water quality. Cultured aquatic organisms impact water quality through production of metabolic wastes (*e.g.*, ammonia, carbon dioxide, urea and soluble/particulate organic faecal material) and consumption of oxygen. Furthermore, treatment systems themselves also influence water quality during operation (*e.g.* nitrite, nitrate, nitrous acid production). The importance of effective water quality management in recirculation operations may be illustrated by the progressively decreased growth performance seen for example, in Atlantic salmon (*Salmo salar*) subjected to reused water (Morrison and Piper 1988). In this study, the observed depression in growth was partly attributed to ammonia. Since ammonium, (derived from ammonia as a metabolic by-product), causes significant problems during water recirculation, it is not surprising to find that considerable attention has been levelled at developing methods for its removal.

Nitrifying biofilters are included in most commercial recirculating systems due to their ability to convert ammonium into less toxic nitrate. All filters that utilise living organisms to remove unwanted substances from the water column are termed biofilters. A relationship exists between the bacterial fauna of biofilters and the constituents of the influent water and the design/management of the system. Apart from inorganic nitrogen, fish tank effluent contains a high concentration of degradable organic matter. Therefore, biofilters also contain heterotrophic bacteria, the population of which will vary depending upon the degree of pre-treatment tank water receives. Nitrifying biofilters are designed to favour autotrophic bacteria, which include: *Nitrosomonas* spp., that gain energy by converting ammonium to nitrite, and *Nitrobacter* spp. which gain energy by converting nitrite to nitrate.

The following review will centre upon the state-of-the-art use of nitrifying biofilters in recirculating aquaculture systems. Where there might exist the potential for technology transfer from other disciplines involved in biofilm research, this will be considered.

2. Nitrifying biofilter configurations

The basic requirements for optimised biofilter configurations are: high and stable nitrifying activity, high surface area to volume ratio, mechanical stability, uncomplicated operation and maintenance, and cost effectiveness. The preceding may be accomplished using several set-ups (Lawson 1995). Submerged filters were the most commonly employed type in early aquaculture recirculation systems. However, these have been supplanted by trickling filters and, more recently, by fluidized-bed and floating bead biofilters. The advantages and disadvantages of each system, including management, energy consumption, and reliability issues, have been reviewed previously (Lazarova and Manem 1994, Hart and O'Sullivan 1993, Wheaton 1991).

3. Biofilter performance

A number of factors, including stocking density and seasonality influence water quality in intensive aquaculture systems (Poxton and Allouse 1987). These factors impact biofilter performance characteristics to the extent that fluctuations in, for example, ammonium and nitrite concentrations occur. Cyclical variations in the same parameters have been observed following backwashing (Vandenbyllaardt and Foster 1992) and with variations in feeding protocol (Poxton and Allouse 1987). Fluctuations in ammonium concentration in fluidized sand biofilter effluent, correlating with perturbations in bacterial population structure, has also been reported (Bullock *et al.* 1993). Issues other than those surrounding biofilter stability which are of importance with respect to overall performance include the start-up period and biofilm sloughing.

3.1. The start-up period

All biofilters require a certain period of time to pass in order to allow the development of a biofilm. Biofilms consist of a consortia of bacteria, extracellular material etc., which form the basis of the nitrification process. The time interval, or "start-up period", over which the biofilm develops is generally considered complete when steady state conditions are achieved. From an economics perspective it is vital that the start-up period is rapid. This enables more efficient use of aquaculture production facilities. An ability to control the development of ammonium and nitrite profiles is also important to ensure that cultured organisms perform optimally. Figure 1 depicts a typical developmental pattern for ammonium, nitrite and nitrate during a start-up period of a nitrifying biofilter. Ammonium excreted by cultured animals as ammonia, accumulates in the water until *Nitrosomonas* spp. establish in the biofilter, at which point a rapid decrease in ammonium concentration occurs, resulting in the accumulation of nitrite (Figure 1). Subsequently, *Nitrobacter* spp. experience fast growth and as a consequence nitrite concentrations decline rapidly.

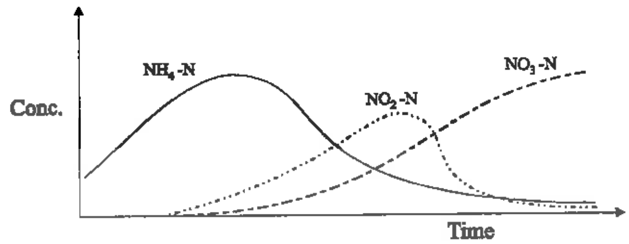

Fig. 1. Typical development of concentrations of ammonium, nitrite and nitrate during start-up of a nitrifying biofilter.

Start-up periods vary with biofilter configuration. For example, the time required for biofilters with new filter media, and without bacterial inoculations, to reach steady state often takes between 4-8 weeks (Bovendeur 1989, Hirayama 1974, Liao and Mayo 1974). In various studies with trickling filters nitrite accumulation commences after approximately 2 weeks, but accumulation ceases after 4 weeks (Bovendeur 1989). Following attainance of steady-state, 4-8 weeks post-start-up, the capacity of the biofilter to remove ammonium increases until, after approximately 12 weeks, the system optimises (Bovendeur 1989). A number of studies have successfully reduced the start-up period with the addition of filtrants from established systems and with addition of commercial available nitrifying inoculants *e.g.* Bower and Turner (1981). Alternatives to this strategy might include addition of commercial nitrifying inoculants (Drouin *et al.* 1994, Bower and Turner 1984).

3.2. Biofilm sloughing

The thickness of biofilm on the filter media may be influenced by a number of factors. These include, but are not limited to: characteristics of the carrier material, amount of substrate available, the bacterial growth rate and the shear forces acting on the biofilm surface (which is partly determined by carrier concentration), flow regime, and reactor geometry. Detachments from the biofilm surface occur continuously, as exemplified by erosion (loss of single bacteria and small biofilm fragments) and by sloughing (loss of larger pieces of biofilm). Severe sloughing can be of particular significance, since the biofilter suddenly experiences a loss in nitrification capacity. In addition, large amounts of suspended material may either clog the filter or enter the fish tank which may effect stocked animals (gill clogging etc.). The reasons underlying sloughing are largely unknown, but sudden drops in oxygen tension, or changes in the amount of organic substrate available, have both been reported to promote sloughing of some types of biofilm (Characklis and Marshall 1990, Bryers and Banks 1989). In addition, toxic compounds, such as biocides, and other chemicals (*vide infra*) used for treating stocked inventory, may cause sloughing.

4. Factors affecting nitrification

A number of factors influence the overall performance of nitrifying biofilter systems. Thus, a complete understanding and control of these parameters would permit more efficient operation of nitrifiers and hence optimise the performance characteristics of production units. Factors which influence biofilter performance may be considered either as biotic or abiotic in nature.

4.1. Biotic factors

4.1.1. Substrate concentration

The nitrification rate of biofilters is contingent upon the bulk water concentrations of ammonium, oxygen and bicarbonate. This dependence results due to the majority of bacteria being located within the biofilm. Thus, substrates must be transported into the biofilm before their transformation can take place. Under such circumstances, the substrate concentration of, for example ammonium, within the biofilm, would differ from bulk water concentrations. Simple models of the kinetics of such biofilms may be constructed when a few basic parameters are known, such as biofilm thickness, diffusion coefficient, volume specific nitrification activity, and limiting substrate concentration (either ammonium, oxygen or bicarbonate). Where substrate uptake kinetics of biofilm bacteria are assumed to be zero order (neglecting Monod kinetics), then nitrification rate can be calculated from bulk water concentrations by zero order kinetics for fully-penetrated biofilms (where the substrate penetrates the entire biofilm) and ½ order kinetics for partly-penetrated biofilms (the rate limiting substrate penetrates only the outermost component of the biofilm) (Nijhof and Klapwijk 1995, Bovendeur 1989).

In Figure 2, the rate of ammonium removal per surface area has been plotted against bulk water concentration at two different oxygen levels and non-limiting bicarbonate concentrations. Curve A shows, in the presence of high oxygen, that ammonium is rate limiting at low concentrations (½ order kinetics). When the concentration of ammonium becomes so high that the entire biofilm is penetrated, any further increase in either oxygen or ammonium does not improve removal rate (zero order). At a lower oxygen concentration (curve B), oxygen limits the removal rate of ammonium except for very low concentrations, so an increase in ammonium concentrations will not increase the removal rate. In such a case the oxygen concentration should be known, so that removal rate can be predicted.

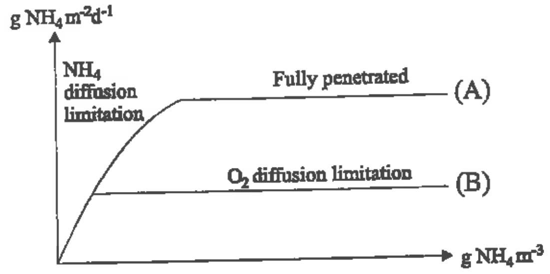

Fig. 2. Illustration of the relation between nitrification rate per surface area of a thin biofilm and the bulk water concentration of ammonium.

Two model equations: describe the nitrification rate for partly penetrated biofilm (½ order kinetics) (Henze *et al.* 1995). Oxygen will be limiting if the ammonium concentration is higher than approximately 0.3 times the oxygen concentration and the resulting nitrification rate will be:

$$r_{A,NH_4} = \frac{k_{1/2A,O_2}}{\upsilon_{NH_4,O_2}} c_{O_2}^{1/2}$$

If ammonia concentration is lower than 0.4 times the oxygen concentration, ammonium will be limiting with a nitrification rate of:

$$r_{A,NH_4} = k_{1/2A,NH_4} \times S_{NH_4}^{1/2}$$

Where:

r_{A,NH_4}	: Nitrification rate	[g NH_4-N/m^2×d]
$k_{1/2A,O_2}$	: Surface rate constant of oxygen	[$(gO_2)^{1/2}$/$m^{1/2}$×d]
$k_{1/2,NH_4}$	: Surface rate constant of ammonium	[(g NH_4-N$)^{1/2}$/$m^{1/2}$×d]
υ_{NH_4,O_2}	: Stoichiometric factor between oxygen and ammonium in the nitrification process = 4.25 g O_2/g NH_4^+-N	[-]
c_{O_2}	: Bulk water concentration of oxygen	[g O_2/m^3]
c_{NH_4}	: Bulk water concentration of ammonium	[g NH_4-N/m^3]

At 15 °C, oxygen concentrations in aerated biofilters in aquaculture are often close to 10 mg/l, whereas those for ammonium are generally below 4 mg/l, at which point it becomes limiting (equation 2). Ammonium therefore, will generally be rate limiting for nitrification in aquaculture biofilter systems when the biofilm is partly penetrated. Once the ½ order reaction rate constant for a specific biofilm has been measured, it becomes possible to modify influent aeration relative to actual ammonium load. This permits optimisation of nitrification. Diffusion coefficients, D=2.1×10^{-4} m^2/d for oxygen and D=1.7×10^{-4} m^2/d ammonium have been used for developing the above equations. Thus it is assumed that substrate is transferred into the biofilm by diffusion alone. However, significant intra-film water flow in relatively thin biofilms (150-200 μm), has been recently demonstrated (Lewandowski *et al.* 1995), such that the preceding assumptions might not be valid. Our experience with nitrifying biofilms indicates that these are more smooth and homogenous than many other types. Thus, further research is required in order to determine the extent of intra-film water flow in aquaculture-based and other nitrifying films.

Nitrification is a two-step process with nitrite as an important intermediary. It is usually assumed that nitrite is oxidized by Nitrobacter spp. as soon as it is produced within the biofilm. However, a concentration gradient between the biofilm fluid and the bulk water results in most cases, with outward diffusion of nitrite. A biofilm specific ratio between ammonium oxidation and nitrite oxidation rate seems to be equal to the ratio between the ammonium and nitrite concentrations in the bulk water of each biofilter system (Nijhof and Klapwijk 1995). Low bulk water oxygen concentrations can result in nitrite accumulation. One reason underlying such events may be that Nitrobacter spp. are more sensitive to low oxygen concentrations when compared with Nitrosomonas spp. (Henze et al. 1995). High bulk water ammonium concentrations (> 1.0 mg/l) may also cause significant nitrite accumulation at high oxygen concentrations (van Rijn and Rivera 1990).

The kinetic model described previously is simple but widely accepted. The usefulness of the model depends on its simplicity, which is one reason underlying the exclusion of substrates other than oxygen and ammonium (*e.g.* phosphate, carbon dioxide, trace elements such as molybdenum, magnesium etc.) which influence bacterial growth. However, the applicability of the model to aquaculture is restricted to biofilters where steady-state conditions exist in a non-developing biofilm. Under normal conditions steady-state conditions rarely exist in aquaculture situations. For example, organic load which shows high diurnal variation in most aquaculture systems, strongly affects the performance of nitrifying biofilters (Bovendeur et al. 1990). Incorporation of dynamic modelling and heterotrophic activity would greatly improve model usability, as considered below.

4.1.2. Competition, dissolved and particulate organic matter

Addition of organic carbon inhibits the activity of ammonium oxidizers (Hem *et al.* 1994). This phenomenon has been attributed to competition between heterotrophs and nitrifying bacteria *e.g.* van Loosdrecht *et al.* (1995). In the presence of high levels of organic matter aerobic heterotrophic bacteria outcompete and overgrow nitrifyers due to their higher growth rate. Nitrification rate thus decreases in proportion to the thickness of the heterotrophic layer which is accompanied by oxygen limitation. A change of substrate from organic carbon to inorganic nitrogen may result in a shear-off of the heterotrophic layer and restoration of nitrification capacity within two days. Several models have been developed to describe the competition between heterotrophic and nitrifying bacteria *e.g.* Okabe et al. (1995).

Thus organic loading on a nitrifying biofilter lowers performance characteristics. An example of quantifying this reduction has been published by (Bovendeur *et al.* 1990) who found that the zero order nitrification process was reduced by 0.015 g NH_4^+-N nitrified/m^2×d per g COD removed/m^2×d measured. Significant nitrite concentrations in the bulk water may also be a possible consequence of competition from heterotrophic bacteria. In a stratified situation nitrifying bacteria are forced deeper into the biofilm with reduced availability of oxygen as a consequence. As previously mentioned Nitrobacter spp. seems to be more sensitive to low oxygen concentrations than Nitrosomonas spp. and nitrite may therefor accumulate (Henze *et al.* 1995). It is not only the soluble fraction of degradable organic matter that promotes growth of heterotrophs. Total (soluble and particulate) organic matter was found to be a much better predictor of nitrification inhibition than soluble organic matter concentration (Figueroa and Silverstein 1992). However uncertainties exist regarding how non-diffusible organic matter is hydrolysed in the biofilter. Larsen and Harremoës (1994) hypothezised that particulate organic matter was hydrolyzed by enzymes released to the bulkwater. However, more recent reports with activated sludge systems (Frølund *et al.*

1995) and in the study of (Ro 1995) indicate that biofilm intrinsic hydrolysis of diffused/trapped particulates may be of some significance.

Particulate organic matter in recirculation systems consist of food waste, faeces and detached biofilm. Chen *et al.* (1993) measured particle size distribution in recirculation aquaculture systems with different particle removal systems (microscreens, clarifier and ozone). Fine particles <20 μm were prevalent in all systems. Thus indicating that effective removal of organic matter is difficult although important. Paller and Lewis (1988) indicate that water ozonation represents an expensive, but very effective method of removing organic matter prior to biofiltration.

4.1.3. Structure

Recent studies have shown that the traditional understanding of biofilms as homogeneous structures is incorrect. New techniques have revealed aerobic biofilms as heterogeneous three dimensional, porous structures, where interstitial voids form a network connected to the bulk liquid (Bishop *et al.* 1995, Lewandowski *et al.* 1995, Gjaltema *et al.* 1994, Zhang and Bishop 1994a). In domestic waste water treatment reactors, biofilm structure is spatially distributed, with density increasing with depth, and with upper layers expressing higher porosity and being more filamentous (Zhang and Bishop 1994b). This heterogenous state seems to develop with biofilm age (Zahid and Ganczarczyk 1994). The characteristics of waste water biofilms however, differ from typical biofilms from nitrifying aquacultural biofilters since they are subjected to much higher organic loading rates.

Biofilm structure may be influenced by water turbulence along the film surface. Water flow also affects biofilm thickness, with larger flow rates resulting in formation of thinner biofilms due to surface shear force effects (Miller and Libey 1984). The spatial distribution of active cells in the biofilm are heterogenous. With most cells in the upper layer being alive, where as only 1/4 - 1/7 of cells in the lower layer are live (Zhang and Bishop 1994a). The heterogenous nature of biofilm structures further retracts the application of the above-described model to aquaculture situations. With thorough review of those phenomena involved, for example, in substrate transport, the applicability of the model to aquaculture could be heightened. For example greater accuracy could result with re-evaluations of diffusion coefficients, since the number of voids, and degree of filamentous structure, determines oxygen transfer rates from the bulk water into the biofilm; with oxygen diffusion decreasing with biofilm depth due to structure stratification (Bishop *et al.* 1995).

In intensive fish culture systems, where nitrate is allowed to accumulate, high background levels of nitrite may follow. This occurs due to the fact that oxygen poor microsites within the aerobic nitrifying biofilter harbour bacteria capable of reducing nitrate to nitrite only (Arbiv and van Rijn 1995). The diverse structure of such nitrifying biofilms strongly support the existence of microniches, which must therefore, be taken into consideration when examining nitrite accumulation.

4.1.4. Predators

In biofilms, protozoa and metazoa predate, or graze, on nitrifying bacteria. The influence of predation upon the efficiency of waste water biofilms has been studied by Lee and Welander (1994). These authors reported a strong inhibitory effect of predators upon nitrification rate, while Parker *et al.* (1989) determined that it was possible to double nitrification rate following their inhibition. The effect of flooding and backwashing upon predator presence in a trickling filter has also been examined (Parker *et al.* 1989). These authors found that filter fly infestation was minimised or avoided following such procedures, while the activity and presence of other predators was also kept to an acceptable level. The potential benefits that predator control will provide in the management of aquacultural biofilters systems presently remains an unknown. However, such procedures would likely provide significant advantage with respect to filter efficiency. Further research in this area is required to enable quantification of the importance of predators and grazers to nitrification efficiency.

4.2. Abiotic parameters

A wide range of abiotic factors have been reported to influence nitrification capacity of biofilters. These include, but are not limited to:

4.2.1. pH and alkalinity

Nitrification represents an alkalinity-consuming process and reduced nitrification rates in biofilms thicker than 500 mm have been recorded (Siegrist and Gujer 1987) at alkalinities lower than 1.5 meq/l. Since low pH inhibits nitrification over the short-term (Boller *et al.* 1994, Bovendeur 1989, Krüner and Rosenthal 1983) and also impacts growth of aquacultured organisms (Jobling 1994), then maintenance of optimal pH becomes high priority. The optimal pH for both biofilms and most cultured aquatic species lies in the range 7-8. However it has also been reported that nitrifying bacteria are able to adapt to reduced pH-levels (Szwerinski *et al.* 1986). In commercial aquaculture situations problems relating to reduced nitrification rate following decreases in pH may be solved with the addition of lime.

4.2.2. Temperature

Optimum temperature for nitrification falls in the range of 28-36 °C (Fdez-Polanco *et al.* 1994). Obviously this range conflicts with temperature optima for growth in most commercially important aquacultured organisms. This is particularly so for temperate species such as salmon and trout which express optimal growth at 15 °C (Petit 1990). However, in considering high value tropical species, such as shrimp and barramundi, temperature would be an issue although it must be remembered that oxygen solubility decreases with a rise in temperature.

4.2.3. Salinity

Nitrification in saline waters has been characterised by reduced nitrification rates and an increased start-up period when compared to fresh water systems (Nijhof and Bovendeur 1990). However, other researchers (Alleman and Preston 1991) have reported that many nitrifying bacteria are able to switch from fresh water to saline environments without significant impact on their nitrifying activity. The importance of understanding the influence of salinity upon nitrification from an aquaculture perspective is that some species such as salmonids (Jobling 1994) when held in saline waters return enhanced growth performance and increased feed conversion efficiencies.

4.2.4. Light

Substrate oxidation by nitrifying bacteria is inhibited by light (Alleman and Preston 1991 Horrigan *et al.* 1981), with nitrite oxidizers appearing to be more affected by light than ammonium oxidizers (Horrigan *et al.* 1981). Therefore, in order to optimise nitrifying capacity, biofilters should be screened from light. Since some species of teleost appear to perform more efficiently under longer than normal photoperiods and perhaps with varying intensities (Jobling 1994), this scenario may influence placement of the biofilter.

4.2.5. Biocides and other chemicals

Under commercial conditions, farmed animals are often treated for disease, with treatments simply being added to the culture tanks. Treatment of fish with anti-bacterial chemicals have been reported to affect biofilter performance (Arbiv and van Rijn 1995, Heinen *et al.* 1995, Klaver and Matthews 1994, Collins *et al.* 1976, Collins *et al.* 1975). For example there is no clear indication of long-term biofilm tolerance to formalin, short-term exposure seems to have limited effect. Treatment of carp with Bromex® resulted in perturbation of the performance of the treatment system resulting in high ammonia concentrations for a period of ten days (Arbiv and van Rijn 1995). Malachite green (6.52 mg/l), which has been used in the treatment of various ectoparasites appears to be without appreciable effect on nitrification performance. However treatments with the anti-protozoal methylene blue at concentrations of 5 mg/l, results in complete cessation of biofilter nitrification for 16 days (Collins *et al.* 1975). According to Klaver and Matthews (1994), nitrification is inhibited by oxytetracycline with a 7-day EC50 level of between 8.6 and 27.0 mg/l; however Collins *et al.* (1976) failt to register any effect at a concentration of 50 mg/l. Water containing heavy metals and different chemical compounds such as pesticides should be used with great caution. These substances can cause significant mortality in hatcheries and depress appetite and growth rates. In addition, experiments indicate that there may be hazard to biofilm performance in reuse systems e.g. Ibrahim (1988). Inhibition of metabolism or even wide-spread sloughing of the biofilm may underlie the effects of the above chemicals. However further research is required in this field to elucidate the mechanism of action of prophylactic drugs etc. upon biofilter nitrification.

4.2.6. Hydraulic Loading Rate

Hydraulic loading rate has been shown to strongly influence the performance of biofilter systems (Kugaprasatham *et al.* 1991). This is obvious since ammonia removal rate must be equal to or less than the ammonia loading rate. The water turbulence in the biofilter is to some extent responsible for biofilm characteristics. High turbulence seems to govern filametous structures, resulting in better mass transport from bulk water to the biofilm (Kugaprasatham *et al.* 1991). Moving bed biofilters where the biofilter media is suspended within the water column are particularly sensitive. For example control of fluidisation in fluidised-bed biofilters is very important to avoid too much shear on the biofilm and to prevent the system to be flooded by biofilter media. The hydraulic loading rate is typically calculated as loading per biofilter surface area (Table 1). However, the loading rate per unit biofilm area is probably a better indicator (Nijhof 1995). High oxygen concentration, while being important when obtained by aeration, may influence water turbulence resulting in shear-off of biofilm.

5. Ammonium Removal Rates

Various methods have been used in quantifying performance of biofilters. These include calculation of the ratio of ammonia converted compared to total excreted ammonia, the maximum amount of feeding while maintaining acceptable water quality, growth of the cultured species and calculation of ammonia removal rates (amount of ammonium nitrified per biofilm area or biofilter volume). Perhaps the most appropriate criteria to use however, is removal rate, since this makes it possible to compare different biofilter configurations. Table 1 provides a summary of reported ammonia removal rates for different types of biofilters in both aquaculture and domestic waste water treatment situations.

Surface specific nitrification rates have generally been used to quantify nitrification in rotating biological contactors (RBC), submerged biofilters and trickling filters. Volume specific nitrification rates have also been used to describe filters with moving biofilter media (*e.g.*, fluidized-bed, moving bed and floating bead biofilters). Fixed type biofilm media generally have surface areas which are easy to determine. However, this can be a problem for media such as sand and small plastic particles (mean diameter without attached biofilm of typically 0.5-2.0 mm) used for example in fluidized bed biofilters.

Surface specific nitrification rates from aquaculture biofilter systems have been measured to fall within the range: 0.1-0.8 g NH_4^+-N/m^{2}xd but large variations occur (Table 1). In contrast, domestic waste water systems generally express higher nitrification rates up to 0.1-0.8 g NH_4^+-N/m^{2}xd (Table 1). This is due to higher influent ammonium concentrations. It is also seen that salinity, temperature and loading of organic matter affects biofilter performance significantly. Reported volume specific nitrification rates (Table 1) express extreme variation, but the indications are that high rates can be achieved in moving bed biofilter configurations (Table 1).

Nitrification rate is in itself of restricted value when rating biofilter performance, since site specific conditions for each biofilter influence efficiency. The most important modifying parameters are: Influent and effluent water characteristics (temperature, pH and concentrations/load of oxygen, ammonium, bicarbonate and presence of degradable organic matter), filter type, surface area to volume ratio, hydraulic loading and biofilm thickness. Although it is possible to measure the most important factors relating to nitrification rate in laboratory studies, similar measurements in full scale aquaculture water reuse systems would be inappropriate due to their time-consuming nature.

Table 1. Nitrification rates reported in the literatute.

Filter type	Water origin	Influent ammonium [mg NH_4^+-N/l]	Effluent ammonium [mg NH_4^+-N/l]	Hydraulic loading rate[a] [$m^3/m^2 \times d$]	Temp. [°C]	pH	Surface specific nitrification rate [g NH_4-N/$m^2 \times d$]	Volume specific nitrification rate [g NH_4-N/$m^3 \times d$]	Ref.
RBC[b]	Sewage	20			10	>7	3.0		1
RBC	Aqua.	1	0.3		28-30	7.2-7.5	0.25		2
RBC	Aqua.	0.8-9.3	0.02-1.3	0.002-0.07	22.5-31	7.1-8.4	2.83		3
Submerged	Sewage	20			10	>7	1.5		1
Submerged	Aqua	0.5-0.7g/$m^2 \times d$			10-15	7.7-8	0.2-0.3		4
Submerged	Aqua.	0.6 g/$m^2 \times d$		150-200	25	7-7.5	0.3[d]		11
Submerged	Aqua.	0.6 g/$m^2 \times d$		150-200	25	7-7.5	0.7[e]		11
Trickling	Sewage	20		72	10	>7	0.3-1		1
Trickling	Sewage	>5		108	11.5-18.5		2.5		5
Trickling	Synth.	2	2	2,259	25	>7	0.15		6
Trickling	Saline[c]	7		3.5	24	8.3	0.28		7
Trickling	Aqua	7		3.5	24	8.2	0.69		7
Trickling	Aqua.	6-10	4-8	75	25	7.0-7.5	0.35		8
Trickling	Aqua.	4-5	3-4	300	25	7.0-7.5	0.75		8
Trickling	Aqua.	0.5 g/$m^2 \times d$		150-200	24		0.6		9
Trickling	Aqua.	0.5-1.8		230	7		0.45		10
Gravel	Aqua.	1			20		0.12-0.21	0.04-0.07	12
Fluid	Aqua.	0.8-1.2	0.2-0.3	35-83	7		0.13-0.23		10
Fluid.[f]	Aqua.	1-2			20			0.12-0.26	12
Fluid.[g]	Aqua.	1-2			20		0.12-0.29	0.4-1.0	12
Floating bead	Aqua	0.5	0.35		28-30	7.2-7.5	0.1-0.15		2
Airlift	Synth.	7500 g/$m^2 \times d$			30	7		6	13
Moving-bed	Sewage	<1 g/$m^2 \times d$			7-18.3		0.2-0.8		14

[a] Hydraulic loading rate per cross-section of filter unit. [b] With prefiltration. [c] Salinity 17-34 ppt. [d] Low organic loading, 1 g COD/$m^2 \times d$ for 3-4 hours. [e] High organic loading, 20 g COD/$m^2 \times d$ for 3-4 hours. [f] Granular carbon as media. [g] Granular carbon as media and ozonation of influent water. References in table: 1: (Boller et al. 1994). 2: (Westerman et al. 1993). 3: (Rogers and Klemetson 1985). 4: (Liao and Mayo 1974). 5: (Parker et al. 1989). 6: (Lu and Piedrahita 1993). 7 : (Nijhof and Bovendeur 1990). 8: (Nijhof 1995). 9: (Bovendeur 1989). 10: (Vandenbyllaardt and Foster 1992). 11: (Bovendeur et al. 1990). 12 : (Paller and Lewis 1988). 13: (Tijhuis et al. 1992). 14: (Rusten et al. 1995).

6. Design of nitrifying biofilters

After a biofilter configuration has been selected, the next stage in the developmental process is the design and sizing of the system. Sparse information exists with respect to design strategies for biofilters in aquaculture. That which is available has been combined by Lawson (1995).

In general, biofilter configuration is selected using an efficiency rating, *E*, which has been derived experimentally, usually by the system manufacturer. Filter water flow rate may be calculated using equation (3), after which the biofilter is sized using two constraints, namely: flow rate of Q_f while maintaining an efficiency of *E*.

$$Q_f = \frac{PR_{TAN} - Q \times C_{TAN}}{C_{TAN} \times E} \tag{3}$$

where

$$Q = \frac{PR_{TAN} \times 4.43}{C_{NO_3}} \tag{4}$$

and

Q_f	: Filter flow rate	[l/min]
PR_{TAN}	: Production rate of total ammonium nitrogen	[mg/min]
c_{TAN}	: Concentration of total ammonium nitrogen in system	[mg/l]
Q	: Fresh water flow rate through system	[l/min]
E	: Filter effeciency (decimal fraction)	[-]
c_{NO_3}	: Concentration of nitrate in the system	[mg/l]

Fresh water flow rate must be adjusted to avoid build up of sublethal levels of nitrate, which can be calculated using (4). C_{NO3} is the accepted nitrate concentration. The filter flow rate must then be adjusted to the acceptable concentration of total ammonia nitrogen (ammonia and ammonium), C_{TAN}. Production of total ammonia nitrogen, PR_{TAN}, may be calculated by multiplying total fish biomass, feeding rate (decimal fraction of body weight) and amount of total ammonium per kilo of feed. Sizing of the biofilter can be effected by selecting an appropriate reported nitrification rate (g NH_4/m^2xd) for a biofilter of similar configuration. This nitrification rate should be multiplied by a safety factor and the surface area of the biofilm calculated by dividing ammonium production with the adjusted nitrification rate.

Assumptions have been made in this simple design method (*e.g.*, steady-state conditions in the system, a strictly nitrifying filter, lack of ammonium and nitrate in the fresh water flow, no denitrification). If the nitrification rate for a biofilter of equal configuration and with equal influent water content is known, then the above method may be applicable. However as has been described in Table 1, considerable variation in nitrification rates occur (0.1-1.8 g NH_4^+N/m_2xd in aquaculture), such that a biofilter can not be ascribed a performance rating with certainty. To optimize design and operation of aquaculture biofilter systems, improved methods need to be developed. This may however be complicated as conditions under which biofilters are selected will, to a certain degree, be site specific (*e.g.*, system set-up, water quality, species cultured, husbandry etc.). More accurate prediction of ammonium load should also be factored into an optimised design and selection process for biofilters by incorporating fish growth models as discussed in Jobling (1994).

7. The Future

In the recent past aquaculture has experienced increasing competition for a limited resource - water. At the same time, the industry has been subjected to stricter environmental legislation. Indications are that such competition and regulations will not become any less severe in the future. The development, refinement and application of novel bioengineering and biotechnological techniques to control water quality and reduce the environmental impact potential of aquaculture are thus of high priority. Recirculation systems, which offer a high degree of water reuse, present the industry with the means of avoiding resource competition while controlling effluent quality. The ultimate goal of such systems must be to improve tank production performance and hence profitability. To reach such an objective, water management strategies must be improved. In the present context, it is clear that opportunity exists for the optimization of nitrifying filters. This can be achieved with sustained research and through application experience.

In addition to traditional methods of evaluating biofilm performance (*e.g.*, bacterial culturing, extraction procedures, enzyme analysis), modern techniques in waste water and biofilm research present a powerful arsenal of useful tools (*e.g.*, scanning electron, and laser confocal microscopy, image analysis, nuclear magnetic resonance, microslicing, microelectrodes {reviewed in Lazarova and Manem 1995}). When combined, the above methods provide the means to examine the structure, kinetics and metabolism of biofilms under varying aquaculture conditions. Recent research in biofilm microbial ecology has revealed the diverse nature of resident bacteria. An interesting advance in this discipline has been the application of *Thiosphaera pantotropha* biofilms which are capable of simultaneous nitrification and aerobic denitrification (Dalsgaard *et al.* 1995). The proposition of a one step conversion of ammonium to nitrogen gas in aquaculture systems is highly attractive. However, considerable research must be undertaken to further characterize the role of *T. pantotropha* in the microbial activity of the biofilm. Genetic engineering technologies provide a potentially exciting direction in aquaculture biofilm research. For example, gene probes may be used to assist in unravelling the diverse nature of biofilms and the presence of specific genetic material involved in the denitrification process. In addition, in the era of genetic recombination, it may be possible to engineer specific bacteria which are capable of one-step conversions as well as competing successfully against heterotrophic bacteria.

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MULTI-STAGE WASTE REDUCTION TECHNOLOGY FOR LAND-BASED AQUACULTURE

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ABSTRACT

Efficient aquaculture effluent treatment facilities need to be adapted to the specific properties of the effluent. Aquaculture effluents are difficult to treat because the wastes occur in low concentrations and at high flow rates. Recent research shows that multi-stage waste reduction involving feeding management, pre-concentration of wastes, combined with suitable effluent and sludge treatment, is a means of reducing the effluent loading from fish farms. The pre-concentration of the waste solids, for example using within tank particle concentrators, separate sludge outlets, tank flushing, or reduced water consumption, can greatly increase treatment efficiency. Microscreens, either stationary or rotating, appear currently to be the most suitable commercially available method of treating the effluents from intensive, flow-through, fish-farms. Sedimentation basins are though not usually suitable for this purpose, but may be integrated into a multi-stage treatment system. A combination of thickening by gravitation, followed by stabilisation by adding lime could be a suitable method for the processing of sludge, though no aquaculture specific system is currently commercially available. It is likely that multi-stage treatment system will become more common within the near future.

INTRODUCTION

Traditional single-pass, flow-through, land-based fish farms require large quantities of water. Without oxygenation of the inlet water, such systems typically consume 100,000-200,000 m^3 of water per tonne of salmonids produced. The effluent water produced has correspondingly low concentrations of waste materials. The effluent is difficult to treat because of this combination of high flow rates and low waste concentrations. Treatment facilities need to operate at a large hydraulic capacity and produce substantial waste reduction efficiencies in effluents that already have low waste concentrations.

Efficient aquaculture effluent treatment facilities need to be adapted to the specific properties of the effluent. There are currently several units commercially available for the treatment of the primary effluent from fish farms, but there are still no aquaculture specific facilities developed for the further dewatering and stabilisation of the sludge water produced by the primary treatment.

With more stringent discharge and water consumption legislation and increases in both farm size and stock density, single, simple methods of effluent treatment are becoming inadequate. Recent research shows that multi-stage waste reduction involving feeding management, pre-concentration of wastes, combined with suitable effluent and sludge treatment, is a means of reducing the effluent loading from fish farms. This paper is mainly based on a review describing this subject (Cripps & Kelly, 1994).

I. EFFLUENT CONCENTRATIONS

The effluent particle, organic matter, nitrogen and phosphorus concentrations from modern farms producing adult salmonids are low (Table 1), typically a factor of 100 lower than domestic wastewater concentrations. In the effluent from tanks stocked with pre-smolt, the concentrations are lower still, but commonly more fluctuating, due especially to concentration peaks during tank cleaning operations. At a Scottish farm Kelly *et al.* (In subm. a) reported approximately 30 times greater effluent concentrations during the cleaning and flushing of parr/smolt tanks. The results presented in Table 1 summarise effluent concentrations from land-based farms without pre-concentration technology. The adult salmonid tanks referred to were however supplied with oxygen supersaturated seawater (ca. 200 % saturation) and hence specific water consumption was reduced, resulting in an effluent with a higher concentration of wastes.

A variable proportion of the waste nutrients are associated with the particles: 10 - 30 % of the total nitrogen (TN) and a greater 20 - 80 % of the total phosphorous (TP). A significant part of TN is ammonia-nitrogen (TAN), which is the dominant dissolved end-product from the excretion of the fish stock. The close relationship between biochemical oxygen demand (BOD) and suspended solids (SS) effluent concentrations has frequently been demonstrated (e.g. Solbé, 1982). The strategy commonly employed currently to treat aquaculture wastes is therefore to separate the particles from the main flow and so reduce the nutrient and organic loading.

Figure 1 indicates the distribution of particles from a salmonid hatchery in northern Sweden (Cripps, 1993). It can be seen that the majority of the number of particles are small (less than 30 µm) and are therefore difficult to remove using either sedimentation, because of the slow settlement velocity, or sieving, because of the large hydraulic load caused by using fine sieves. The pollutant carry capacity of the particles is more related to their volume Cripps (1995). It can be seen that even individual particles at the large diameter end of the scale can have a volume that is greater than many hundred smaller diameter particles. So whilst it would be difficult to remove all the suspended particles, even the removal of relatively fewer larger particles (greater than 30 - 60 µm diameter) can be beneficial.

Table 1. Typical effluent concentration at land-based farms for salmonids.

Criterion	SDM	BOD5	TN	TAN	TP	Review source
Aquaculture effluent, mg/l:						
Adult Salmonid Tanks	2-10	-	0.2-0.8	0.2-0.5	0.05-0.2	Bergheim et al. (1993 a)
Parr-Smolt Tanks	0-50	0-35	-	0-0.3	0.05-1.1	"
Typical values	14	8	1.4	-	0.125	Cripps (1993)
Domestic/industrial wastewater, mg/l:						
Domestic (medium conc.)	720	220	40	-	8	Tchobanoglous & Burton (1991)
Meat processing	300	640	3	-	-	Henry & Hilke (1989)

-: not monitored

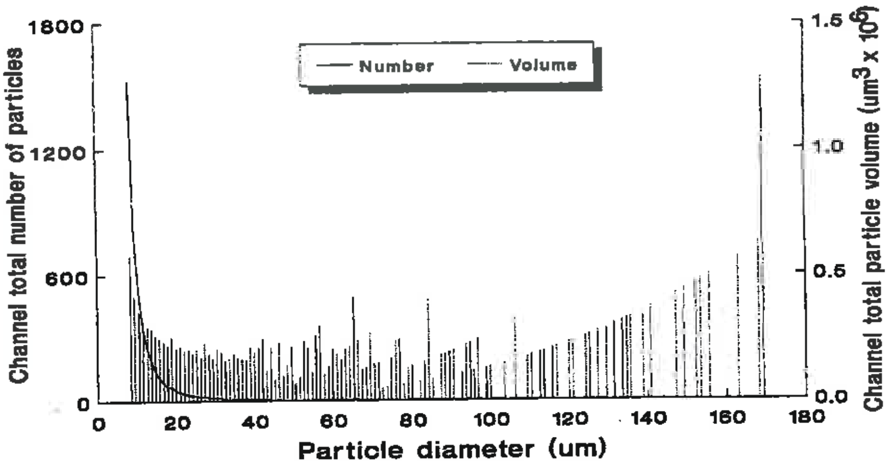


Figure 1. Size distribution of particles in the effluent from a salmon hatchery (Cripps, 1993).

II. EFFLUENT PRE-CONCENTRATION

Recent research is starting to show that the pre-concentration of wastes is one of the keys to successful effluent treatment. Large variations in treatment efficiencies using different models of the same type of separator, at different sites and at different times have been experienced. A close analysis of the management of the separators indicates that in those systems that removed the greatest proportion of suspended wastes, some form of pre-concentration was used. If pre-concentration is used, waste suspended particles are not merely allowed to exit the culture facilities with the primary effluent flow, they are in some way intermittently retained, or constantly redirected.

II.1. Within tank particle concentrator

Particle concentrators, though sometimes expensive, are becoming more popular. They are devices at the tank outlet which aid the settlement and consolidation of solids. This concentrated waste is then removed from the tank periodically, or preferably continuously, through an outlet which is separate from the primary flow. This sludge outlet is then led to the treatment device. The primary flow commonly does not require treatment.

Figure 2 illustrates a tested system which combines a within tank particle concentrator with a separate outlet and sludge dewatering unit (whirl separator). The particle-enriched outlet flow constituted 5 - 6 % of the total flow (Eikebrokk & Ulgenes, 1993) thus pre-concentrating particles by a factor of 20 (assuming approximately 80 % of the particles were trapped). An overall system removal of 71 % SS, 38 % TP and 14 % TN was estimated. The dry matter content of the dewatered sludge from the whirl separator was c. 14 %.

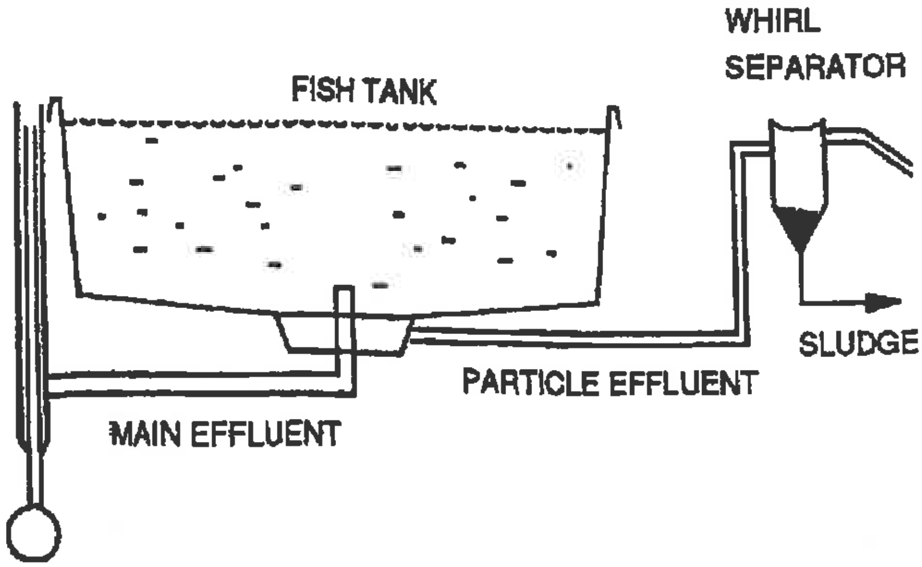


Figure 2. Diagram of a fish tank effluent pre-concentration management and separate sludge dewatering (after Eikebrokk & Ulgenes, 1993).

Mäkinen *et al.* (1988) studied the effluent P budget in tanks with two separate outlets: a "bottom effluent" and a main "surface effluent" with flow rates of 10 % and 90 % of the total flow, respectively. Without tank flushing, the average P concentration in effluent from the tank bottom was more than double the surface concentration. Using a stationary microsieve removing particles from the bottom effluent, the overall P treatment efficiency was 46 %, incorporating the flushing load.

A commercially available particle concentrator system has recently been developed (AquaOptima). This system combines both a specially designed particle trap that separates excess feed pellets from fecal wastes so that feeding can be more closely monitored, and collectors for sludge and dead fish.

II.2. Tank flushing

At most hatcheries and smolt farms the self-cleaning and hydrodynamics in the tanks are inadequate. If no form of within-tank particle concentrator and removal system is employed, waste particles can build up in the tanks leading to a decline in culture water quality. These accumulated solids on the tank bottom need to be flushed away frequently, in the form of a concentrated plug of wastes. Rather than allowing this plug to exit the farm in the main effluent, it may be stored in separate holding facilities to allow treatment devices sufficient time to function at a lower hydraulic load than if treatment of the primary flow was required. Whilst this flushing strategy may be beneficial in terms of effluent treatment efficiency, there are obvious disadvantages in terms of internal tank hygiene.

Even though this method can function at sites with a minimum of waste handling equipment, it can still be regarded as multi-stage because tank management needs to be integrated with the operation of some form of particle separator such as screens or sedimentation tanks.

II.3. Reduced water consumption

To increase the productivity in both smolt and land-based ongrowing salmonid farms it has become common practise to add oxygen to the inlet water. By using tank inlet water super-saturated to 160 - 200 % saturation, the specific water consumption of salmon (*Salmo salar*) can be reduced from 1 - 2 l/kg/min down to about 0.2 l/kg/min. The outlet waste concentration is then increased by a factor of 2 - 5 that without oxygenation, assuming a constant food conversion ratio. This will aid primary treatment. A higher fish density in oxygenated fish tanks also commonly improves self-cleaning, especially in small smolt tanks, reducing the need for manual cleaning and flushing of tanks. Whilst the waste from cleaner tanks is not available for pre-concentration using the flushing strategy described above, the culture environment will be improved and some form of particle concentrating system can be employed.

II.4. Pre-concentration effects

Overall, there are two treatment advantages associated with the production of a concentrated waste:

reduced hydraulic load;

- formation of a filter mat.

All of the above pre-concentration strategies can be operated in conjunction with a separate sludge outlet. A treatment device with a smaller hydraulic capacity, with associated savings in capital and running costs, can then be operated. Sludge flows of less than 1% of the primary flow should be possible.

Recent studies of particle size characteristics in fish-farms (Cripps, 1995) have revealed the mechanism for the improved treatment efficiency evident from particle screens in which wastes were pre-concentrated. Highly concentrated wastes form a transient mat on the face of the screen which is washed off frequently, commonly with backwash jets. This mat reduces the effective pore size of the screen, allowing particles smaller than the nominal pore size, to be removed from suspension. Treatment efficiency is increased at the cost of some increase in hydraulic load, but the flow should anyway have been reduced by the use of pre-concentration devices. This again emphasises the importance of multiple stage treatment.

III. EFFLUENT TREATMENT

Having preconcentrated the wastes into a form that can be better handled by particle separators, the next stage in the treatment train is to determine the most appropriate separator to integrate into the system. Several authors have described the available types of particle separators, including Wheaton (1977), Cripps (1994) and Cripps & Kelly (1994). Figure 3 summarises the types available, though not all, for example sedimentation basins, are suitable for the treatment of the main effluent from a farm.

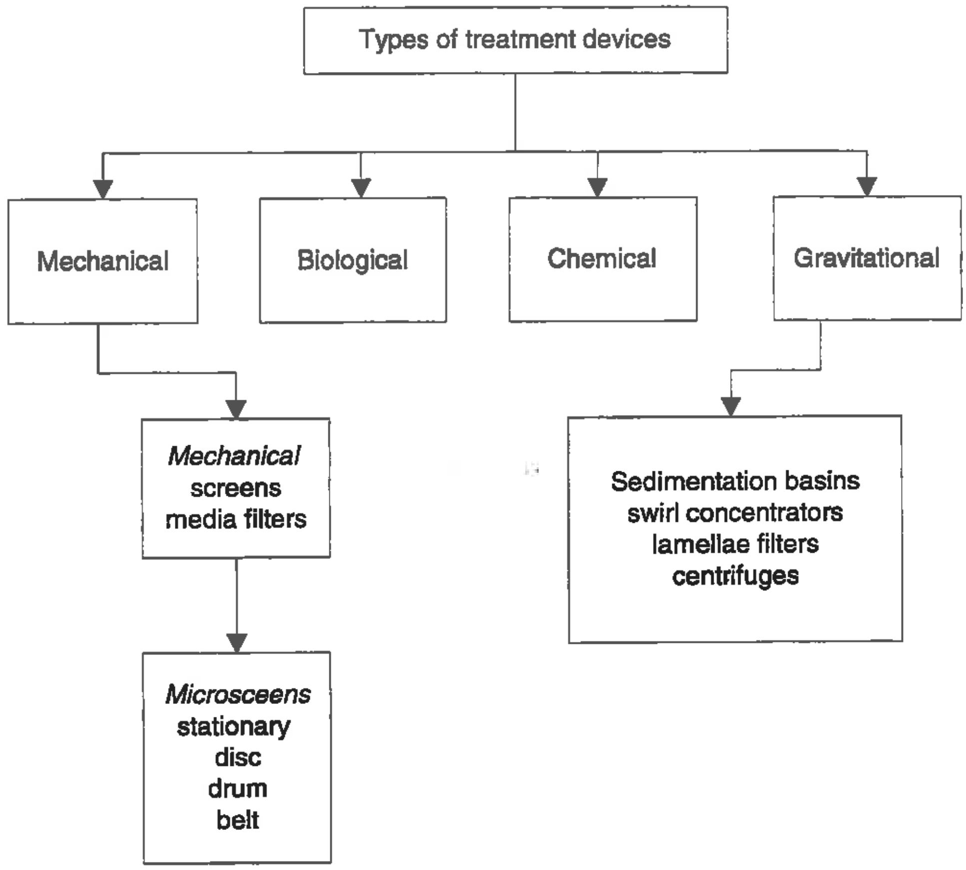
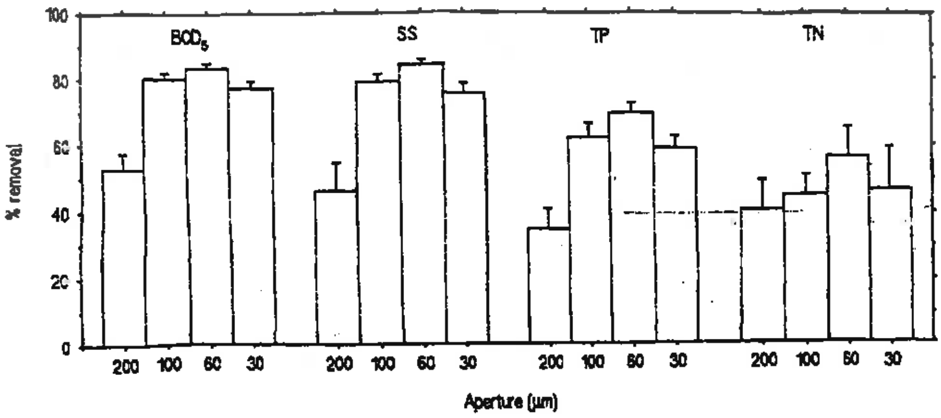


Figure 3. Summary of aquaculture effluent treatment units.

III.1. Primary effluent treatment

Sieving

The solid removal potential of microsieves was clearly demonstrated in a recent study at two Scottish hatcheries (Figure 4). At cleaning/flushing of fish tanks the overall removal efficiency of suspended solids, organic matter and nutrient salts increased several times due to higher effluent concentrations. The relationship between mesh size and removal rate found in those studies (Kelly *et al.*, in subm.[a]) was in accordance with expected values based on particle size distributions of hatchery effluent (Figure 1) previously reported (Cripps, 1993). Generally, these studies indicate that a screen mesh size of about 60 μm seems to be a reasonable compromise between hydraulic capacity restrictions and particle removal potential.



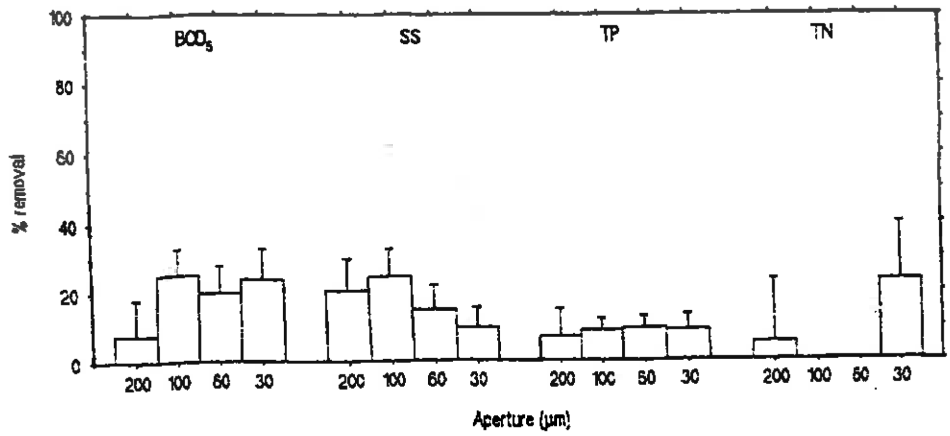


Figure 4. Relationship between mesh size and removal rate at two Scottish salmonid hatchery. Upper figure: during cleaning/flushing of fish tanks. Lower figure: without cleaning/flushing.

Whilst microsieves are now probably the most suitable type of commercially available treatment unit for aquaculture effluents, current designs have two drawbacks. Firstly they function better when the effluent has be concentrated, as explained previously. Continuous use to treat the main flow will result in sub-optimal waste removal efficiencies and a large volume of sludge waste requiring further treatment. Secondly, current designs of disc and drum screens are not well suited to the removal of larger uneaten feed particles which are too large to adhere to the screens and thus be washed to waste. Such particles will tend to remain in the vescinity of the screen unit until they broken down sufficiently to be lifted up to the backwash sprays. These units can be though of as being suitable for stopping rather than removing particles and are hence more applicable to intakes. They do however comprise the best available technology at present and serve a value environmental protect function. It is expected that some form of belt screen or enclined disc, in which particles are lifted at a shallow angle out of the water, will be a useful future development for integration into a multistage treatment system.

Sedimentation

Sedimentation basins of various designs are common throughout the industry. They range in design from simple ponds dug downstream of the farm, up to compact second stage (e.g. after a microscreen) cones, or advanced basins incorporating automatic sludge removal and flow manipulation. Their main advantage is that spare ponds or tanks, should there ever be any, can be adapted for this use. Despite their widespread use, they are, in any form, rarely suitable for the treatment of the primary effluent from land-based, flow-through facilities because of inadequate flow dynamics and sludge removal problems. Though particle settlement velocities of aquaculture wastes are sufficiently fast to allow the use of sedimentation as a means of separation, flow rates from farms are high. This can lead to various flow dynamics problems including: insufficient residence time to allow the particles time to settle out; scouring of settled particles off the bottom; and short circuiting of influent water direct to the outflow. The settled sludge also needs to be removed as quickly as possible to avoid leaching of nutrients from the particulate to the dissolved fraction. The frequency of removal has to be balanced against the quantity of sludge that is resuspended during the removal process. Even advanced automatic vacuum suction devices cause some resuspension of particles, which can then be carried out of the basin. The practice of draining the basin and removing sludge, after harvesting, or every few months, can result in considerable leaching and the loss to the outlet of a large short-lived plug of sludge-rich water.

The use of sedimentation is not inherently wrong. It is the application to which the operation is applied that is often inappropriate. Flow rates of the primary effluent are high, but sludge flows from other forms of treatment, such as screening, are far lower, commonly less than 1 % of the primary flow. This sludge almost always requires further thickening. Sedimentation is one of the most suitable methods to accomplish this. Sedimentation therefore is appropriate for the localised (i.e. within tank) pre-concentration of wastes, and for second stage de-watering of separated sludge within a multi-stage treatment system.

III.2. Sludge treatment

All the above methods for removing contaminants from the main effluent produce a sludge water. Unlike the primary treatment of fish farm effluent, little work has been conducted to develop suitable methods for sludge processing.

The sludge water backwashed from microsieves, is dilute and has to be processed further before transportation and utilisation. At a common solids content of several hundred mg DM L^{-1}, the sludge volume must be reduced 400 - 1000 times to obtain a DM content of 20 %. Prior to further treatment, the initial sludge water can be significantly reduced by using vacuum suction (Bergheim *et al.*, 1993b), or discontinuous backwashing (Ulgenes & Eikebrokk, 1993) instead of standard backwashing to remove particles.

At an average salmon hatchery producing 20 t smolt/year, the annual microscreen sludge water production can be estimated as 10,000 m^3, or a daily average of 20 - 30 m^3. The corresponding annual quantities at a land-based ongrowing farm producing 300 t of fish is about 150,000 m^3 of diluted, unprocessed sludge (about 400 m^3 a day). These calculations are based on the assumption that the tank effluent is pre-concentrated using oxygen supersaturated inlet water.

Sedimentation, as a first step for dewatering of sludge water, is quite efficient at producing a settled sludge. The settling velocity of particles after microsieving is fairly high (Warrer-Hansen, 1992), and a settling removal of 85 - 90 % in a thickening tank at an overflow rate of 1 m h^{-1} can be expected (Figure 5). Organic matter and nutrient salts are in principle particle-bound in the sludge water produced, and are therefore settled at about the same rate as suspended dry matter. After a settling period of less than 24 hrs, the dry matter content (TDM) is in the range 5 - 10 %. This sludge has to be further processed (Liltved & Vethe, 1990; Bergheim *et al.*, 1993a).

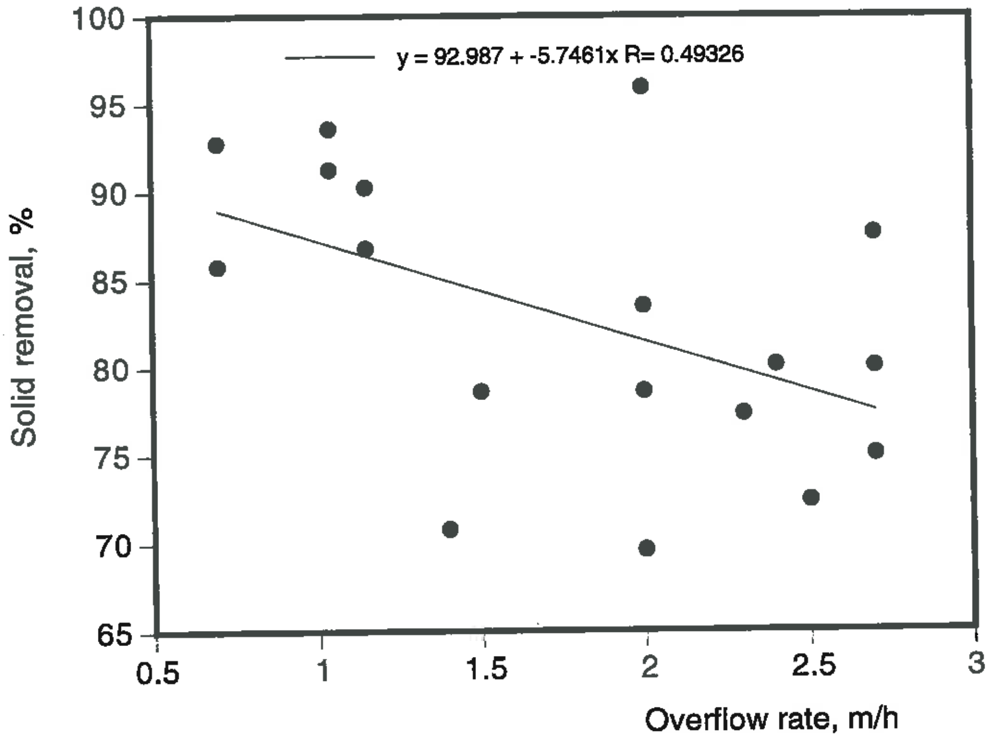


Figure 5. Solid removal efficiency ($p<0.05$) of sludge water in a gravitational thickening tank. Bøvågen Smolt Farm, Norway (UNIK Filtersystem, Nor. Inst. Wat. Res. (NIVA) & Rogaland Research, unpublished).

Stabilisation by adding lime appears a suitable method for the further treatment of settled sludge from fish farms (Mäkinen, 1984; Liltved *et al.*, 1991). In tests, stabilisation with a permanent pH > 12 (after 30 days) has been achieved by dosing approximately 300 g $Ca(OH)_2$ per kg of sludge DM. Such pH levels will kill most fish pathogenic micro-organisms. The stabilisation tank should be able to store the sludge production for at least 4 - 6 days, so a volume of about 1,000 L at a smolt farm with an annual production of 20 t will be required. Due to high concentrations of organic matter, N and P, the decanting water produced should not be lead directly to the recipient. On-site natural infiltration could be employed as the final stage of the system.

Similar levels of solids removal and settled sludge quality have been reported from test studies using different waste reduction regimes (Table 2). This indicates that a verity of systems can, with care, be used with similar success. A commonly used pre-concentration system, oxygen supersaturation of tank inlet water, generally needs a more comprehensive system for end-of-pipe treatment than systems based on sophisticated pre-concentration within the fish tanks.

Table 2. Overall removal efficiencies for two different systems combining effluent pre-concentration and treatment at land-based farms for salmonids (after Ulgenes & Eikebrokk, 1994).

Effluent treatment		Parameter	Overall removal	Sludge	Review source
Pre-concentration	End-of-pipe		efficiency, %	contents, g/l	
System I:					
Inlet water oxygenation	Microsieving (60 µm)	TDM	-	71	
(spec. water consumption	Sludge water:	STS	55	-	Bergheim et al. (1993 b)
< 0.2 l/kg fish/min)	Microsieving (60 µm)	TP	51	1.8	
	Sedimentation	TN	11	3.4	
System II:					
Tank particle	Concentrated outlet:	TDM	-	74-83	
concentration	Whirl separation	STS	79-80	-	Ulgenes & Eikebrokk (1994)
(particle trap)	Main outlet:	TP	30-47	1.5-1.9	
	No treatment	TN	13-18	1.7-2.5	

-: not monitored

IV. SLUDGE UTILISATION

Due to the nitrogen and phosphorus content of fish farm sludge it has potential as a fertiliser in agriculture (Wang, 1993). In a Norwegian study, the crop yield of barley for silage with varying quantities of fish farm sludge was studied in a greenhouse experiment (Myhr, 1989). Yield increased up to the equivalent of 40 t of sludge TDM per ha. A dosage of 80 t per ha, led to crop failure with a yield level lower than with no fertilizer supply. Between 2.5 - 5 t of sludge TDM had a fertilising potential equal to 1 t of compound fertiliser per ha.

Fish farm sludge may be composted, either in a dry process or in liquid composting as in manure. In the composting process, temperature is raised to a high enough level for disinfection of the material. Organic material is mineralised. Composting is used commercially for the treatment of fish slaughter wastes in Norway and is also reported as suitable for the treatment of fish farm sludge. In a laboratory experiment, sludge mixed with bark was treated in a dry composting reactor (Vethe, 1988). The mixture reached a temperature of 60 - 65 °C for about two weeks. Therefore, composting has the advantage of maintaining a sufficient temperature for the removal of pathogenic organisms. The end product is expected to be suitable for use on agricultural land and in horticulture.

A brief cost budget of a sludge processing system was estimated by Bergheim & Liltved (1994). To process the sludge from a farm producing 90 t rainbow trout annually, the investment costs of the complete processing unit was found to be about 100,000 NOK resulting in fixed costs of 20,000 NOK/year. Adding operational costs of 30,000 NOK/year, the overall sludge processing costs correspond to about 0.55 NOK/kg of trout produced. Assuming the cost of compound fertiliser in Norway to be 2.40 NOK/kg, the use of the annual produce of sludge as a fertiliser in agriculture represents a value of about 10,000 NOK. Thus, the additional net costs of sludge treatment amounts to 2-3 % of the total production costs at a typical rainbow trout farm.

V. CONCLUSIONS

- Aquaculture effluents are difficult to treat because the wastes occur in low concentrations and at high flow rates.
- Pre-concentration of the waste solids can greatly increase treatment efficiency.
- Microscreens, either stationary or rotating, appear to be the most suitable commercially available method of treating the effluents from intensive, flow-through, fish-farms.
- Sedimentation basins are not usually suitable for treating the primary effluent from such farms, but may be integrated into a multi-stage treatment system.
- There are currently no well-designed systems developed for the treatment of fish farm sludge water.
- Based on preliminary tests, a combination of thickening by gravitation, followed by stabilisation by adding lime could be a suitable method for the processing of sludge.
- The costs of a system for sludge processing were estimated to be about 0.5 NOK per kg of fish produced at a typical landbased ongrowing rainbow trout farm.
- Given the current constraints on fish farm effluents and water consumption, it is likely that multi-stage treatment system will become more common within the near future and hence further work is required to quantify the necessary design parameters.

VI. ACKNOWLEDGEMENTS

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LOCAL ECOLOGICAL SOLUTION FOR TREATMENT OF WASTE WATER FROM AQUACULTURE

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ABSTRACT

Is it possible to operate a land fish farm with low contamination problems. In Norway studies are now established to see if a local ecological solution can be possible. In the system the waste water is considered as a resource, which can be utilised in a biological recycling system. Agricultural land is suitable for application of the plant nutrients in waste water. By mixing waste from aquaculture, agriculture and the domestic domain, a local solution is possible at reasonable costs. The proposed solution contains four main units: 1. The fish farm with an integrated recycling system for water. 2. A filtration unit for the separation of sludge from the waste water. 3. A soil based system to take care of the purified waste water. 4. A liquid composting reactor for hygienization and stabilization of the separated sludge. The soil based systems are still on an early experimental stage considering waste water from aquaculture, and both infiltration systems and wetlands/ponds are evaluated. Studies with the liquid composting reactor show an increase in the temperature to over 60 °C using sludge from an eel farm, and both hygienization and stabilization of the sludge is achieved. The reactor has also been used to treat a mix of cadaver fish and domestic black water with similar results as with sludge. The process is operated at a positive energy budget, and the excess energy can be used for heating purposes. Composted material from the reactor is rich in plant nutrients and, thus, valuable for agriculture.

Introduction

Today effluent from aquaculture in fresh water is a problem (Lekang, 1995, Lekang & Grøndahl, 1995). The waste water contains nutrients and organic matter that is unwanted in the receiving waters. It might also contain fish pathogens that can affect the native fish species (Stevik & Lekang 1995).

The methods used today are based on conventional treatment technology, with separation of sludge using mechanical filters (Lekang & Fjæra 1995). The sludge is then dewatered. Sludge that not is stabilized and hygienized represents a problem because it can not be used as it is. If there is a risk that the waste water contains fish pathogens, the water must be desinfected before it is led to the recipient. Desinfection of waste water from aquaculture represents an economical problem caused by the large water flows. Poor desinfection performance can also be a problem with water from aquaculture because it contain much organic substances.

Both waste water, separated sludge and dead fish contain a substantial amount of plant nutrients and can thus be used as manure in agriculture. In this way, the effluent is recycled back into the biological system, where it belongs. All parts have their own positive and necessary functions in this kind of systems. However, if the system shall work all components must be adapted to each other. Therefore these problems must be taken into consideration when planning the fish farm, and the treatment of waste water.

Local ecological solution

At the Agricultural University of Norway two R&D programs in environmental technology are carried out. The aim of the program "Natural Systems Technology for Waste Water Treatment" (NAT-program) is to develop a nature based waste water treatment technology based on natural processes and energy sources. The aim of the program "Environmental Technology" is to develop technical solutions or methods in biological systems where it is possible to attain environmental profit. In both these programs local solutions for waste treatment are given priority. A local ecological solution for treatment of effluent from domestic and agricultural domain is developed. Local solutions for handling of the effluent will be favoured because of less transportation of waste. Mixing of waste from agricultural and domestic domain (e.g. black water, septic tank sludge, organic kitchen waste, animal manure) can also result in lowering of the total costs for effluent treatment.

A natural question is if local solutions can also be used for treatment of waste from aquaculture. We mean yes, and in this paper a possible solution, and some experimental results are presented.

Local ecological solutions for treatment of effluent from aquaculture

A possible solution for taking care of the effluent from a land based fish farm contains 4 major parts (Fig. 1).

1. The fish farm, which must use a recycling system for water to reduce the amount of outlet water (Lekang 1995b, Lekang & Fjæra 1995).
2. A filtration unit which separates the waste water into sludge and purified waste water.
3. A natural (soil/plant) system for further treatment of the filtered waste water. One reason for the using recirculation of water in the fish farm is to avoid exceeding the often low hydraulic capacity of the soil based systems.
4. A liquid composting reactor for hygienisation and stabilisation of the sludge. In connection with this, there must be a storage tank for the sludge before it is spread on agricultural land.

This solution represents a complete system. However, there is no reason for using single parts of the system alone or together with other technology.

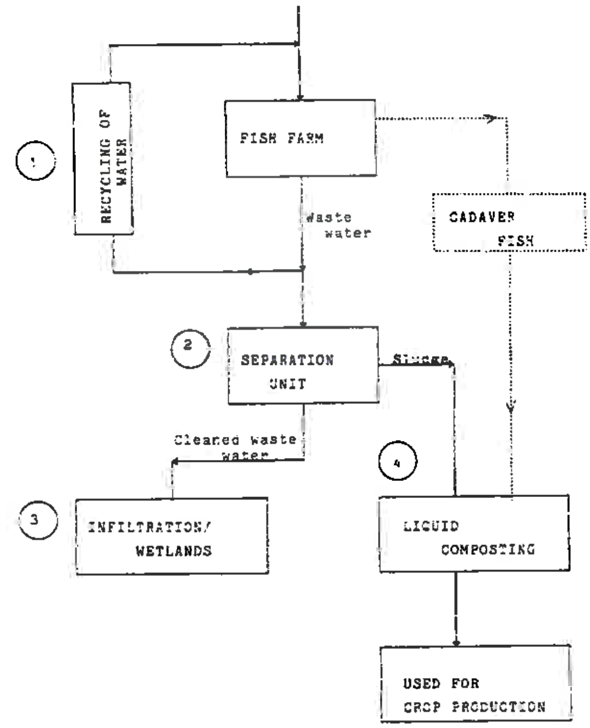

Figure 1. A possible solution for fish farming without environmental contamination.

Treatment of waste water with nature-based treatment technology

Even if the waste water is purified through a filtration system, it still contains both nutrients, organic matter, and can also contain fish pathogens. Some of the nutrients (mainly N and some P) are also dissolved in the water, and for this reason not removed in the filtration unit which only separates particles from the water flow.

Nature-based waste water treatment technology covers several methods that can be used alone or in combinations (Jenssen et al. 1992). The three main methods that can be used are soil infiltration-, wetland- and pond system. The infiltration systems can either be open ponds or subsurface trenches (Fig. 2). Infiltration systems normally use local soil, but soil or a suitable porous media (LECA) can also be trucked to the site (e.g. sandfilter or mound systems). Treatment of waste water from aquaculture by soil infiltration is not commonly used, and the research activity has so far been low. The main problem is the large effluent flows in fish farms, versus the low hydraulic capacity of the soil based systems. Using soil infiltration therefore requires recycling systems for water in the farm, so the effluent volumes are reduced. Soil infiltration systems have commonly used for treatment of domestic wastewater in the USA (USEPA, 1980). In Norway the interest for infiltration systems is growing. To illustrate the performance of infiltration systems an example from treatment of domestic wastewater is described (Jenssen, 1992). In northern Norway, an infiltration plant treating waste water from 5000 people has been in operation for 7 years. The results show constantly more than 70 % nitrogen removal and 99 % phosphorus removal, 70 % COD removal and close to 100 % removal of fecal coliforms despite its location at 69° northern latitude and a an average annual temperature of +1,2° C. The water flow to the infiltration plant is normally about 750 m^3 per day, but in the snow melting periode it has been up to 3500 m^3 per day. There are three separate infiltration basins each with an area of 2000 m^2. One basin is always in use, while the others areas at rest. The total investment cost for the plant including pump stations and sedimentation basin is around 3 mill Nkr and the annual operation cost is about 100 000 Nkr.

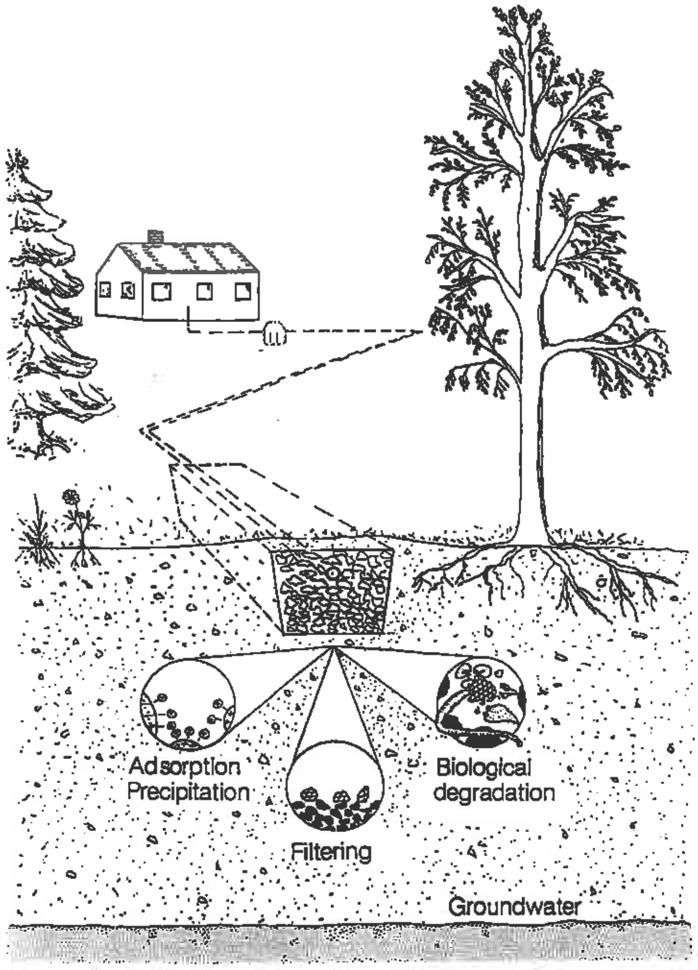

Figure 2. Soil treatment of waste water.

Natural and constructed wetlands have been used wordwide for purification of various types of polluted water such as domestic and industrial waste water (Fig. 3) (Jenssen et al. 1991, Jenssen et al. 1993). In Norway this method is still in an experimental stage. One question that has been asked is how the cold winters will affect the wetland and pond systems. Preliminary results from a pilot plant optimized for nutrient removal from domestic domain show 55% Nitrogen and 98 % phosphorus removal. The large phosphorus removal is obtained by using sand with high content of iron oxides and a fabricated porous medium that has a high phosphorus adsorption capacity (LECA). Constructed wetlands has not been used for treatment of effluent from aquaculture in Norway, but experiments are being planned. Constructed wetlands and ponds have low hydraulic capacity compared to the water flows used in aquaculture, and using such systems will therefore require recycling of water at the fishfarm.

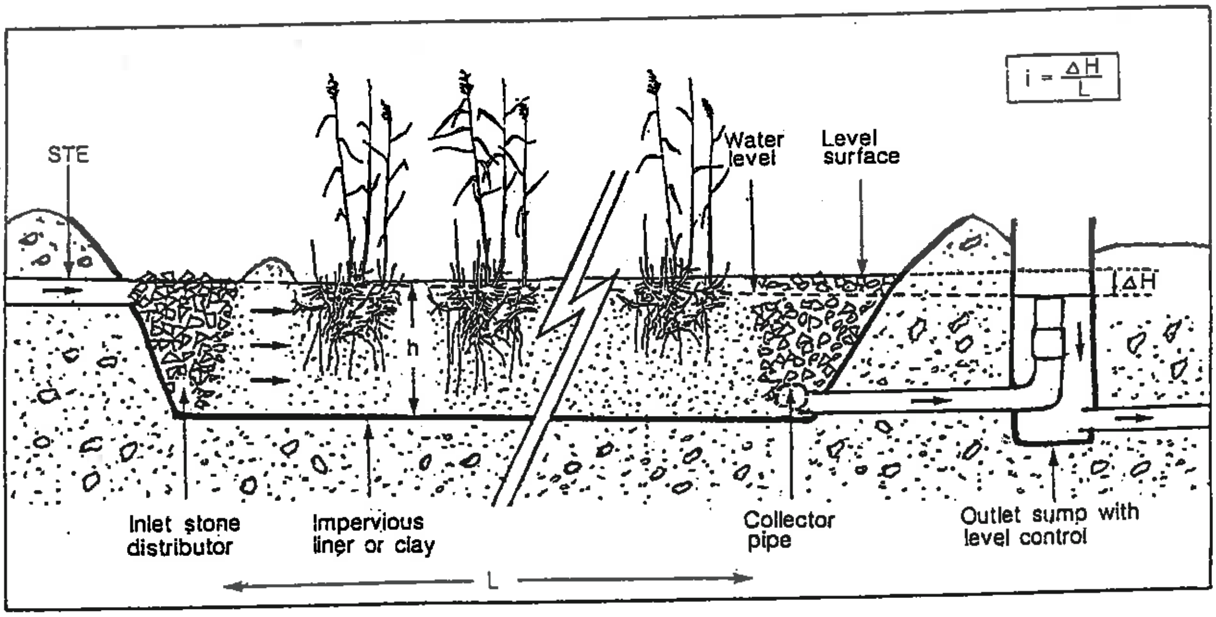

Figure 3. Cross sectional view of a constructed wetland with subsurface flow (Jenssen et al 1991).

A liquid composting reactor for treatment of sludge and dead fish.

Composting is an air demanding process, which can be performed using solid or liquid organic materials (sludge). Air is blown into the sludge and this stimulates production of bacteria that decompose organic matter. The process is thermophilic, thus sufficiently high temperatures for hygienization are reached. The process also yields a stabilized end product.

At the Agricultural university of Norway, a liquid composting reactor that treats organic waste and renders a stable, hygienically safe manure product, has been developed (Fig. 4) (Skjelhaugen & Sæther 1994). No unpleasant odours are produced when composting, neither is there any loss of nutrients to the atmosphere or the ground water. Composted material is stored until it can be spread onto agricultural land. The reactor is built as an isolated, cylindrical tank with a conical bottom. The tank is specially designed to fit a newly developed submerged aerator. Atmospheric air is bubbled into the biomass by the aerator. The design of the aerator and the biomass flow pattern are critical to achieve good process results. The reactor is controlled by a PLS to fulfil the criteria for obtaining a stable product (7 days retention time) and a hygienically safe product (combination of temperature and time) before new supply of raw material. The lower and upper levels of the biomass are controlled by the outlet valve position and a level indicator respectively. The PLS gives an alarm if the airflow is too low, the outlet valve is not properly closed, or if the biomass level is too low.

The reactor was developed for processing of liquid cattle manure, but has proven successful for hygienization and stabilization of a variety of waste materials such as septic tank sludge, blackwater milled food waste. Also combination of several wastes has been successfully composted (Skjelhaugen et al 1994, Jenssen & Skjelhaugen 1994, Donantoni et al 1994).

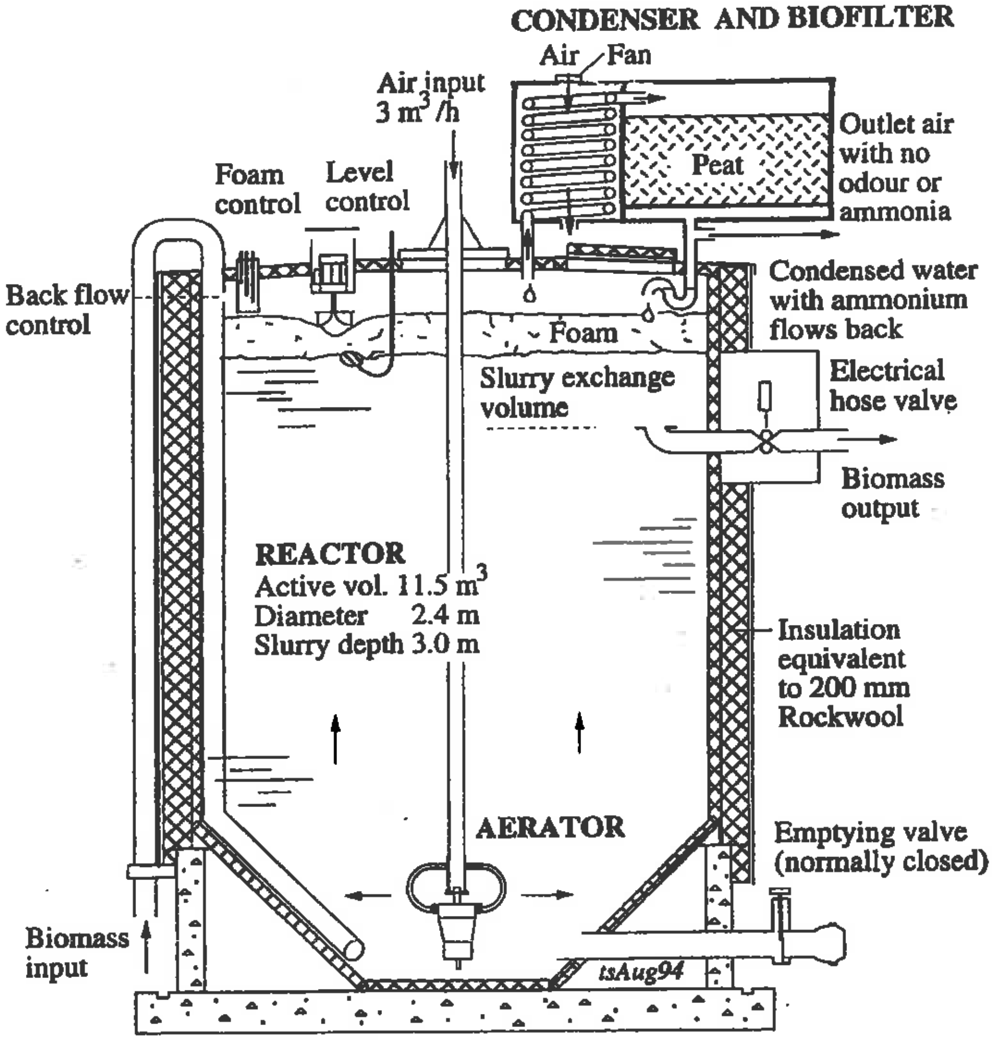

Figure 4. Design of a liquid reactor for treatment of sludge (Skjelhaugen & Sæther 1994).

Requirements for hygienisation and stabilisation of sludge and dead fish

The veterinarian authorities require that waste (dead fish) and sludge are treated so that the disease causing organisms are inactivated. The *Aeromonas salmonica* (furunkulosis) bacteria and the ILA virus are used as indicator organisms to control the effect. Laboratory studies have shown inactivation of ILA after 10 minutes at 55 °C, and inactivating of *Aeromonas salmonicida* (furunkulosis) after 14 hours in a liquid compost at 55 °C.

In combination with blackwater from the domestic domain the guidelines for septic sludge must be used. Preliminary guidelines say less than 2500 termotolerant coliform bacteria per gram DM, and no salmonella bacteria or parasites should be present. The claims for temperature and time combination are 50 °C over a period of 23 hours, 55 °C over 10 hours or 60 °C over 4 hours. To obtain satisfactory stabilization 7 days holding time is required.

If there is any suspicion or indication of disease on the farm, the dead fish is classified as high risk waste according to Norwegian regulations, not low risk which it is classified as elsewhere. High risk waste can not be composted but must be transported to a central plant for destruction.

Results from experiments using liquid composting of waste from aquaculture.

Composting of sludge

An experiment was conducted to study the effect of composting of sludge from aquaculture (Skjelhaugen 1994). Sludge was retrieved from an eel farm The sludge was separated from the effluent water with a radial flow rotary screen and dehydrated to a content of dry matter (DM) of 15 %. Before taking the sludge into the reactor it was diluted to a DM content of 3,1 %. The pH in the sludge was 5,9 and it was free of antibiotics.

Upon starting the composting process the temperature in the sludge increased rapidly. After 4 days the temperature reached 60 °C and the highest temperature obtained was almost 70 °C (Fig. 5). Analysis were performed on total bacteria and coliform. Both the amount of total bacteria and coliform was reduced to under 100 per gram wet weight. It was also planned to do tests on IPN, but the raw sludge does not contain IPN. The raise in temperature does, however, show that both of the indicator organisms - *Aeromonas* and ILA - should be inactivated.

The sludge had before composting a heavy smell. The smell was strongly reduced after the composting process. The utilization of oxygen was over 90 % and the amount of dissolved oxygen (DO) was less than 0.1 ppm. During the experiment there was a heavy foam production and a better cutting knife for foam was installed.

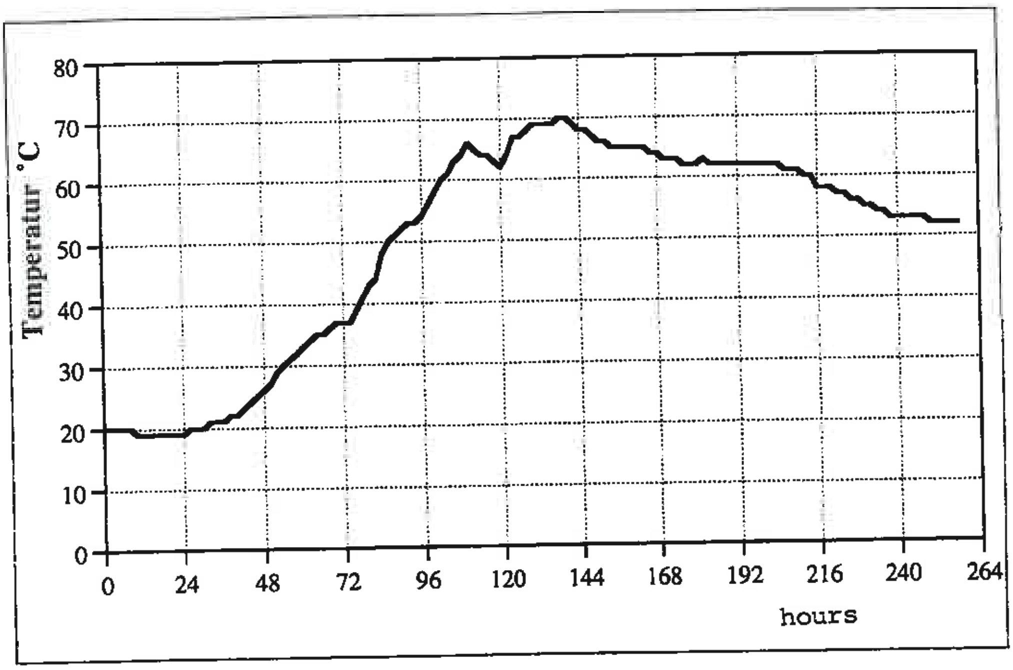

Figure 5. The temperature raised rapidly when composting sludge from aquaculture (from Skjelhaugen 1994).

Composting of cadaver fish mixed with black water

Normally all dead fish from Norwegian fish farms are preserved with acid, collected and reused as fodder for fur-bearing animals or used in other articles in the food industry. It was, however interesting to study the possibilities to use it as nutrient in manure for agriculture.

An experiment was therefore conducted to evaluate the effect (Sæther & Skjelhaugen, 1994). Because cadaver fish is very energy rich it was mixed with black water (toilet effluent). In total 630 kg dead Atlantic Salmon and Rainbow trout were mixed with 4.1 m^3 black water. The DM in the mix was 1.7 %.

Also here there was a rapid increase in temperature after starting the composting process. After 3 days the temperature had almost reached 60 °C. Unfortunately, the aerator now crashed and stopped for 4 days before it was fixed. After it was fixed the temperature increased again to over 70 °C.

Bacterial analysis was not executed but the heavy raise in temperature should indicate that satisfactory hygienisation was obtained. Also the cadaver fish have a heavy smell, but this was strongly reduced during composting. Even if the aerator absorbs much air, the utilization of the supplied oxygen was approximately 90 %.

Energy production in the reactor when composting sludge and cadaver fish

The liquid composting process produces energy through a biological oxidation processes. Some of the energy is lost as heat, i.e. warm slurry leaving the reactor. However, it is possible to transfer about 2/3 of this loss to the slurry input and thereby increase the net heat, which can be used as a by-product (e.g. powering the reactor or heating of nearby houses). Both sludge and cadaver fish are energy rich and the energy production in the reactor was respectively 80 and 95 kWh/m^3 (Tab. 1). Since the reactor consumes approximately 19 kWh/m^3, the reactor can be operated at a positive energy budget. The excess energy can be used for heating purposes.

Table 1. Energy production in the liquid composting reactor, when composting sludge from landbased fish farm, and a mix of milled deadfish and blackwater.

Composted material	% DM	kWh/m3	kWh/kg DM
Sludge from landbased fishfarm	3.1	95	3.1
Milled deadfish + blackwater	1.7	80	4.7

Conclusion

Based on theoretical studies and results from treatment of waste and waste water from aquaculture and the domestic domain it seems possible to operate a land based fish farm with almost no contamination of the environment (Fig. 6). Before recommending the solution economical analyses and full scale studies must be performed.

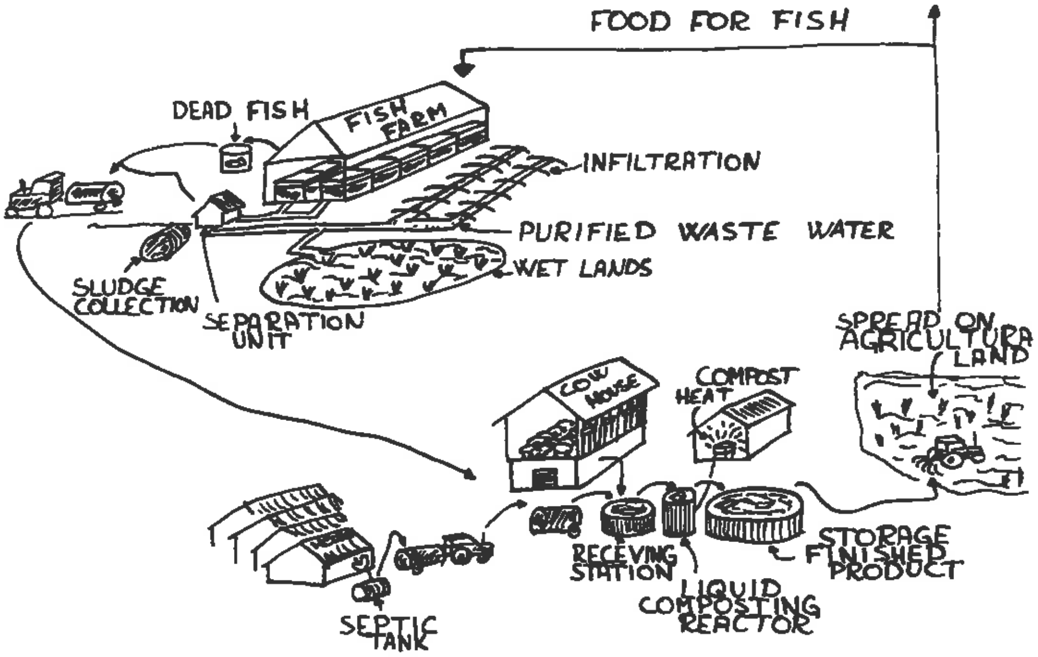

Figure 6. A local ecological solution for treatment of waste water from aquaculture.

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GREEN ROCK PRODUCTS (Paroc Ltd.) FOR THE TREATMENT OF SLUDGE AND WATER FROM FISH FARMS

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1. The production of rock wool and its general properties

Rock wool is made of two or more rock types that are melt and centrifuged into fiber-like material. Resin, which acts as an agglutination agent, is added simultaneously. Rock wool used for insulation is water-repellent, a property that is achieved by adding oil to the mixture during the process of namufacture. If the rock wool is to be used as a filter, no oil is added and therefore it adsorbs water.

During the process of manufacture it is possible to obtain precisely the desired hydraulic conductivity for the filter. Hydraulic conductivity can be high parallel with the board and slow perpendicular to board. The normal pore size of the fiber-pipe filter is about 2 μm.

The thickness of the board can be chosen. If needed, the filter can be shaped into a pipe or a trough.

The suitability of rock wool filters for the treatment of drinking water has been tested as directed by the Ministry of Social Affairs and Health. Fibers or other materials do not come off the filter into the water.

2. The use of rock fiber filter for the treatment of groundwater

Groundwater often contains iron 1-10 mg/l, manganese 0.1-1.0 mg/l and the COD value is 1-4- mg/l. In addition, groundwater of this type is often devoid of oxygen, i.e. iron and manganese are in their reduced form. When oxidation of the water occurs, the iron and manganese begin to flocculate forming brown and black layers of residue.

Iron and manganese can be removed biologically, usually almost without using any chemicals.

The normal process includes preliminary filtering and slow sand filtering. In preliminary filtering, iron and manganese oxidize and become microbiologically polluted. Slow sand filtering removes the rest of the residue. The problem is that the slow sand filter requires quite a large area. A normal dimensioning of the slow sand filter is 0.1-0.5 m^3 of water for each square meter of the filter in one hour.

For example, figure 1 shows a container that is 1 m in diameter. It holds 6 filter pipes, each of which is 1 m in length and 20 cm in diameter. Thus the filter area (the outer surface area of the filter pipes) is approximately 4 m^2. A part of the iron residue runs from the pipe surface to the bottom of the container. If needed, the filter pipes are easy to remove and clean and the residue left in the container can be rinsed out.

Figure 2 shows the Onkamo water supply plant in Haukipudas. The dimensional output of the plant is 2,400 m^3/d. Above are the coarse filters, 8 units in all and below are the 18 slow filter units. The area needed for both the preliminary filters and the slow filters is about the same. The slow filter containers are round in shape and 1.6 m in diameter. There are 28 filter pipes, similar to those described earlier, placed in each containers which means that the filtering area of each containers is 17 m^2 and the capacity is 8 m^3/h. After the slow filtering, the water flows into the lower basin and pumped into the water distribution system. No chemicals are used for the removal of iron and manganese in this plant.

The total building area of the plants is 170 m^2 (Figure 2). If slow filtering had been realized using a more traditional technique, namely a slow sand filter, an area of about 250 m^2 would have been required to obtain the same removal capacity.

Figures 3 and 4 show that the sand filtering and the rock wool filtering operate in a similar efficiency when run side by side in a test environment. The removal of iron begins almost instantly, but the process of removing manganese requires usually 1-2 months to begin.

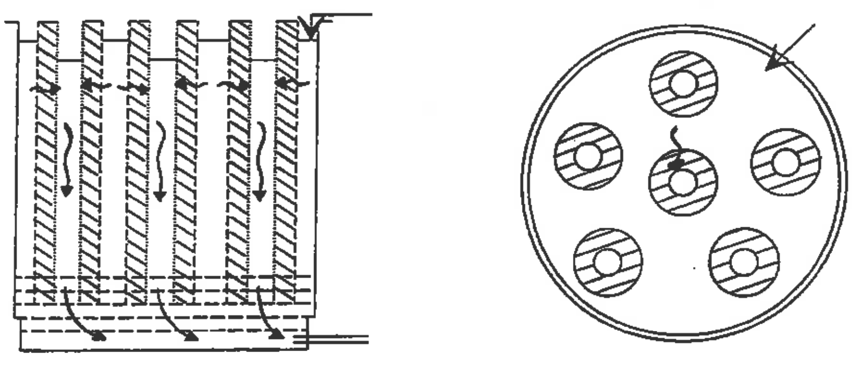
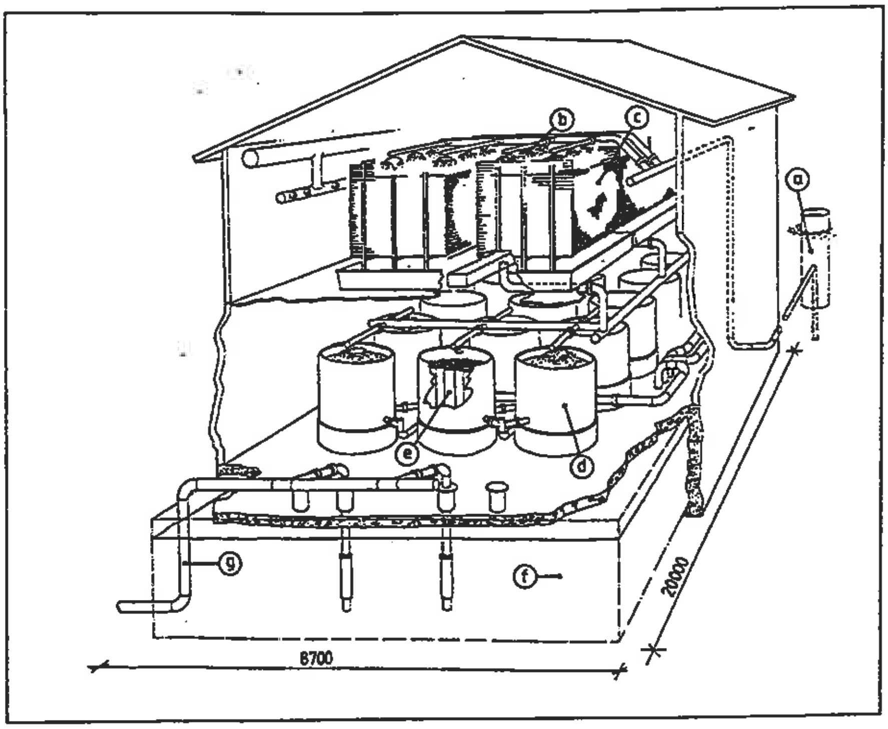


Figure 1. Rock wool filters that are used for slow filtering and their placement in a container of 1 m in diameter.



a= groundwater well
b= water inlet to coarse-grained filter
c= coarse-grained filter batteries
d= slow filter
e= rock fiber cartridges
f= filtered water basin
g= water to consumption

Figure 2. The iron and manganese removal plant in the municipality of Haukipudas.

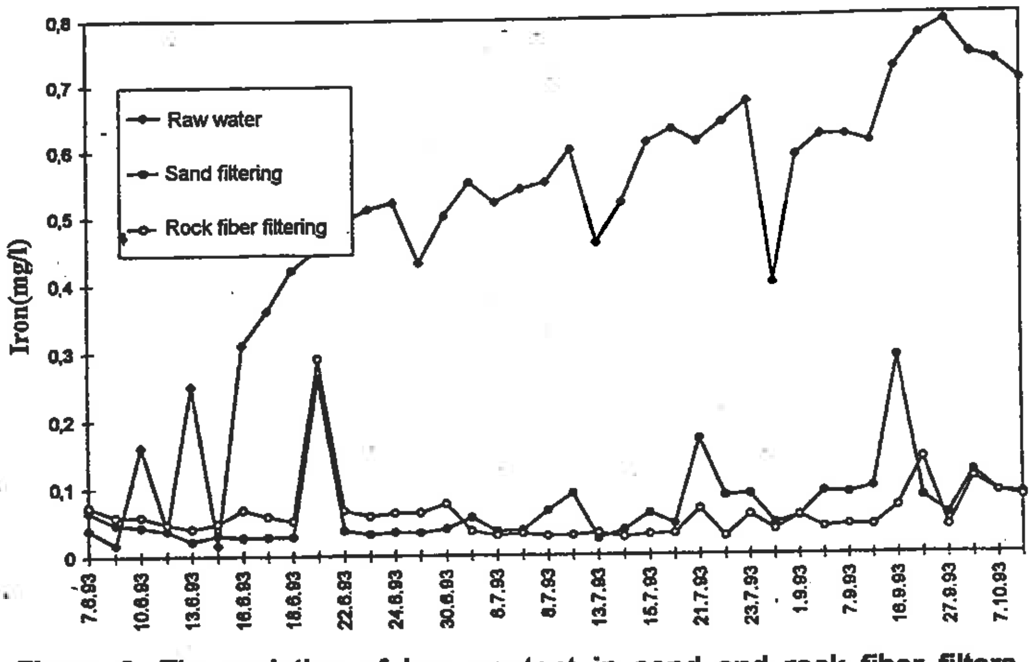


Figure 3. The variation of iron content in sand and rock fiber filters installed in connection with a trial pumping at Aaltokangas groundwater intake plant in Ii.

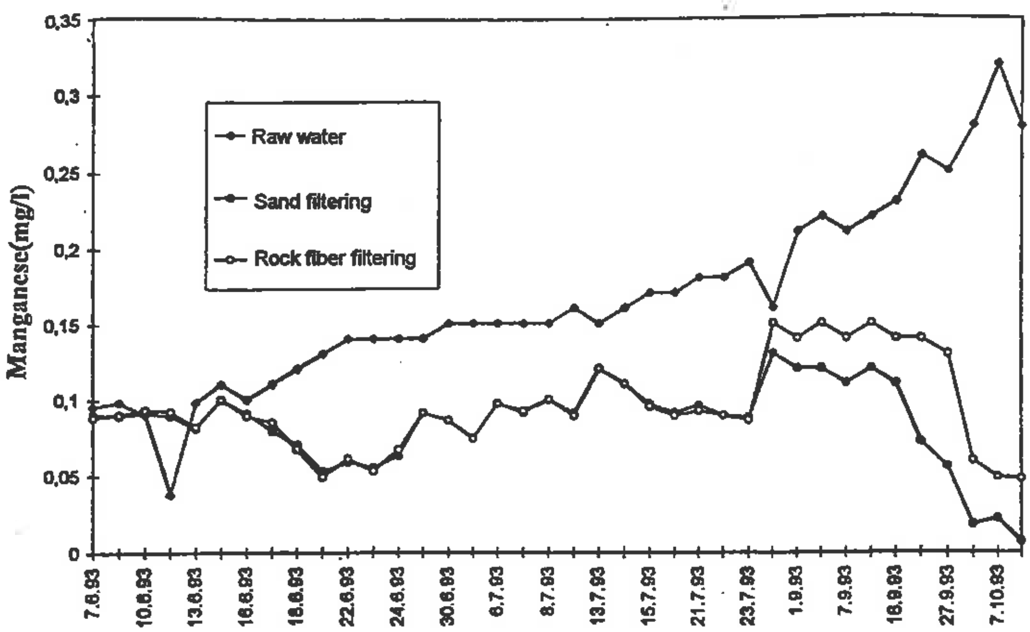


Figure 4. The variation of manganese content in sand and rock fiber filters installed in connection with a trial pumping at Aaltokangas groundwater intake plant in Ii.

3. Rock wool filter for treatment of small amounts of wastewater

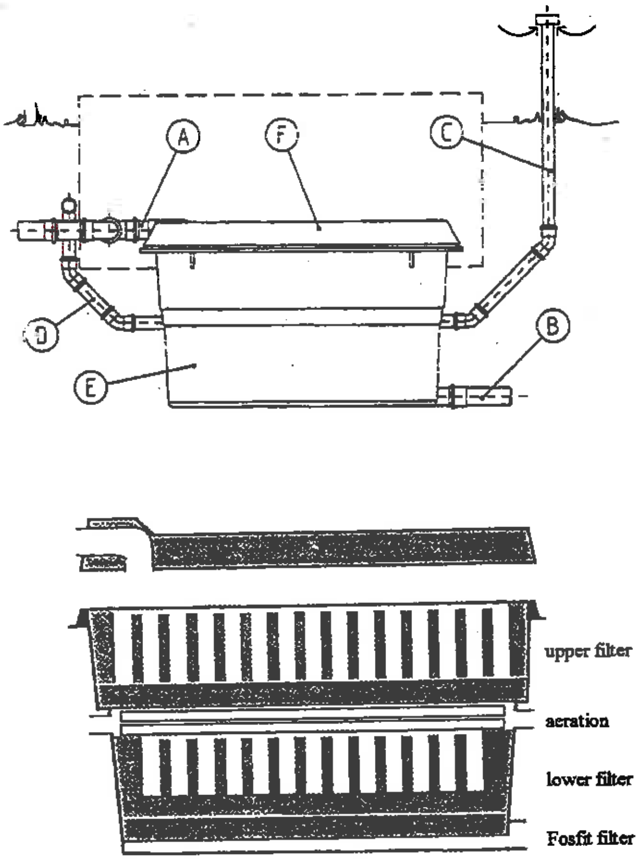
Wastewater from residential areas along with other similar wastewaters can be efficiently and reliably purified by using a treatment plant similar to the one shown in Figure 5. The upper section of the treatment plant acts mainly as a mechanical filter separating the solid matter from the wastewater and leading it between the lamellae made of rock wool. Aeration of the mid-section of the filter is based on natural air circulation. The lower section of the treatment plant acts a biological filter separating dissolved organic matter from the wastewater. The removal of phosphorus can be made more efficient by using a chemical Fosfilt filter in the lowest part of treatment plant.

Tens of Green Pack filters similar to the one represented in the figure have been installed during a period of two years. The maintenance can be taken care of by changing the rock wool lamellae placed inside the filter.

The period between the changes has been estimated to 3-5 years for the upper lamellae and 6-10 years for the lower lamellae. The used lamellae can be composted or broken into pieces and used as a fertilizer.

The University on Oulu researched a Green Pack treatment unit equipped with a Fosfilt filter at Hollihaka waste water pumping station. Wastewater from the sewage system of the town of Oulu was pumped to the treatment plant. The pumping followed the changes in water usage of a normal household, i.e. the pumping was concentrated to the morning and evening being approximately 1.5 m^3/d. There were long breaks in the pumping during midday and especially during night-time. Figures 6-8 show the preliminary treatment results obtained at the test unit. P-mid given in the figures gives the quality of the wastewater after the biological treatment process, before the Fosfilt filtering.

As Figures 6-8 shows, the treatment plant has functioned extremely well during the whole period of observation, that being 1 Feb.- 8 Sept. 1995. If the phosphorus removal is to be made more efficient, a chemical Fosfilt filter is needed. The oxidation of ammonium to nitrate began 4-5- months after the filter was taken into use.



Green Pack - filter and cross section

A = inlet
B = outlet
C ja D = aeration pipes

E = reinforced plastic cover
F = cover

Figure 5. Green Pack filter for the treatment of small amount of waste water.

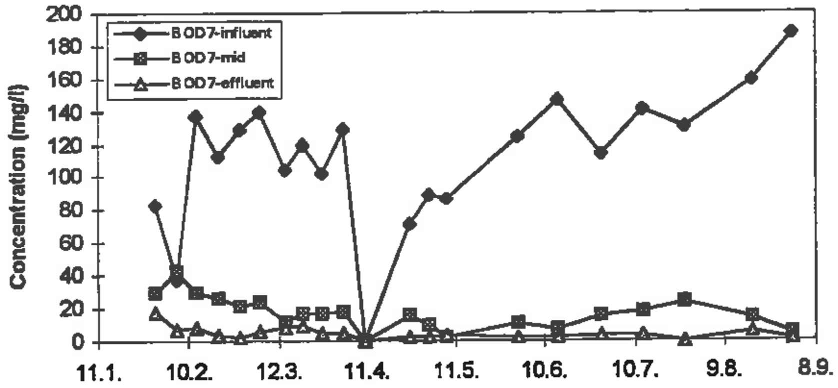


Figure 6. BOD_7 contents measured in the Hollihaka research of Green Pack filter in 1995.

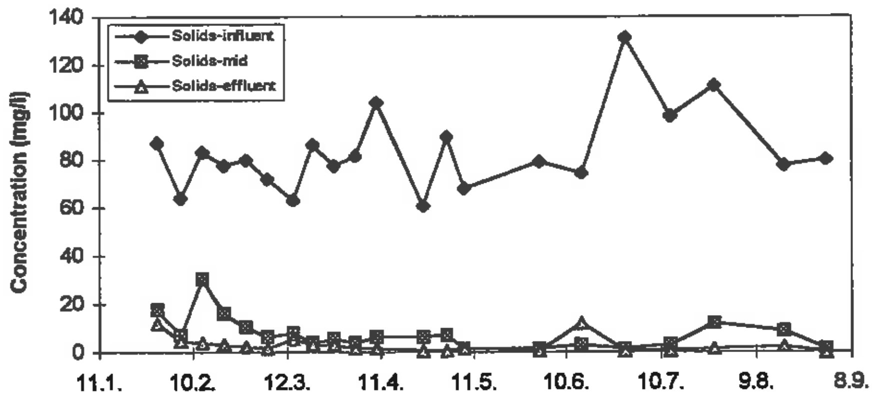


Figure 7. Solid contents measured in the Hollihaka research of Green Pack filter in 1995.

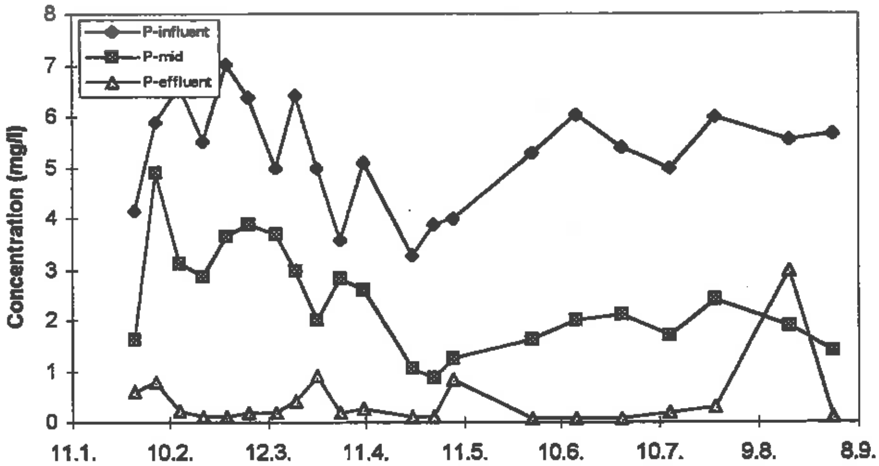


Figure 8. Phosphorus contents measured in the Hollihaka research of Green Pack filter in 1995.

4. Drying the sludge produced by fish farms with a rock wool filter

To prevent the nutrients from dissolving in water, it is essential to remove the sludge from the fish breeding ponds as quickly as possible. An applicable solution is to remove sludge daily, for example, with the help of mud trap. The sludge gathered in this way has a very high water content; the solids content is only 100-3.,000 mg/l. the phosphorus content is usually high, 10-100 mg/l.

Figures 9-10 show a solution for filtering sludge. The area of the filter is about 8,5 m^2. Sludge is run to the filter for 1-2 min, after which it can dry for 5-10 min. The dried sludge is brushed off and the process is begun again. The content of the dry solid matter of the brushed-off sludge is about 20 %. The separating degree in regard to the solid matter is about 90 % and in regard to the phosphorus 80 %. The treatment capacity of the device is about 10 m^3/h of watery sludge pumped from the breeding pond.

As the rotating brushes remove the sludge from the surface of the rock wool, they simultaneously make the rock wool layer thinner by 1-2 mm. The dried sludge can be composted, for example.

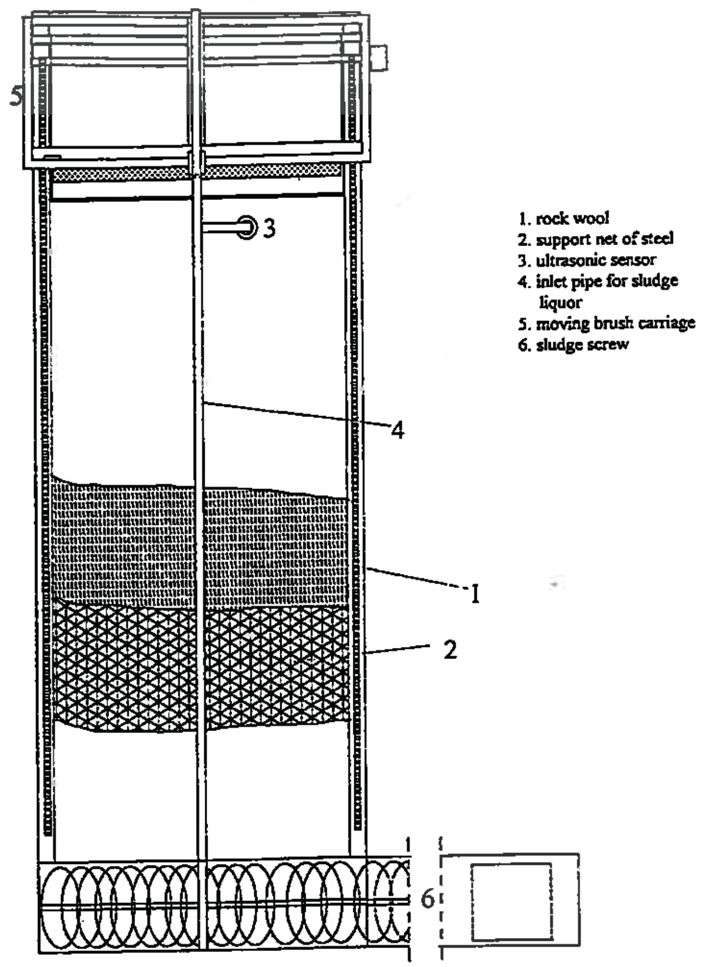


Figure 9. The drying device for the sludge produced by fish farms, seen from above.

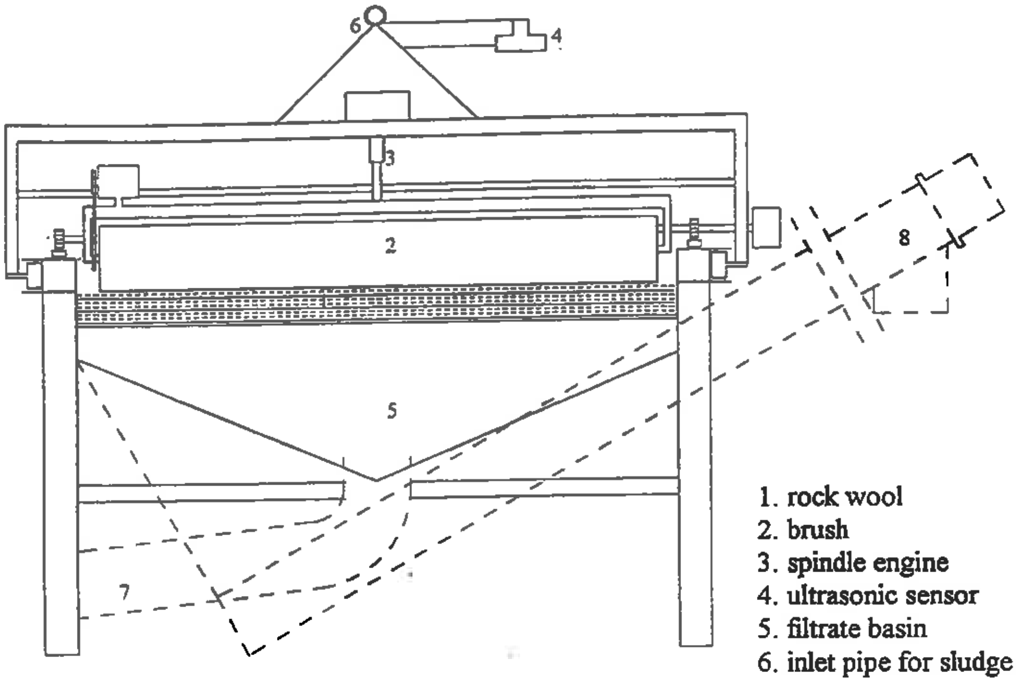


Figure 10. The drying device for the sludge produced by fish farms, seen from the front.

5. Conclusion

An advantage of the rock wool in water and wastewater treatment is the exact and even quality of the product. The filtering qualities can be adjusted accurately in advance. When using rock wool it is possible to make use of the vertical surfaces, thus making the filtering area of a volumetric unit large. In addition to this, rock wool is a relatively cheap material. For instance, the single household waste water treatment unit discussed earlier costs only about 10,000 FIM, and changing the inner parts of the unit costs about 500 marks.

The processes taking place on the surfaces of and inside the rock wool and sand filters are basically the same. When using rock wool, the structures are easy to build. In addition, the surface of rock wool can be cleaned by brushing or whit water, depending on the circumstances.

NJF Seminar nr 258 on "Technical Solutions in the Management of Environmental Effects of Aquaculture"

Place:	**Hotel Rantasipi, Oulu, Finland**
Address:	**Kirkkokatu 3, FIN - 90100 OULU, Finland**
Phone:	**+358 - 81 - 3139111**
Date:	**13 - 15 September, 1995**

Seminar Program and Timetable

Wednesday 13 September

08.00	**Registration**
10.00	**Opening formalities** (Markku Pursiainen, Finland)
10.10	**Welcoming address** (Director Kai Westman, Finnish Game and Fisheries Research Institute, Aquaculture)
10.30	**SESSION 1** (Chairperson: Odd-Ivar Lekang, Norway) **Site Selection versus proper Farming Technologies with Respect to the Environmental Impacts of Aquaculture**
10.30	Site selection versus proper farming technologies with respect to the environmental impacts of aquaculture, a review (Håkanson, L., Sweden)
11.30	Decision analysis - a set of tools to design environmentally sustainable aquaculture (Sistonen, K., Kettunen, J. & Mäkinen, T., Finland)
12.00	**Lunch**
13.30	Comparison of the nutrient loads into the water from rainbow trout cage culture based on autochthonous or allochthonous food resources (Ruohonen, K., Finland)
14.00	Towards optimized pendel feeding - a video (Mäkinen, T., Finland)
14.30	Discussion and summary of SESSION 1 (Lekang, O-I., Norway)
15.00	**Coffee**
15.30	**SESSION 2** (Chairperson: Anders Alanärä, Sweden) **Internal Measures in the Management of Environmental Aspects; Farm Management and Technological Solutions to Minimize the Waste from Aquaculture**
15.30	Internal measures in the management of environmental aspects; farm management and technological solutions to minimize the waste from aquaculture, a review (Braaten, B., Norway)
16.30	Waste phosphorus and solids flow in aquaculture system - a practical study (Makkonen, J. & Pursiainen, M., Finland)
17.00	Closing the day's Seminar
19.00	Evening program

Thursday 14 September

09.00	**SESSION 2** (contd.)
09.00	Biotechnological initiatives for reducing the environmental loading of aquaculture (McLean, E. & Rønsholdt, B., Denmark)
09.45	Minimizing the waste from Kuusamo Aquaculture (Pasanen, P., Finland)
10.15	Break
10.30	Biofilters in recirculating aquaculture systems - state of the art (Skjølstrup, J., Nielsen, P.H., Frier, J.O. & McLean, E., Denmark)
11.15	Discussion and summary of SESSION 2 (Alanärä, A., Sweden)
12.00	**Lunch**
13.30	**SESSION 3** (Chairperson: Lars Heerfordt, Denmark) **Effluent Treatment Methods; Problems and Constraints in Fish Farm Effluents and Technological Solutions to Minimize their Environmental Impacts**
13.30	Effluent treatment methods; problems and constraints in fish farm effluents and technological solutions to minimize their environmental impacts, a review (Michelsen, K., Denmark)
14.30	Multi-stage waste reduction technology for landbased aquaculture (Bergheim, A., Norway)
15.00	**Coffee**
15.30	Methods for waste water treatment in aquaculture (Lekang, O.-I., Norway)
16.00	Fish farm effluent filtration by using mineral wool (Huhta, J., Finland)
16.30	Discussion and summary of SESSION 3 (Heerfordt, L., Denmark)
17.00	Discussion, summary and closing the Seminar (Eskelinen, U., Finland)
17.30	Free evening

Friday 15 September

	The visit to Kainuu Fisheries Research and Aquaculture
08.00	Departure from Oulu, bus to Paltamo 2 hours - presentation of aquaculture and water treatment processes - bus to Kajaani (arrival about 12.30, via airport, if requested) - a possibility to travel to Helsinki from Kajaani by train or flight - lunch in Kajaani (reservation during the seminar necessary) - one hour free time in Kajaani after lunch
17.00	Arrival to Oulu (to the airport, if requested)

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