Constructing a Coolwater Aquaponic System

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Norwegian cluster

- The group working with Aquaponics

✓Bioforsk (research institute)

- Siv Lene Gangenes Skar, Olav Langmyr, Atle Beisland, Ove Hetland

✓NIVA (research institute)

- Helge Liltved, Rolf Høgberget, Ole Kristian Hess-Erga

✓AqVisor (privat company)

- Jan Morten Homme, Asbjørn Drengstig, Jan Erik Jensen

Definition Temperatures

- Three Classifications:
  - ✓cold-water species below 15 ° C
  - ✓cool-water species between 15 °- 20° C
  - ✓warm-water species above 20° C

Water quality parameters

Parameter	Tilapia	Trout
Temperature, °C	25 to 30	10 to 20
O_2, mg/L	4 to 6	6 to 8
O_2, mm Hg	90	90
CO_2, mg/L	40 to 50	20 to 30
TSS, mg/L	< 80	< 10
TAN, mg/L	< 3	< 1
NH_3-N, mg/L	< 0,6	< 0,02
NO_2-N. mg/L	< 1	< 0,1
Chloride, mg/L	>200	> 200

From: Timmons and Ebeling

Regulations

Parameter	Unit	Driftsforskr. 1)	VKM 2)	Aquaponics3)
O_2 saturation	%	80-120	85-140	
O_2 in	%	> 90	< 140	
O_2 out	% (mg/l)	> 80	>85	70 (5,6)
Total gas saturation	%		< 110	
Temperature	ºC		6-20	27,9
pH in	log_{10}	6,2-6,8	> 6	7,1
CO_2	mg/l	< 15	10-20	
Alkalinity	ppm $CaCO_3$		50-300	115,9
TAN (NH_3+NH_4)-N	mg/l	< 2		0,95
Amonnia (NH_3-N)			0,012-0,025	
Amonnium (NH_4-N)				
Nitrit (NO_2-N)	mg/l	< 0,1	< 0,1	0,21
Nitrate (NO_3-N)	mg/l		150-400	27,5
TSS	mg/l	< 10	15-100	13
TDS	mg/l			236
Electrical conductivity (EC)	µS/cm			500

1) Indicative values given in Norwegian aquaculture regulations. **2)** Indicative values given in a new report on recirculated aquaculture from «Science commity for food production (VKM). **3)** Rakocy 2004

Temperature

- As a general rule
  - ✓ $Q_{10} = 2$
  - ✓ This means that growth (and other biological processes) doubles for every increase of 10^{o}C.

Fish growth

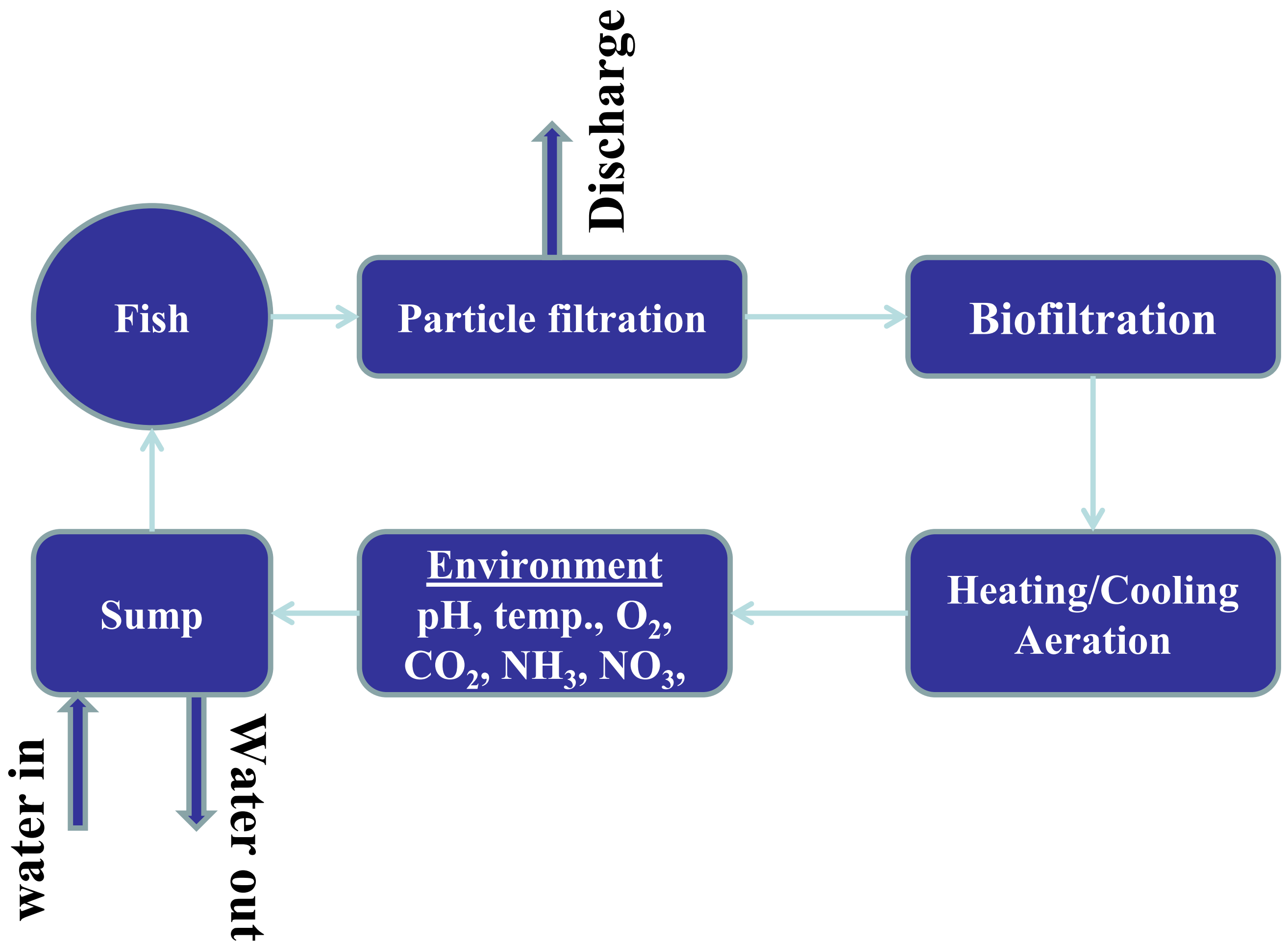
Ørret, vår- og høstutsett

Tilvekst (% per dag) og biologisk fôrfaktor for regnbueørret (Skretting ARC)

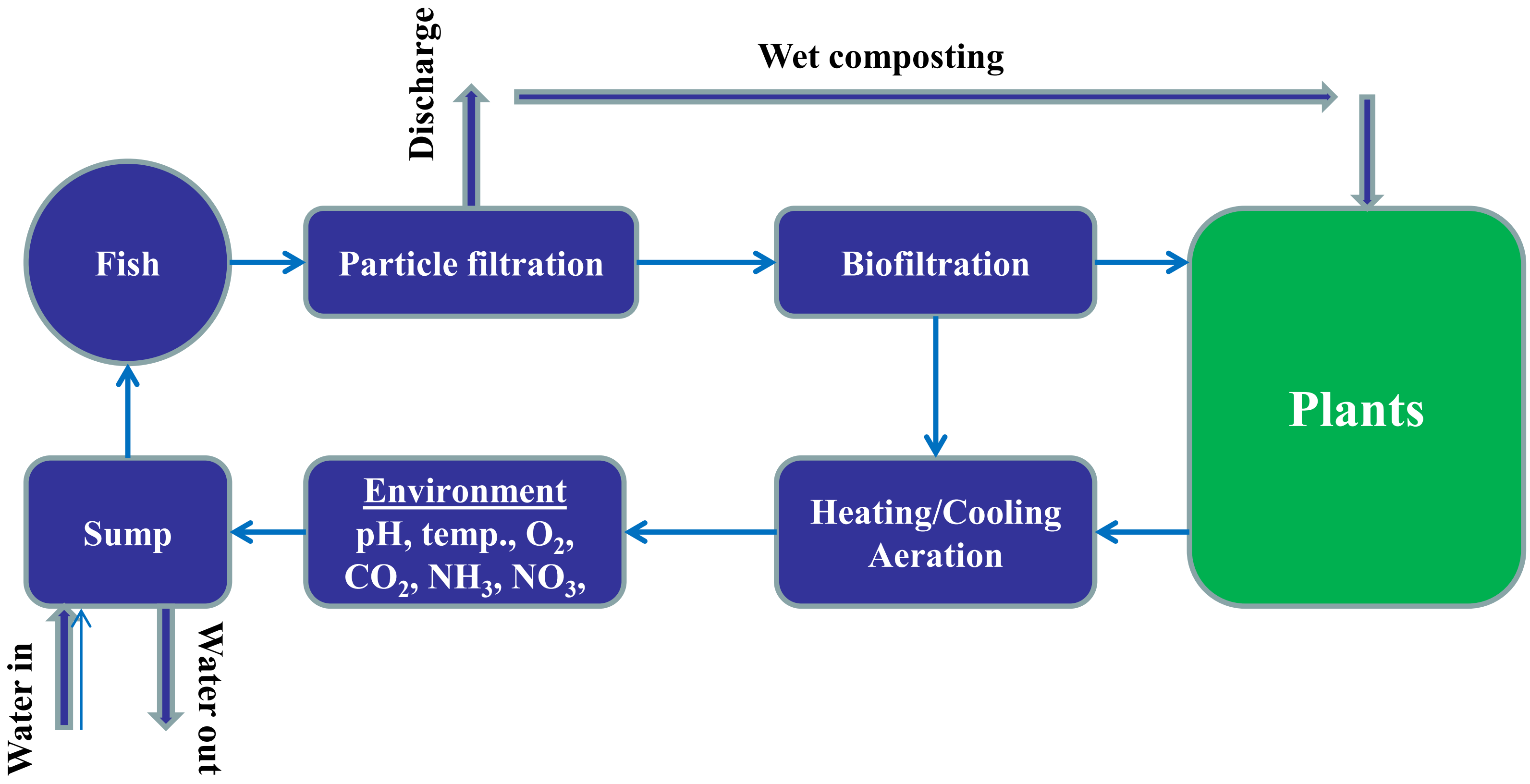
	Temperatur (°C)																				
gram	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	FF_{bio}*
30–60 g	0,46	0,66	0,88	1,10	1,33	1,57	1,80	2,10	2,30	2,60	2,90	3,10	3,40	3,60	3,90	4,20	4,40	3,95	3,50	2,95	0,74
60–100 g	0,34	0,48	0,64	0,80	0,96	1,13	1,30	1,40	1,60	1,80	2,00	2,20	2,30	2,50	2,70	2,90	3,10	2,70	2,25	1,70	0,76
100–200 g	0,30	0,42	0,56	0,71	0,85	1,00	1,15	1,32	1,50	1,65	1,80	2,00	2,15	2,30	2,50	2,65	2,80	2,40	1,90	1,30	0,78
200–300 g	0,26	0,37	0,49	0,61	0,74	0,87	1,00	1,20	1,30	1,50	1,60	1,75	1,90	2,10	2,20	2,40	2,50	2,10	1,70	1,20	0,80
300–400 g	0,21	0,30	0,40	0,56	0,70	0,80	0,95	1,10	1,20	1,35	1,50	1,60	1,75	1,90	2,05	2,20	2,30	1,95	1,55	1,10	0,82
400–600 g	0,19	0,28	0,37	0,51	0,63	0,75	0,88	1,00	1,13	1,25	1,38	1,49	1,63	1,75	1,87	2,01	2,13	1,78	1,41	1,01	0,84
600–800 g	0,17	0,25	0,33	0,46	0,56	0,67	0,78	0,89	1,01	1,12	1,23	1,34	1,46	1,57	1,68	1,79	1,91	1,62	1,28	0,90	0,87
800–1000 g	0,16	0,23	0,31	0,41	0,52	0,62	0,73	0,83	0,93	1,04	1,14	1,25	1,35	1,46	1,56	1,67	1,77	1,50	1,19	0,83	0,90
1000–1250 g	0,15	0,22	0,29	0,38	0,48	0,58	0,67	0,77	0,87	0,96	1,06	1,16	1,25	1,35	1,45	1,55	1,64	1,39	1,10	0,77	0,95
1250–1500 g	0,14	0,20	0,27	0,35	0,44	0,53	0,62	0,72	0,80	0,89	0,98	1,07	1,15	1,24	1,34	1,43	1,51	1,24	0,98	0,69	1,00
1500–2000 g	0,13	0,19	0,25	0,33	0,41	0,49	0,57	0,66	0,74	0,82	0,91	0,99	1,07	1,15	1,24	1,32	1,40	0,99	0,63	0,33	1,05
2000–2500 g	0,12	0,17	0,23	0,30	0,38	0,45	0,52	0,60	0,68	0,75	0,83	0,90	1,00	1,05	1,12	1,20	1,30	0,82	0,58	0,30	1,10
2500–3000 g	0,12	0,17	0,22	0,29	0,36	0,43	0,50	0,58	0,65	0,72	0,79	0,86	0,94	1,01	1,08	1,15	1,22	0,78	0,55	0,29	1,15
3000–3500 g	0,11	0,15	0,20	0,27	0,34	0,41	0,48	0,55	0,61	0,68	0,75	0,82	0,89	0,96	1,03	1,09	1,16	0,74	0,52	0,27	1,20
3500–4000 g	0,11	0,15	0,20	0,26	0,33	0,39	0,46	0,52	0,59	0,65	0,72	0,78	0,85	0,92	0,98	1,05	1,11	0,71	0,50	0,26	1,25
4000–4500 g	0,10	0,14	0,19	0,25	0,31	0,38	0,44	0,50	0,57	0,63	0,69	0,75	0,82	0,89	0,94	1,01	1,07	0,68	0,48	0,25	1,30

** FF_{bio}: biologisk fôrfaktor ved temperatur 8–10 °C*

RAS

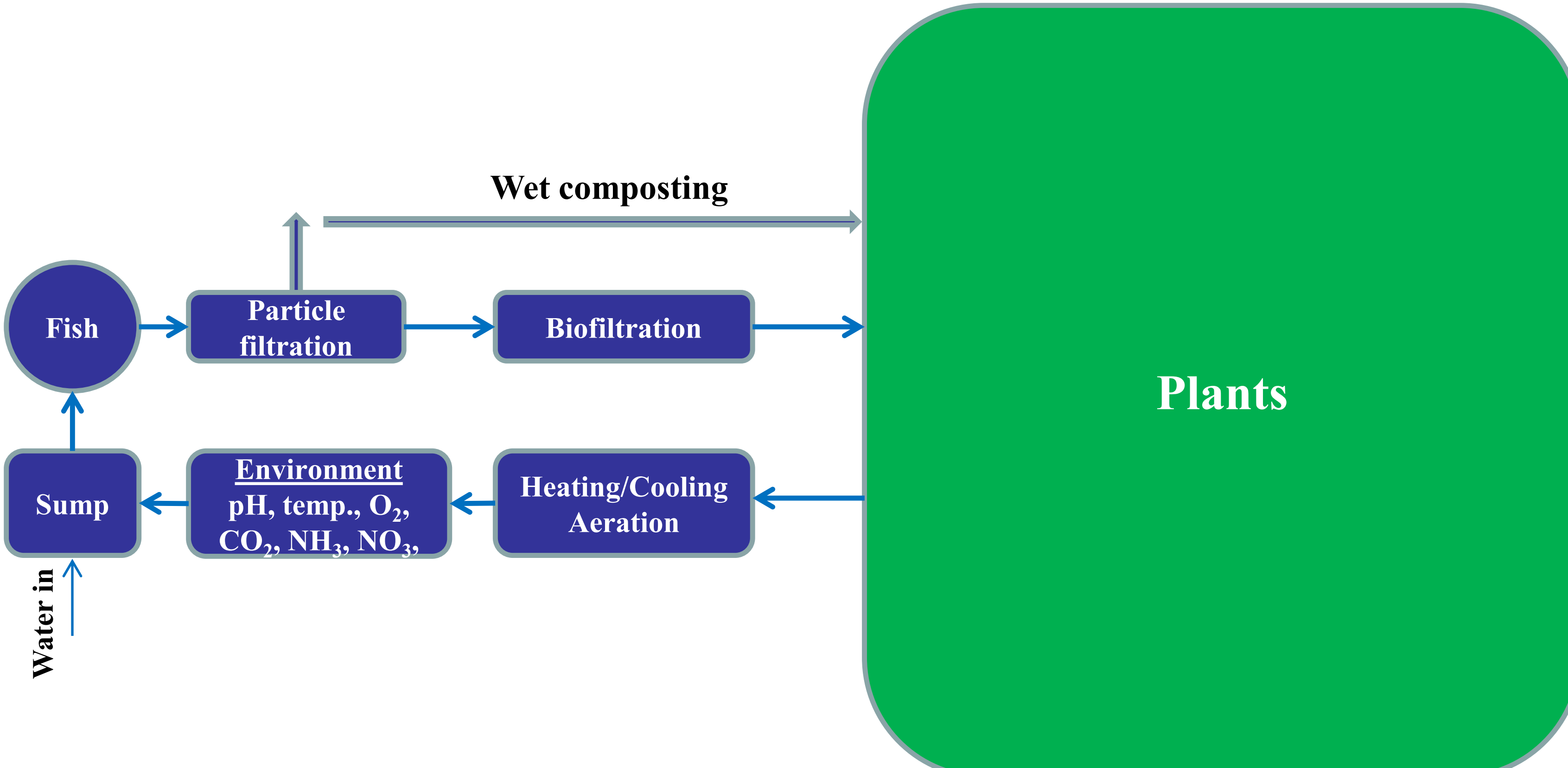

Discharge
Fish
Particle filtration
Biofiltration
Sump
Environment
pH, temp., O_2,
CO_2, NH_3, NO_3,
Heating/Cooling
Aeration
water in
Water out

RAS + Hydroponics



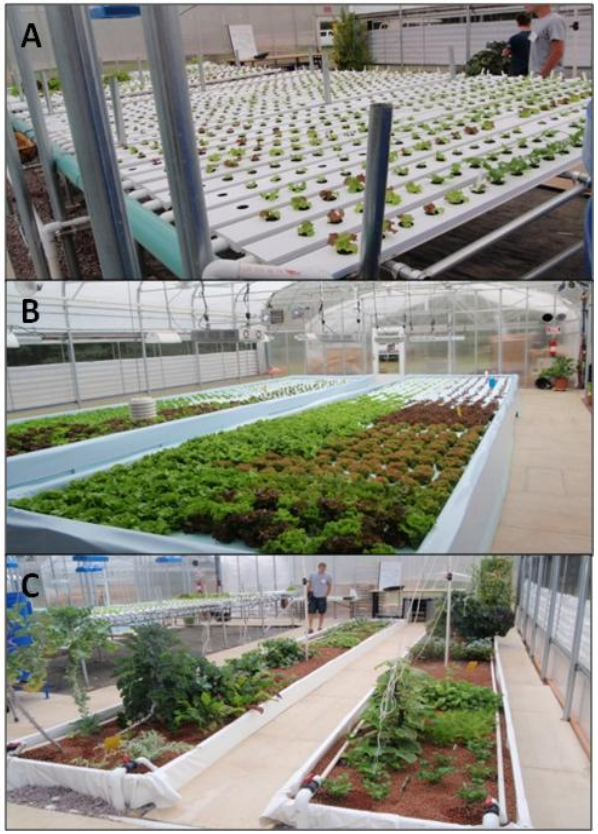
Zero Discharge

The domination of plants



Hydroponic systems

- Floating Raft (Deep Water System)
- Nutrient Film Technology (NFT)
- Media Bed
- Drip Systems



Pilot aquaponic system design at Bioforsk

- To secure stability we have chosen to use deep water systems
- High water volume makes the system resistant to sudden changes in parameters
- We will apply wet composting to conserve nutrition
- The system is designed as a zero discharge system

Aquaponic Deep Water System

Production experiment with Okra (Rakocy 2004)

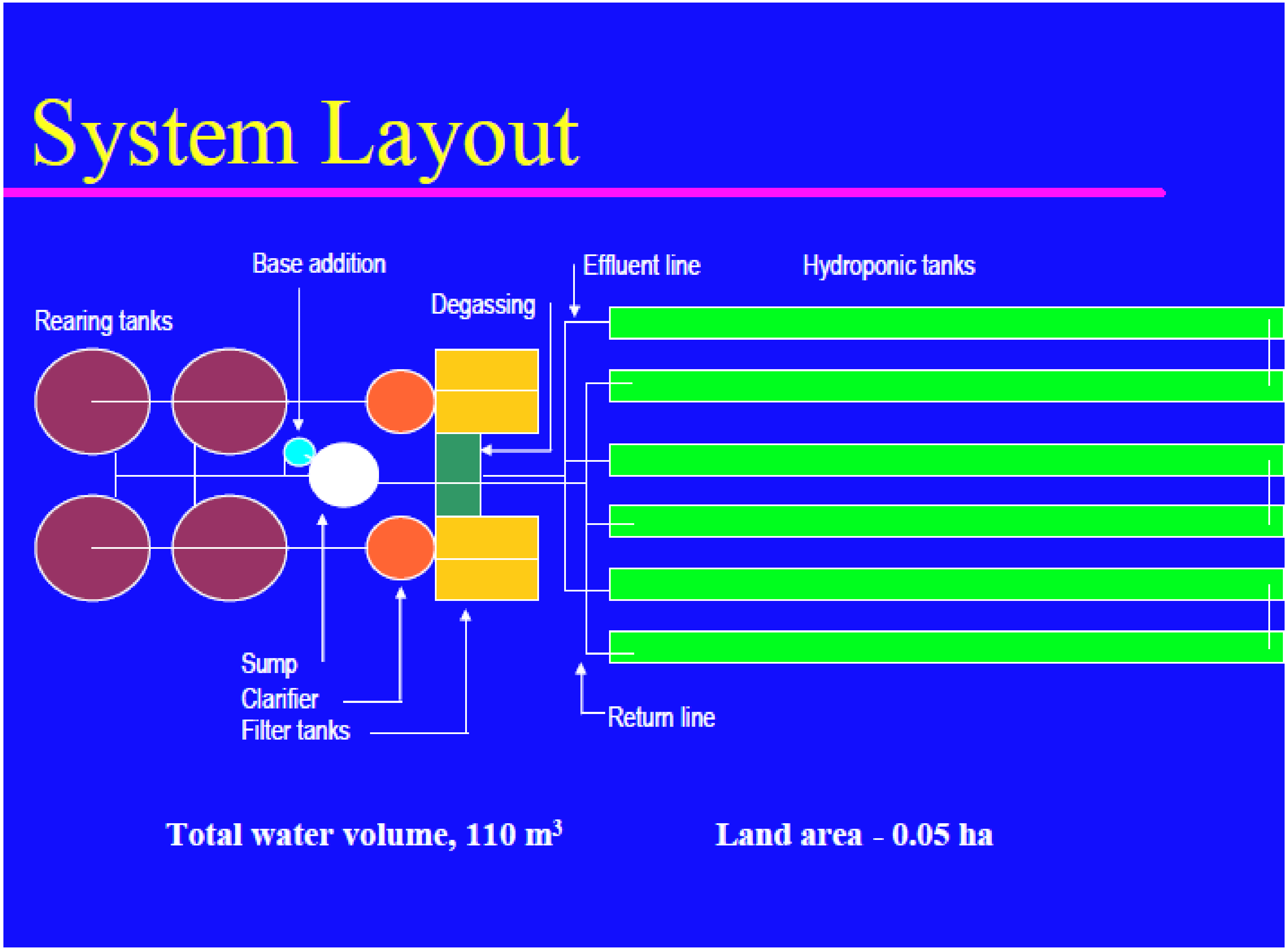
Elements	Parameter	Unit	Plants water in	Plants water out
Total nutrition	EC	mS/cm	0,5	0,5
	TDS	mg/l	236	236
Macro nutrients	NO_3-N	mg/l	26,3	27,5
	TP	mg/l	16,4	15,9
	Ortofosfat	mg/l	15,0	15,2
	K	mg/l	63,5	64,6
	Ca	mg/l	24,2	24,3
	Mg	mg/l	6,0	6,0
	SO_4	mg/l	18,3	18,8
Micro nutrients	Cl	mg/l	11,5	11,5
	Fe	mg/l	1,3	1,3
	Mn	mg/l	0,06	0,05
	Zn	mg/l	0,34	0,34
	Cu	mg/l	0,03	0,03
	B	mg/l	0,09	0,09
	Mo	mg/l	0,01	0,01
Others	Na	mg/l	13,7	13,7

Aquaponic system with drip/irrigation

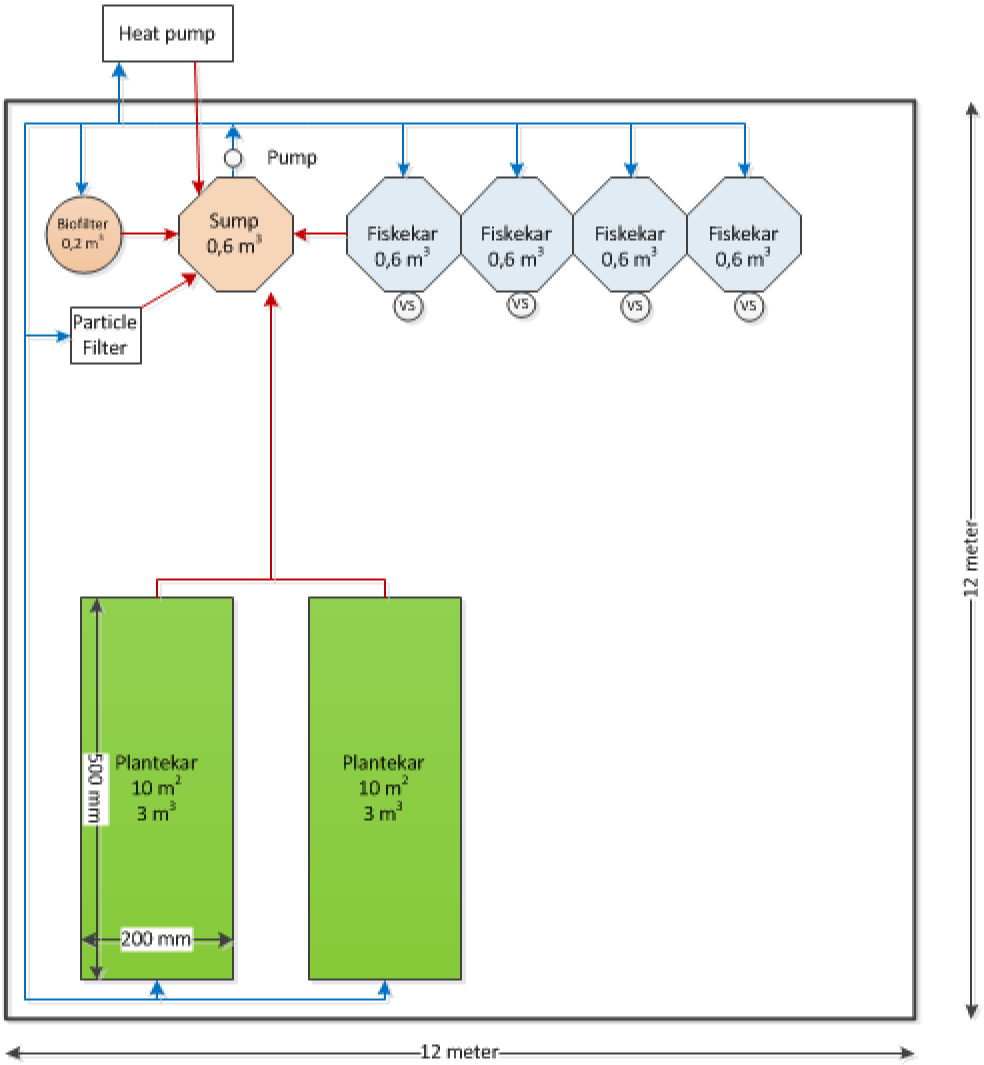
(Endut et al 2010)

HLR (m^3/m^2 day)	Plant bed	BOD	TSS	TAN	NO_2-N	NO_3-N	TP
0,64	In (mg/l)	6,7	74,6	12,02	0,58	19,8	17,0
	Out (mg/l)	1,7	23	2,68	0,19	5,8	6,7
	Removed (%)	**47,3**	**67**	**64,1**	**67,2**	**62,4**	**50,0**
1,28	In (mg/l)	6,7	74,4	12,04	0,56	20	17,1
	Out (mg/l)	1,3	21,1	2,23	0,14	5,4	6,3
	Removed (%)	**54,5**	**69,5**	**68,4**	**75**	**64,9**	**52,8**
1,92	In (mg/l)	6,8	74,8	12,01	0,56	19,9	16,9
	Out (mg/l)	1,3	19,2	1,94	0,11	6,2	7,0
	Removed (%)	**55,4**	**72,3**	**71**	**80,4**	**60,4**	**47,8**
2,56	In (mg/l)	6,9	74,4	11,99	0,57	20	17,0
	Out (mg/l)	1,0	14,2	1,68	0,09	6,6	7,1
	Removed (%)	**61,4**	**79**	**73,3**	**84,2**	**58,5**	**47,5**
3,20	In (mg/l)	6,7	73,9	11,98	0,57	20,1	17,1
	Out (mg/l)	0,7	11,2	1,14	0,06	9,7	7,9
	Removed (%)	**65,5**	**82,9**	**78,3**	**89,5**	**42,3**	**42,8**

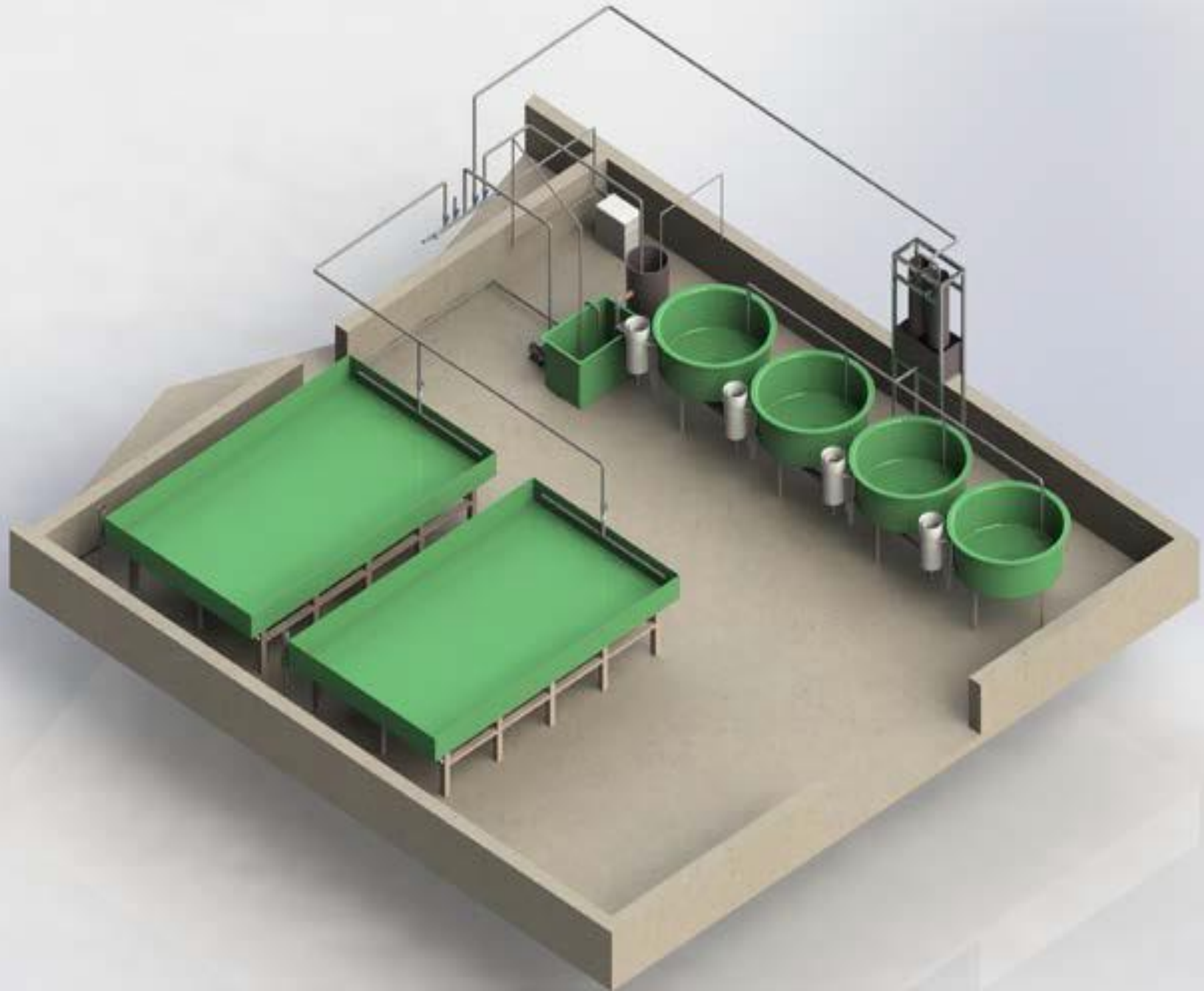
Virgin Island system (Rakocy)



Pilot aquaponic system at Bioforsk



Pilot aquaponic system at Bioforsk



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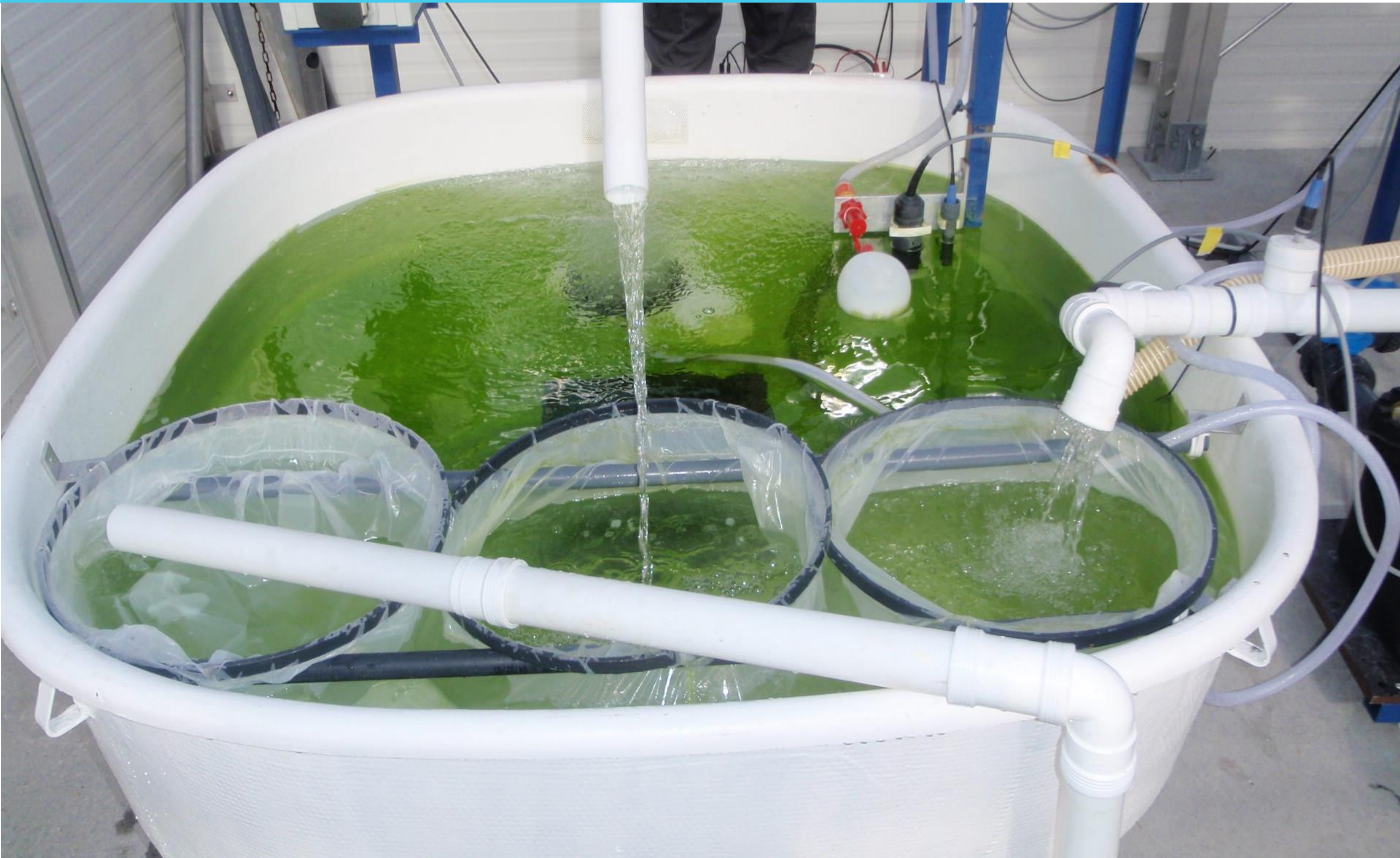
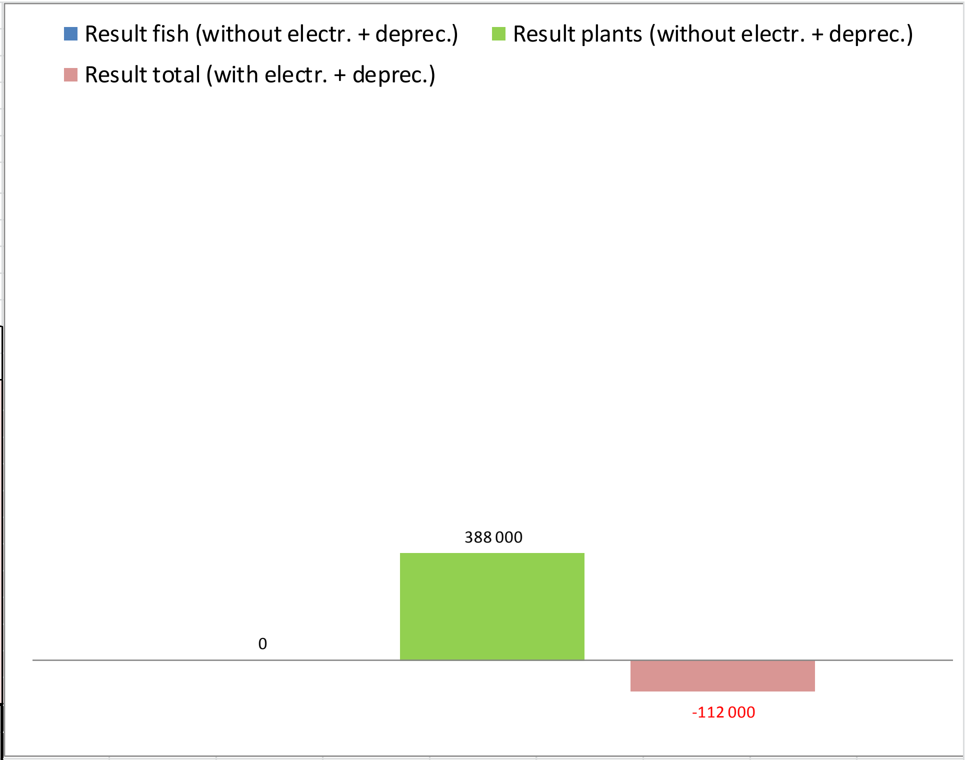


Aquaponic production

Parameter	Unit	Value
Weight ar harvest	kg per fish	0,30
Growth rate (SGR)	per day	1,00 %
Standing stock	kg	2 000
Feed conversion rate (FCR)	ratio	1
Production plants	kg per kg fish	2
Electrisitry	kWh/m^2	300
Production fish	kg/year	7 300
Number of fish	number	24 333
Feed demand	kg	7 300
Production plants	kg/year	14 600

	Unit	Amount	Per unit	Total
Investments			NOK	NOK
Greenhouse	m^2	1 000	3 000	3 000 000
Equipment total	number	1	500 000	500 000
Depeciation	year	10		350 000
Running costs shared				
Electricity	kWh	300 000	0,50	150 000
Running costs				
Feed	kg	7 300	15	109 500
Juveniles	number	24 333	3	73 000
Plants, miscalanious		50 000	1	50 000
Income				
Sales fish	kg	7 300	25	182 500
Sales plants	kg	14 600	30	438 000
Result fish (without electr. + deprec.)	**NOK**			**0**
Result plants (without electr. + deprec.)	**NOK**			**388 000**
Result total (with electr. + deprec.)	**NOK**			**-112 000**



Plant growth

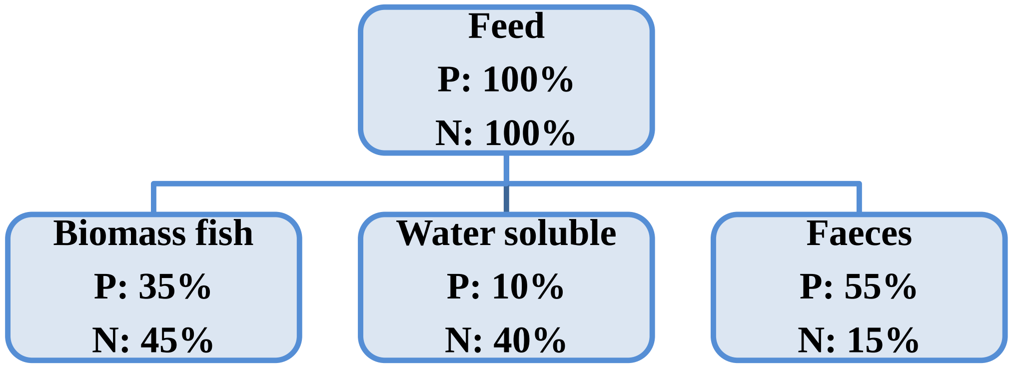
Light

Photosynthesis: $6\ H_2O + 6\ CO_2 \xrightarrow{\text{Light}} C_6H_{12}O_6 + 6O_2$

Elements	Proportion of dry weight	
	ppm	%
C	450 000	45
O	450 000	45
H	60 000	6
N	15 000	1,5
K	10 000	1,0
Ca	5 000	0,5
Mg	2 000	0,2
P	2 000	0,2
S	1 000	0,1
Cl	100	0,01
Fe	100	0,01
Mn	50	0,005
B	20	0,002
Zn	20	0,002
Cu	6	0,0006
Mo	0,1	0,00001

(Benton Jones, 2005)

How much is it possible to increase plant production relative to fish production?

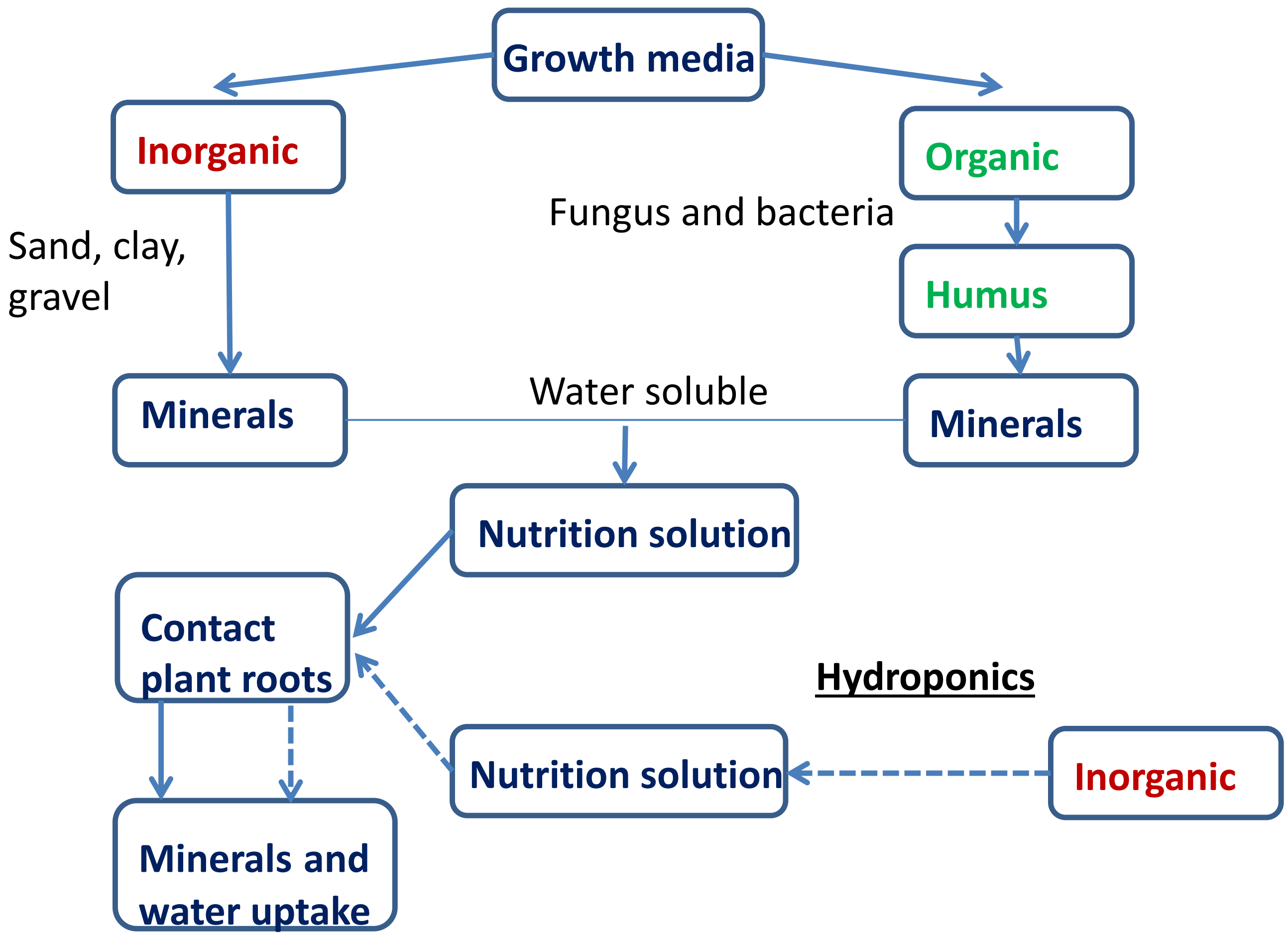


- Total N-content of 1 kg feed eaten = 1kg * 40% (protein content) * 16% (N content of protein) = 0,064 kg
- TAN = 0,064 kg * 45% = 0,0288 kg

- Dry weight plant biomass = 0,0288 kg * 100/1,5 (1,5% N-content of plants) = 1,92 kg
- Wet weight of plant biomass = 1,92 kg * 100/10 (90% water in plants) = 19,2 kg

- With a feed conversion rate of 1, this gives a ratio of plants to fish produced of **19,2 : 1**

Nutrition uptake



Production of brown trout (*Salmo trutta*) in 4 tanks à 0,6 m^3. Pilot production.

Parameter	Unit	Amount
SYSTEM		
Total volume whole systemet	m^3	9,2
Number of fish tanks	number	4
Volume per fish tank	m^3	0,6
Total volume fish tanks	m^3	2,4
FISH		
Weight fish start	kg per fish	0,025
Number of fish start	number per year	600
Biomass of juveniles	kg per year	15
Weight of fish at harvest	kg per fish	0,3
Number of fish at harvest	number per year	600
Biomass at harvest	kg per year	165
Total biomass produced	kg per year	150
Max standing stock	kg	27
Number of fish per tank	number	50
Average standing stock	Kg	20
Average standing stock per m^3	kg/m^3	8,3
Biomass per tank (max)	Kg	15
Biomass per m^3 (max)	kg/m^3	25
Water exchange per tank (max)[1)]	l/min	26
GROWTH		
Specific growth rate (SGR)	% per day	2
Feed conversion rate (FCR)	kg feed per kg weight gain	1
Average daily feed demand	kg per day	0,4
Total feed demand	kg per year	150
Total production TAN [2)]	kg per year	6
Production time [3)]	months	4

[1)] ΔO_2 = 2 mg/l [2)] 42% protein in feed [3)]from 25g til 300g

Water quality, basic reactions

Nitrification:

$2NH_3 + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 2H^+$

$2NO_2- + O_2 \rightarrow 2NO_3^-$

Overall reaction:

$NH_4^+ + 1{,}83\ O_2 + 1{,}97\ HCO_3^- \rightarrow$

$0{,}0244\ C_5H_7O_2N + 0{,}976\ NO_3^- + 2{,}90\ H_2O + 1{,}86\ CO_2$

Alkalinity, carbonate system:

$H^+ + HCO_3^- \longleftrightarrow H_2CO_3 \longleftrightarrow CO_2 + H_2O$

Ammonia Production

1 kg feed ⇒ about **0,03-0,04 kg ammonia** – nitrogen (depending on protein content in feed)

1 g of ammonia yields:	4,42 g nitrate NO_3^-
	5,93 g carbon dioxide
	0,17 g cell mass
1 g of ammonia consumes:	4,57 g oxygen
	7,14 g alkalinity

Mass balance, production terms

P_{oxygen} (negative) - 0,25 kg consumed by fish

- 0,12 kg by nitrifiers

- 0,13 kg by heterotrophs

Total: = - 0,50 kg per kg feed for system

P_{CO2} = 1,375 grams produced for each gram O_2 consumed (both fish and bacteria)

$P_{TAN} = F \cdot PC \cdot 0{,}092$

P_{Solids}, TSS = 0,25 kg per kg feed fed (dry matter basis)

Response times

<u>High</u> (fast response time – minutes)

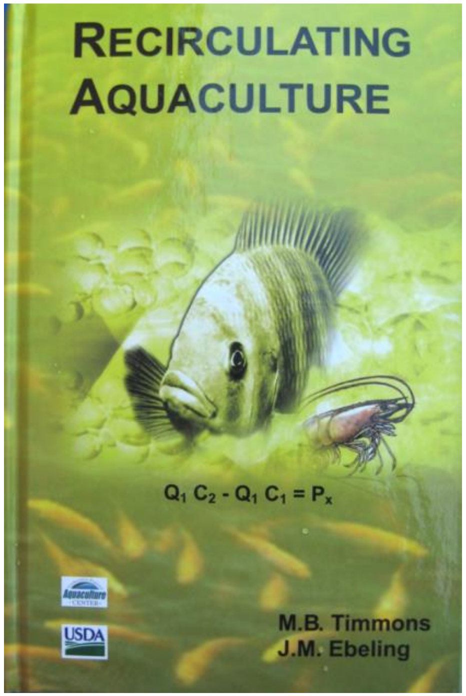
- electrical power
- water level in tanks
- dissolved oxygen –aeration system/ oxygen system

<u>Medium</u> (moderate response time – hours)

- temperature
- carbon dioxide

<u>Low</u> (normally slowly changing – days)

- pH
- alkalinity
- ammonia-nitrogen
- nitrite-nitrogen
- nitrate-nitrogen



Highly recomended

Thank you for your attention