8. Case Study: Murgat

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1. Description of the farm

Charles Murgat SA fish farm (www.charlesmurgat.com) is located at Beaurepaire, Isère, in southeastern France. The farm is operated as a flow-through system and produces on average 600 tonnes of Brook Trout (Salvelinus fontinalis), Brown Trout (Salmo trutta fario), Rainbow Trout (Oncorhynchus mykiss) and Arctic Char (Salvelinus alpinus) per year. The average standing stock is 160 tonnes, corresponding to a fish stocking density of about 60 kg/m3.

The on-growing unit is divided into two sectors (Figure 1):

- sector 1 consists of seven concrete raceways (each 70 m x 6 m x 0.8 m deep) with four species reared from 50 g to more than 2 kg (55-70% harvested at 200 g);
- sector 2 consists of two concrete raceways, with only Rainbow Trout from 200 g to 1 kg (50% harvested at 500 g).

Both sectors are operated with high quality and constant temperature well water (around 11 °C). In the first three tanks (raceways) of sector 1, the water flow rate varies from 600 l/s to 2000 l/s, corresponding to a water renewal rate between

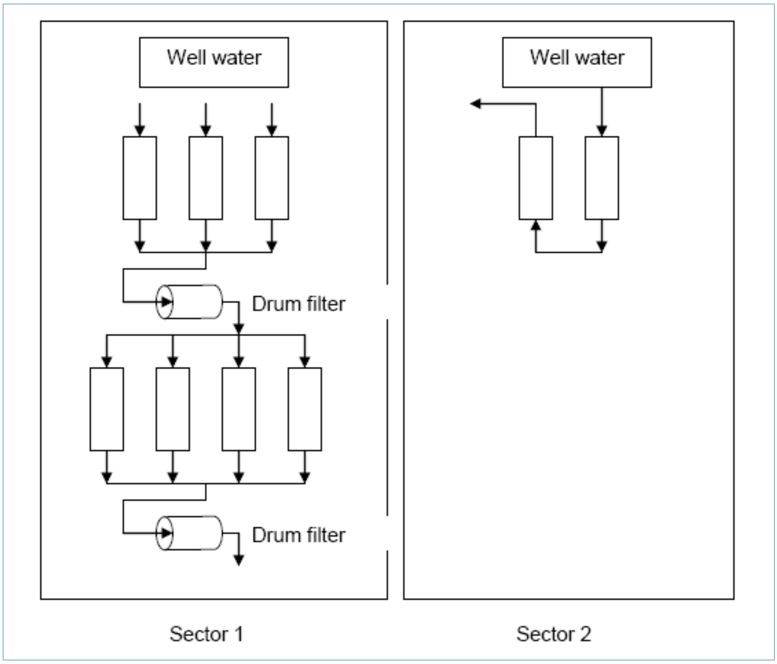

Figure 1: The on-growing unit of Murgat farm, divided into two sectors

200% and 600% per hour per tank. After first use in the three raceways, the water is filtered through a mechanical drum filter, oxygenated and used again in the four following raceways of the sector. The effluent of that sector is filtered with another drum filter before being released into the river through a sport fishing area.

The two raceways of sector 2 are fed with well water, with a flow rate varying around 500 l/s.

2. Characterisation of the farm effluent

The AquaETreat Project included on-farm verification of a method for predicting waste fluxes from fish culture by comparison with data obtained from sampling and analysis of actual waste from the farm.

Quantitative characterisation

The methods used to quantify fish culture wastes are based either on feed digestibility (nutritional approach) or on the analysis and evaluation of dissolved and suspended-solid wastes produced by the fish (hydro-biological approach)[1]. Both methods were used in order to evaluate the wastes produced by the farm[2]. The daily flux of wastes, predicted with the nutritional method and measured with the sampling method, are presented in Table 1.

Table 1: Comparison of predicted and measured daily waste production of the whole farm. For further explanation, see text

	Flux (mean values)			
Parameter	**Predicted** (kg/d±SD)	**Predicted** (g/kg feed/ d±SD)	**Measured** (kg/d±SD)	**Measured** (g/kg feed/ d±SD)
Total N	59.8 ± 6.0	42.58 ± 0.38	54.1 ± 10	38.5 ± 7.1
Particulate-N	10.1 ± 1.0	7.21 ± 0.02	11.8 ± 3.4	8.4 ± 2.4
NH4-N	39.7 ± 4.0	28.3 ± 0.3	31.6 ± 7.5	22.5 ± 5.3
Urea-N	-	-	10.7 ± 2.5	7.6 ± 1.8
Total P	6.33 ± 0.6	4.51 ± 0.11	13.6 ± 3.5	9.7 ± 2.5
Particulate-P	-	-	9.6 ± 3.6	6.8 ± 2.6
PO4-P	-	-	4.0 ± 0.2	2.8 ± 0.1
Suspended Solids	206.5 ± 20.7	147.0 ± 0.2	317.8 ± 165.7	226.2 ± 117.9

The differences between the ‘Predicted’ and ‘Measured’ results in Table 1 can be explained by the different sensitivities of the methods:

- the nutritional method depends on the digestibility of feed ingredients and on the quantity of feed eaten

- the hydro-biological method relies on sample preservation and the precision of flow-rate measurement. The physical properties of the solid wastes, subjected to sedimentation and re-suspension due to fish harvesting, tank cleaning or hydrology also have a strong impact.

Both methods give similar waste production values when expressed per tonne of fish grown (147.5 kg for suspended solids, 40.8 kg for N, and 8.7 kg for P).

Qualitative characterisation

The sampling method provides some detail on the different forms of nitrogen and phosphorous fluxes:

- 21% of nitrogen wastes are present as particulate-N, 59% as ammonium-N (NH4-N) and 20% as urea-N
- 68.8% of the phosphorous wastes are in the particulate form and 31.2% are dissolved PO4-P (Figure 2).

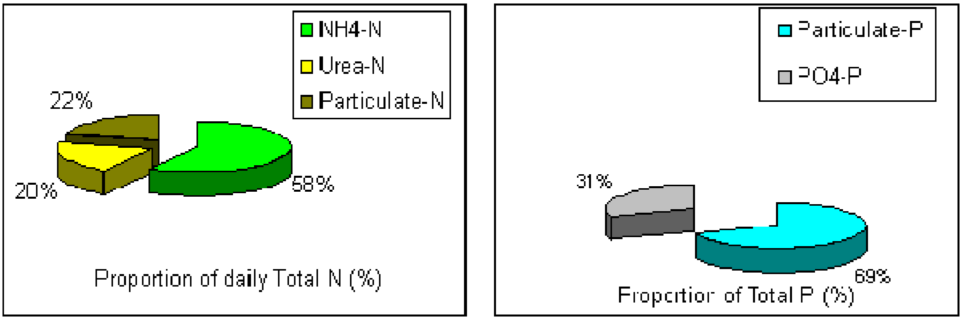

Figure 2: Forms of Nitrogen and Phosphorous in Murgat effluent (% of total N and total P produced by fishes by day)

3. Effluent treatment system

System description

The system in use at the farm (Figure 3, see next page) is composed of three mechanical filters, one in the pre-growing unit sited adjacent to the main farm and two in the on-growing unit, and primary and secondary effluent thickening systems.

The effluent from the pre-growing tanks is filtered through a first drum filter (Figure 4, see next page).

After first use, the rearing water of the first tanks of the on-growing facility is filtered through a mechanical filter, oxygenated in a low head oxygenator, and used again in the four following tanks of sector 1. The effluent of those tanks is filtered with another drum filter before being released into the river through a

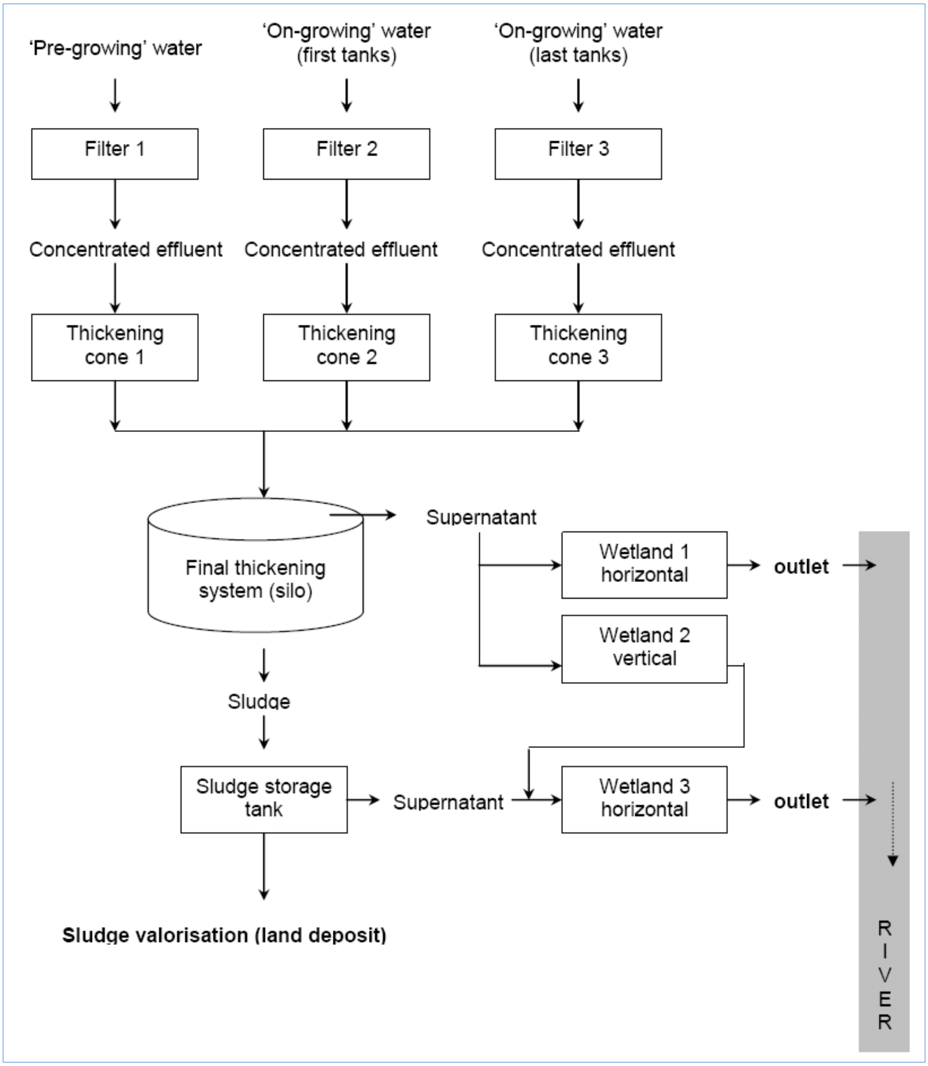

Figure 3: Murgat farm effluent treatment scheme

Figure 4: Mechanical drum filter

sport fishing area. The waste water of the three filters (backwash water) is passed through three thickening cones (around half a cubic meter each) (Figures 5 and 6).

Figure 5 and 6: Thickening tanks

A final silo (Figure 7) collects the concentrated effluents of the three thickening cones. The sludge is released from the silo to a storage tank through an automated valve. This sludge valve is opened automatically for 10 seconds every 10 minutes: if the supernatant becomes dark a colour-detector cell (Figure 8) operates the sludge valve for 25 seconds every 6 minutes. After eight such activations, if the supernatant is still dark, the sludge valve is opened again, for 2 minutes and 30 seconds, to partially empty the silo.

Figure 7: Final silo

Figure 8: Supernatant colour detector system

Effluent characterisation

Filter effluents

The average SS concentration of the rearing water is about 4 mg/l. Each drum filter has a capacity of 600 l/s. After filtration, the average SS concentration of the filtered water is around 2-3 mg/l, and the backwash water (around 1 l/s) is around 1 g/l. Table 2 presents the concentration of dissolved substances in the backwash waters.

Table 2: Concentrations of significant dissolved substances in the backwash water from the three mechanical filters installed at Murgat Farm.

	Backwash water - pre-growing unit Concentration (mg/l)			Backwash water - on-growing unit, sector 1 Concentration (mg/l)			Backwash water - on-growing unit, sector 2 Concentration (mg/l)		
	mean	min	max	mean	min	max	mean	min	max
NO3-N	5.0±2.0	1.8	6.9	6.9±0.9	4.6	7.5	5.6±1.9	1.6	6.8
TAN[1]	3.4±3.4	0.5	8.6	0.3±0.1	0.2	0.6	1.5±1.6	0.4	5.4
PO4-P	2.3±2.6	0.4	8.7	0.3±0.1	0.1	0.5	0.8±0.7	0.2	2.4
NO2-N	0.6±0.6	0.2	1.6	0.4±0.1	0.2	0.6	0.5±0.3	0.1	0.8
Urea-N	0.2±0.1	0.1	0.5	0.1±0.0	0.1	0.2	0.2±0.1	0.1	0.5

Thickening cone treatment

The backwash waters coming from the three filters are collected in three thickening cones. After this primary concentration, the mean SS concentration of the effluent from the thickening cone is around 1-5 g/l (with an mean flow rate of 0.4 l/s). Table 3 shows the concentration of dissolved substances in the concentrated effluents and in the supernatants of the three thickening cones.

Concentrated effluent from the final thickening system (silo)

A final thickening silo receives the concentrated effluent from the three thickening cones. This secondary concentration treatment generates supernatant and a concentrated sludge.

Table 3: Mean concentrations of dissolved substances in the supernatant and the concentrated effluent of the thickening cones.

	Supernatant (mg/l)	Concentrated Effluent (mg/l)
	Pre-growing unit	
NO3-N	6.6±0.6	2.4±2.4
TAN	0.8±0.7	6.6±6.2
PO4-P	0.9±0.7	5.7±3.9
NO2-N	0.2±0.2	0.5±0.5
Urea-N	0.1±0.0	0.3±0.2
	On-growing unit, sector 1	
NO3-N	7.4±0.5	3.1±3.1
TAN	0.3±0.2	2.9±2.4
PO4-P	0.4±0.3	4.4±4.7
NO2-N	0.2±0.2	0.6±0.6
Urea-N	0.1±0.1	0.3±0.1
	On-growing unit, sector 2	
NO3-N	7.4±0.8	1.9±2.5
TAN	0.3±0.3	10.0±8.5
PO4-P	0.6±0.5	7.6±6.9
NO2-N	0.3±0.4	0.5±0.5
Urea-N	0.1±0.1	0.3±0.1

4. Management of the final effluents

Management of the silo supernatant

The flow rate of the supernatant from the silo averages 15 m^3/day. Suspended solids concentration fluctuates between 90 and 500 mg/l. The mean concentrations (±SD) of TAN and PO_4^--P are respectively 9.2 ± 8.1 mg/l and 8.4 ± 6.3 mg/l. The high nutrient concentrations and low flow rate of the supernatant are favourable characteristics for an efficient treatment of effluent before release into the river. Constructed wetlands are appropriate systems to treat this type of effluent.

Three wetlands were constructed in an existing unused raceway divided into three equal sections (each 25 m x 6 m x 0.8-1 m deep) (Figures 9 and 10). Each wetland was filled with a layer of stones (5-15 cm diameter), geotextile, and a layer of sand approximately 10 cm thick). *Typha latifolia* (common bulrush) plants were planted in March 2006.


Figure 9 and 10: Constructed wetland systems (Fig 9. After planting, Fig 10. Current wetlands)


Figure 11 and 12: Horizontal wetland system and vertical wetland systems

The supernatant from the final silo is treated in two types of constructed wetland:

- horizontal wetland where the effluent passes horizontally through gabions and through the entire substrate (Figure 11)

- vertical wetland where the effluent is distributed by pipes and passes vertically down to the bottom of the wetland (Figure 12).

The third wetland treats the supernatant from the sludge storage tank and the effluent from the vertical wetland.

Results

Physical, chemical and biological processes are combined in wetlands to purify the effluent.

- *Suspended solids treatment*

A proportion of the suspended solids remaining in the final effluents and supernatant are physically filtered out by the wetland media (sand and gravels): (1) the SS within the supernatant from the final silo are reduced by 89.7% in the horizontal and vertical wetlands; (2) the SS of the supernatant from the sludge settling tank and the effluent from the vertical wetland are reduced by 72.7% in the horizontal wetland. Values for selected physico-chemical parameters of the wetlands are presented in Table 4.

All the wetland systems present anaerobic conditions, with oxygen concentrations lower than 1 mg/l, which is confirmed by negative redox values at their outlets.

- *Nitrogen transformation*

In aerobic conditions, ammonia ($NH_{3(aq)}$) is oxidised into nitrites (NO_2^-) and nitrates (NO_3^-) through nitrification (*Nitrosomonas* bacteria oxidise ammonia to nitrite and *Nitrobacter* bacteria oxidise nitrite to nitrate). Both nitrate and nitrite are reduced in the wetlands, as suggested by very low outlet concentrations (see Table 4). As the experimental wetlands present anaerobic conditions, we can suppose that denitrification processes occur in the systems, following the general sequence shown[4], with nitrous oxide (N_2O) and nitrogen (N_2) gases as end products:

$$NO_3^- \dashrightarrow NO_2^- \dashrightarrow N_2O \dashrightarrow N_2.$$

Table 4: Physico-chemical parameters of the three constructed wetlands, June 2006 - January 2007. Average values of 8 monthly samples.

	Effluent treated		Silo supernatant		Sludge storage tank supernatant and Vertical Wetland Effluent	
Wetland type	Horizontal		Vertical		Horizontal ('Wetland 3')	
Sampling point	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
pH	6.8	7	6.8	6.9	6.8	6.9
Redox (mV)	42	-64	42	-62	-38	-65
O2 (mg/l)	1.3	0.4	1.3	0.43	0.6	0.6
T °C (summer)	36	17.4	36	17	20.2	17.6
T °C (autumn)	15.7	15.5	15.7	15.9	15.9	16.3
T °C (winter)	7.8	7.6	7.8	7.3	7.1	9.5
PO4-P (mg/l)	3.2	7.5	3.2	5.2	11.2	9.5
NO2-N (mg/l)	0.4	0	0.4	0	0.1	0
NO3-N (mg/l)	1.3	0	1.3	0.1	0.3	0
TAN (mg/l)	12.1	50.3	12.1	54	66.9	44.9
Suspended solids (mg/l)	784	104	784	57	422	115

Denitrification is considered[5] as the predominant microbial process modifying the balance of nitrogenous components in a wetland.

In most of the Murgat samples, the TAN concentrations are higher at the outlet of the wetlands treating the supernatant of the silo than at the inlet (Table 4). This is probably due to an important organic nitrogen mineralization. It has been shown[6] that NH_4^+ can be immobilised onto negatively charged soil particles. Under anaerobic conditions the immobilised NH_4^+ can be stable and predominates[7]. In such wetlands, part of the effluent ammonia is probably stored in this stable form.

In the third wetland (treating the sludge supernatant and the vertical wetland effluent), ammonia outlet concentrations were lower than the inlet concentrations; in this system the transformation of the ammonia into N_2 through an anammox process (Figure 13) could explain the difference.

- *Phosphorus transformation*

Organic phosphorus contained in the silo supernatant is mineralised in its PO_4-P form by micro-organisms in the wetlands (horizontal and vertical), as PO_4-P increases at the outlet. The third wetland, treating the supernatant of the sludge storage tank and the effluent from the vertical flow wetland, presents a lower PO_4-P concentration at the outlet. This could be explained by a PO_4-P fixation on the media similar in nature to that suggested above for NH_4-N.

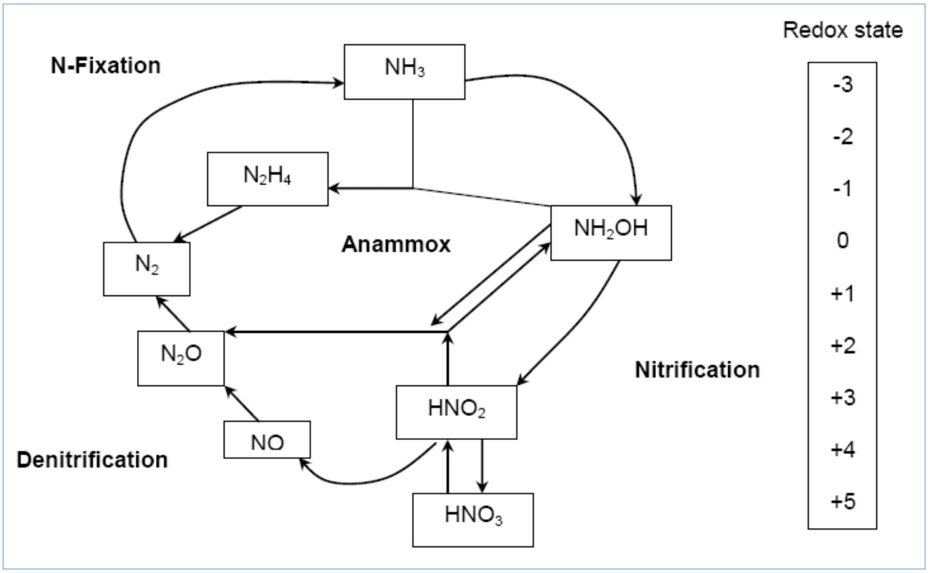

Figure 13: Nitrogen cycle showing the educts, intermediates and products of the important processes of N-fixation, nitrification, denitrification and anammox[8]

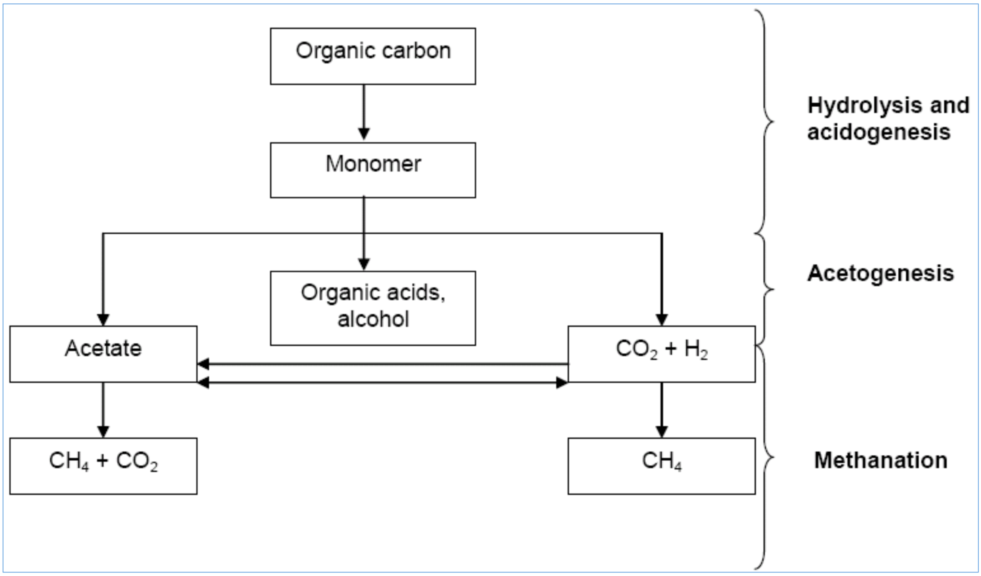

Figure 14: Methanogenesis pathways

Figure 15: Current sludge storage system: settling tank with wood shavings

- *Effect on the water quality in the river*

The three wetland outlets are released into the sport fishing area. At this point, the concentrations of the main pollutants are very low: 9 mg/l for suspended solids, 0.7 mg/l for NH_4-N and 0.03 mg/l for NO_2-N.

Future experiments

Further experiments are necessary to understand and model the functioning of the bacterial component in greater detail: bacteria characterisation (autotrophic, heterotrophic and sulphur bacteria, for example), and gas production. Nitrogen gas production through the de-nitrification process and carbon gas production through the methanation process (Figure 14) are likely to be important and will be studied.

Management of the final sludge

The sludge flow rate from the silo is around 3 m^3/day and the solids content of the sludge at the outlet of the silo averages only 60-80 kg/m^3. For handling purposes and to add value, the sludge has to be concentrated to 200 kg/m^3. The sludge is currently stored in a sludge storage tank (Figure 15) and covered with wood shavings (spread daily), which avoids bad odours and increases the solids content of the sludge up to 140 kg/m^3 after a few months of storage.

The sludge has a good agronomic value, as shown in Table 5.

Table 5: Sludge composition at Murgat Farm

		sludge (silo outlet)	sludge after 5 months of storage	sludge after 9 months of storage
pH		5.9	6.6	-
Suspended Solids	kg/m3	60	117	129
Organic Matter	% dw	74.3	62.3	-
Mineral Matter	% dw	25.7	37.7	-
Total Organic Carbon	g/kg dw	412	467	-
Total N (Kjeldahl)	g/kg dw	32.3	38.6	35.8
Total P (P2O5)	g/kg dw	20.6	92.1	89
Potassium (K)	g/kg dw	1.5	1.2	1.3
K2O	g/kg dw	-	< 2.0	1.5
NH4-N	g/kg dw	5.3	6.5	-
Calcium (CaO)	g/kg dw	87	147.6	159.9
Magnesium (Mg)	g/kg dw	1.2	1.1	1.1
Zinc (Zn)	g/T dw	601	-	534
Copper (Cu)	g/T dw	17.8	-	28.6

Table 6 presents the heavy metal concentrations; all are below the EU legal threshold.

Table 6: Heavy metals content of sludge at Murgat Farm; PAH = Polyaromatic hydrocarbons

Parameter	Unit	Value
Cadmium (Cd)	g/T dw	1.2
Total chromium (Cr)	g/T dw	15.6
Nickel (Ni)	g/T dw	4.3
Lead (Pb)	g/T dw	<8.2
Mercury (Hg)	g/T dw	<0.1
Selenium (Se)	g/T dw	<1.2
Cr+Cu+Ni+Zn	g/T dw	582.7
PAH benzo(a)pyrene	mg/kg	<0.8
PAH benzo(b)fluoranthene	mg/kg	<1.4
PAH fluoranthene	mg/kg	<1

The Polychlorinated biphenyls (PCB 28,52,101,118,138,153,180) are below the EU legal threshold.

The current way of sludge valorisation is a land application, twice a year.

Summary of the whole treatment system

This treatment system reduces by 50% the suspended solids that would otherwise be released to the ecosystem (river). For an average annual farm production of 91 tonnes of solids, around 47 tonnes are collected by the treatment system shown (Figure 3).

5. Physical and chemical treatment processes and valorisation limits

Sludge concentration

Different bacteria, coagulants and flocculants were tested in order to improve the settling process.

Bacterial treatment

An activated bacterial concentrate was injected for two months into the final silo. The considered by the farmer to be too high at the farm scale (€15,000 per year). bacterial treatment was difficult to apply, because of the necessity of warming up the product before injection at a very low flow rate.

The results were unconvincing; there was no improvement of the particle sedimentation in the silo. Even worse, the SS content of the sludge decreased and the SS content in the supernatant increased. This could be explained by a bacterial activity involving mineralization of the particulate matter in the silo, which was shown by an increase of TAN and PO4-P concentrations in the supernatant, as shown in Figure 16.

Coagulant-flocculant treatment
Coagulants and flocculants selected through an earlier project (CRAFT project n° FAIR CT98-9110 coordinated by STM aquatrade S.r.l.) were tested on a small scale. The cost of these treatments was.

Geotextile tube
It was intended to test a sludge dewatering system using a geotextile tube, which is claimed to allow dewatering of the suspended solids. However, the local solution of sludge dewatering and storage in a settling tank covered with wood shavings (which increased the SS content up to 14 kg/m3), before draining (through a liquid manure pump) and subsequent transport away as a fertilizer, was considered to be satisfactory.

Sludge treatment
Some experiments were planned to test a constructed wetland as a sludge treatment system. However, the plants (common bulrush, Typha latifolia) were burned after few weeks, probably because of the acidity of the sludge. Other wetland species, such as common reeds (Phragmites australis), may

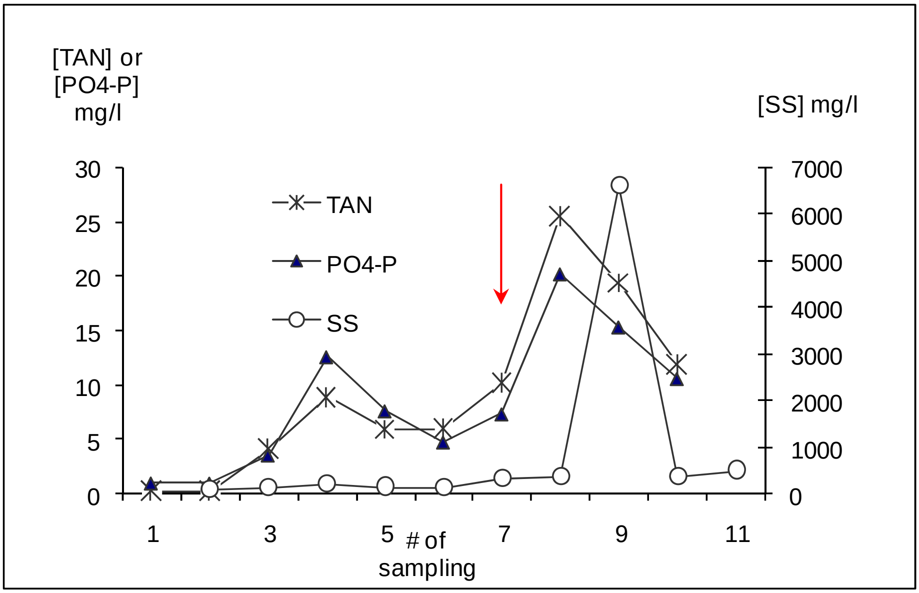

Figure 16: Suspended Solids, Total Ammonia Nitrate and Phosphorous (PO4-P) concentrations in the silo supernatant before and after bacteria injection (red arrow)

have been more resistant to the sludge acidity but were not tested, because the sludge problem was solved.

Sludge valorisation

There are two main difficulties for sludge valorisation, which are related to the costs of transport and treatment. It was decided to work on possible sludge valorisation through land application and composting. A local private enterprise asked for around €50/tonne of sludge to treat the sludge as a compost. This was considered too expensive at the farm level, representing around €25,000 per year, or €0.041/kg of fish produced, before adding the cost of transport.

6. Recipient ecosystem quality: water and biology

The concentrations at the river control point are below the maximum authorized concentrations, as shown in Table 7.
The water quality at the river control point was very high before 2004, and there

Table 7: Average concentrations at the river control point (2004 - 2005) in comparison with the maximum authorized concentrations for the farm discharge (fixed by prefectoral order).

	2004 Average (mg/l)	2005 Average (mg/l)	2006 Average (mg/l)	Maximum Authorised (mg/l)
NH_4-N	0.59	0.50	0.55	1
SS	2.62	2.45	2.10	5
BOD_5	< 3	5	< 3	10

has been a further decrease in the average SS content since the treatment system has been in operation.

The recipient-water biological quality was evaluated using the French standard known as the IBGN (standardised global biological index), as it applies to French water law. This index is based on a study of the insects, crustaceans, molluscs and worms living in the superficial layer of the sediment at the site concerned.

This evaluation established the diversity in the river of the 138 determinant macro -invertebrate species listed in the Standard Protocol and the presence/absence of pollution-sensitive indicators, of the 38 listed. Those two data gave the IBGN score, equivalent to a specified biological water quality (Table 8, see next page).

In 1985-1986, the recipient ecosystem below the Murgat farm showed a ‘Fair’ biological quality, with an IBGN score of 11/20. One year after the whole effluent treatment system installation (in April 2007), another IBGN study was done downstream the farm outlet. According to the IBGN score obtained (14/20), the recipient ecosystem showed a better biological quality, corresponding to a ‘Good’

Table 8: IBGN scores and their associated water quality colour categories

IBGN mark	>16	15-13	12-8	8-5	<5
Colour category	Blue	Green	Yellow	Orange	Red
Corresponding water quality	Excellent	Good	Fair	Poor	Very poor

river quality category. The Murgat effluent treatment system had a positive effect on the recipient ecosystem biological quality, and nowadays there are more rare and pollution-sensitive species in the recipient river. The IBGN studies are described elsewhere in this manual.

7. Future prospects for improvement

Currently, as described, the rearing water is passed through mechanical filters: particles are trapped on the mesh and discharged in the backwash water. The filtered water is reused in other tanks, before release to the river after the final mechanical filter. This filtered water contains less solids than if left untreated, but still contains high concentrations of dissolved components, such as TAN. The removal of TAN from wastewater is important because of its toxicity to organisms and ecosystems.

French legislation sets maximum authorised concentrations at the river control point for three parameters: SS, BOD_5 and NH_4-N. One way to improve the effluent treatment system would be to treat the dissolved nutrients in the filtered water. The literature shows that wetlands could provide an efficient ammonia treatment and reduce it to acceptable levels through nitrification. The minimum residence time necessary for successful nitrification in a biological filter is around four minutes. If we consider the nitrification process to be as efficient in the wetland as in a biofilter, a planted raceway (6 m x 75 m x 0.8 m deep) will be sufficient to reduce part of the ammonia in the filtered water of the farm. A difficulty in the case of the Murgat farm would be to divert the farm outlet flow (600 - 2000 l/s) from the farm outlet point to the wetland system. A pump or a gravity system would be necessary, potentially generating additional costs.

8. References

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