Discharges from Kälarne fisheries laboratory - survey and future strategies

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Scope of work:
Fiskeriverket's Research Station at Kälarne has been required by the Environmental Protection Unit (Miljövårdsenheten) of the county authorities (Länsstyrelsen Jämtland), to revise its plans and operations so that environmental impacts, primarily due to effluent discharges, are reduced. The project has had the following aims, in order to produce the report required by the authorities:

1. Current TP discharges to be quantified. In order to obtain the most reliable picture of what are known to be highly variable parameters, discharge variability with both time and location will be examined.
2. A suitable effluent TP reduction strategy to be recommended.
3. The likely TP reduction achievable using the proposed waste reduction strategy to be presented. Of necessity, such reductions will need to be achievable within sensible practical and economic constraints.

Key-words:
Effluent, wastewater, fish farm, aquaculture, phosphorus, particles, suspended solids, sieves.

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Summary

Fiskeriverket's Research Station at Kälarne has been required by the Environmental Protection Unit (Miljövårdsenheten) of the county authorities (Länsstyrelsen Jämtland), to revise its plans and operations so that environmental impacts, primarily due to effluent discharges, are reduced. The project has had the following aims, in order to produce the report required by the authorities: to quantify current TP discharges in order to obtain the most reliable picture of what are known to be highly variable parameters; to recommend a suitable effluent TP reduction strategy; and to predict the likely TP reduction achievable using the proposed waste reduction strategy within sensible practical and economic constraints.

Effluent TP concentrations were found to be low, with a mean of about 19 - 34 µg/L; TDP were 9 - 17 µg/L; and TPP were 5 - 19 µg/L. About 39 % of the TP was in the particulate fraction and thus available for separation. SS concentrations varied within the range 0.5 - 9.5 mg/L, with an average of 2.3 mg/L. On average, 66 % of the volume of the waste particles was larger than 60 µm, 51 % larger than 80 µm, 39 % larger than 100 µm and 25 % larger than 200 µm. The expected regular and substantial diurnal fluctuations in wastewater quality were not found.

The low waste concentrations, high effluent flow rates and small fraction of the TP in the particulate phase indicated that it would be difficult to achieve substantial reductions in waste P levels. A seven stage integrated waste reduction system was suggested for use at Kälarne. Factors such as available facilities, cost and treatment efficiency have been considered. Trials will be required to establish if all 7 stages will be required. The seven stage waste reduction system would include: 1. feed composition adjustments; 2. feeding management up-grading; 3. culture tank collection of wastes; 4. screen separators; 5. sludge sedimentation; 6. sludge stabilisation; and 7. reuse of sludge. In particular, there appears to be a need for a more modern feeding system at Kälarne, that would be expected to drastically reduce feed wastage. This would have three advantages: reduced feed costs, reduced wastes in the wastewater and an improved tank environment.

It should be possible to remove 80 % of the solids from the waste stream using a within-tank separation system incorporating a separate sludge outlet and tank-specific hydrocyclone separators. This corresponds to a 31 % removal of the TP at Kälarne. It is estimated that 66 % of the volume of particles in the wastewater from the tanks may be separated from the main flow using a 60 µm pore size screen. This corresponds to a conservative estimate of TP removal of 44 %. Though conservative, this figure is thought to be more reliable than a previous estimate of 60 %. It should be possible to sediment out 90 % of the solids, and an approximately equivalent proportion of the TP, in the sludge flow from the screen separators.

Substantial reductions in waste nutrient discharge to the recipient should be possible if an integrated reduction strategy, such as that suggested, is adopted. An overall TP removal efficiency of 60 % or more will however probably be difficult to achieve within sensible practical and economic constraints.

List of abbreviations

Table 1: List of abbreviations and terms

Abbreviation	Units	Parameter
Location A	--	Effluent from the A-hall
Location C	--	Control - inlet culture water to the farm
Location P	--	Effluent from the earthen ponds
Location X	--	Effluent from the X-hall
N	--	Nitrogen
P	--	Phosphorus
PSA	--	Particle size analysis / characterisation
Series 1 - K1	--	5 June 1996
Series 2 - K2	--	9-18 September 1996
Series 3 - K3	--	27 January - 4 February 1997
Series 4 - K4	--	14 - 23 April 1997
DO	mg/L	Dissolved oxygen concentration
SS	mg/L	Suspended solids
TDN	mg/L	Total dissolved nitrogen concentration
TN	mg/L	Total nitrogen concentration
TPN	mg/L	Total particulate nitrogen concentration (by calculation: TN-TDN)
TDP	µg/L	Total dissolved phosphorus concentration
TP	µg/L	Total phosphorus concentration
TPP	µg/L	Total particulate phosphorus concentration (by calculation: TP-TDP)

1 Introduction

1.1 Environmental protection

The majority, if not all, Swedish industries discharging into the Gulf of Bothnia and Baltic Sea are required by international agreement to reduce pollution and nutrient loads. Presumably as part of this international plan, Kälarne Research Station has recently been informed, by the Environmental Protection Unit (Miljövårdsenheten) of the county authorities (Länsstyrelsen Jämtland), that it must revise its plans and operations so that environmental impacts, primarily due to effluent discharges, are reduced.

The decision of the authorities (Lindberg, 1996) was to permit a maximum annual production of 30 tonnes fish, subject to the following conditions:

- The facility is to be operated as described in Fiskeriverket's operation application.
- Wastewater from the fish-farm is to be treated prior to discharge into the recipient lake (Ansjöån).
- The treatment efficiency, i.e. reduction in, the *available* total phosphorus (TP) discharged must be at least 60 %.
- A plan for the installation of treatment facilities is to be prepared.
- Nutrient discharges are to be reduced by changes in feed quantity and quality and the evaluation of these changes is to be reported.
- Prior to a final decision, all operations that lead to a discharge of nutrients or that use up dissolved oxygen (DO), are to be performed so that discharges are minimised.
- Feed is to contain as low a concentration of P and as high an energy content as possible, so that the feed coefficient is maintained low.
- Future operation plans, including monitoring protocols are to be presented to the authorities.

1.2 Aims

Whilst no maximum allowable TP concentration or loading was stated, the recommendation of a 60 % reduction in phosphorus discharges is central to the planning of a future effluent reduction strategy for the farm. In order to estimate what TP concentration can be regarded as a 60 % reduction, current TP discharge concentrations must be monitored. So that both suitable remediation strategies and technologies can be suggested, as well as to predict feasible reduction targets, the waste must be characterised in more detail. Whilst many aspects are to be considered and acted upon by the Research Station, this study will examine current phosphorus discharges and the potential for their reduction as described below.

The project will have the following aims, in order to produce the report required by the authorities:

1. Current TP discharges will be quantified. In order to obtain the most reliable picture of what are known to be highly variable parameters, discharge variability with both time and location will be examined.
2. A suitable effluent TP reduction strategy will be recommended. Experience suggests that such a strategy will incorporate more than just end-of-pipe treatment, so an integrated plan will be proposed, based on data gained in the effluent quality survey.
3. The likely TP reduction achievable using the proposed waste reduction strategy will be presented. Of necessity, such reductions will need to be achievable within sensible practical and economic constraints.

1.3 Previous relevant studies at Kälarne

A study of the phosphorus input to the recipient from the farm between July 1992 - June 1993 (Henricson, 1993) estimated that TP values downstream of the farm were typical of Norrland forests and coastal rivers at 8 - 25 µg/l, depending on water flow. This was an increase over background levels of about 2 - 3 times. TP concentration increases were low, but flow rates were high, leading to an annual phosphorus loss to the environment of approximately 300 kg-TP, assuming a fish production of 32 t, feed usage of 39 t and feed coefficient of 1.22. This corresponded to 1650 - 3300 person-equivalents.

Whilst TP loading were lower than the loading capacity of the recipient, as described by (Wiederholm *et al.*, 1983, cited in Henricson, 1993), potential means of reducing TP discharges were discussed. It was concluded that because of the large quantity of water, the large proportion of TP in the dissolved fraction (and as such difficult to treat) and the small size of the particles, that treatment was not a preferred option. Optimisation of feed quantity, i.e. feeding management, and feed quality, were considered more promising means of reducing TP losses to the environment.

As part of its ongoing strategy of reducing P emissions, a study of the potential of filtration technology was commissioned, and conducted by fish-farm equipment consultants Seacool AB (Steiner, 1994). Based on studies by Ulgenes (1992), which indicated that by using a 60 µm pore size Hydrotech drum filter, a reduction of 60 % of the TP discharges was considered feasible. In the unlikely event that the earth ponds were replaced with cleanable tanks, the reduction in wastes was expected to be even greater.

Following these two, and other studies not summarised here as they were not directly related to wastewater discharges, a summary of suggestions for an improved farming environment was prepared (Hanell & Henricson, 1996). Investment recommendation

4 in this report was that a treatment facility for the reduction of P in the form of waste feed and faeces should be installed.

The current study follows up this recommendation and attempts to combine theory, previously published information and new monitoring data, to both document the current situation and plan for future treatment facilities.

2 Materials and methods

2.1 Farm facilities

The Swedish National Board of Fisheries has a Fisheries Experimental Station, which includes a fish-farm and laboratory facilities, at Kälarne (63°00'N, 16°05E), north-west of Sundsvall, 100 km inland in central Sweden (Näslund and Henricson, 1996). The farm is a land-based freshwater facility. A full description of the facility is given by Hanell (1991), see Appendix 1.

Several species and stocks of salmonids are grown at the Kälarne Station. Smaller, first year fish are grown in the X-hall, which contains two hundred 1 m^2 and four 12 m^3 tanks (Bil.3 App.1). Larger 1 - 3 year fish are held in forty-two 4 m^2 and twelve 24 m^2 tanks in the A-hall (Bil.2 App.1). In view of differences in the size of the fish and the food consumed, effluents with different characteristics are expected from the two halls.

2.2 Monitoring

2.2.1 Time

As stated in section 1.2 above, the monitoring programme was conducted in order to quantify current P discharge concentrations. The concentration of waste material (TP, TN and SS) in the wastewater from land-based aquaculture facilities is known to fluctuate considerably as a result of a variety of factors. Shorter term fluctuations in effluent quality arise primarily because of changes in management protocol, for example diurnal fluctuations in feed inputs and weekly (approximately) tank cleaning. Longer term variations arise from changes in the growing stock, e.g. size, appetite, and environmental conditions that effect feeding, food conversion and growth, e.g. temperature and the ambient light regime.

Three sampling regimes were therefore designed to monitor water quality over three different time scales (diurnal, weekly, seasonally), to give the most representative picture of discharge levels possible, given sensible economic constraints on laboratory analysis cost. The regimes were also combined so that the most efficient use of samples was obtained, i.e. some samples from one regime also formed part of another.

Diurnal series

Single samples have been shown to be of limited value in estimating diurnal fluctuations or mean diurnal values. In order to sample throughout a 24 h period, two programmable automatic water samplers (Isco 6700 Portable Samplers) were employed.

The samplers were programmed to collect a defined and repeatable volume of water frequently. Every 10 min, 80 ml of water was collected during a 24 h period. Samples were though integrated over each 4 hour period during the day (4h: 6 h^{-1} x 4 h x 80 ml = 1920 ml). This resulted in the production of six, 4 h integrated samples for later analysis. Such a protocol aimed give a reliable quantification of mean water quality during the integration period and indicate general fluctuations during a day.

Weekly series

Similarly, in order to quantify water quality parameter concentrations on a weekly basis, the two samplers were programmed to collect water during a seven day period, starting the day after the above diurnal series. The samplers were programmed to collect 40 ml water every 30 min. These were integrated over a day, resulting in the production of seven, 24 h integrated samples for later analysis (24 h @ 2 h^{-1} x 40 ml = 1920 ml).

Seasonal series

Daily and the weekly series' were repeated 4 times within the project period. Sampling was spread throughout the year as much a possible, given the constraints of the project reporting deadline, so that representative periods could be covered, as described in Appendix 2:

Series 1 was conducted, as described above (except that no weekly series was taken) in June, during a period when near peak growth was expected. Feed input quantities should have been at about their highest, so that faecal waste levels should be high.

Series 2 was conducted in September to indicate the early autumn situation when growth, appetite and hence waste losses are still as high as that from June - August.

Series 3 was conducted during January/February to indicate the mid-winter situation, with little, if any, growth and very low food inputs.

Series 4 was conducted as late as possible in the project period (April), but to allow sufficient time for the water quality samples to be analysed and the results to be incorporated into the report prior to the reporting deadline.

2.2.2 Location

As stated above, two automatic water samplers were required to monitor concurrently the wastewaters from the A and X halls. These were located in the first accessible points of the effluent flow downstream from each facility. In order to ensure that water from all parts of each building was sampled, the sample points were located outside and hence required some minimal heating and thermal insulation, in the form of two purpose built insulated boxes, during the winter. This helped to prevent freezing water damage to the auto-samplers and prevented the majority of ice blockages in the collection tubing.

Single samples were taken during each series as an extra indication of waste levels from the earthen ponds. In addition, two individual controls were taken from the two separate intakes to the farm, to indicate background levels.

2.2.3 Earthen ponds

Every 10 min, 80 ml of water was collected during a 24 h period. In January and April samples were integrated over a 12 h period (2 x 12 h). Samples were taken downstream of ponds 3 and 4.

2.3 Water quality

2.3.1 Sample protocol

Each sample was handled according to the scheme described in Fig. 1. The number of samples analysed is shown in Table 2.

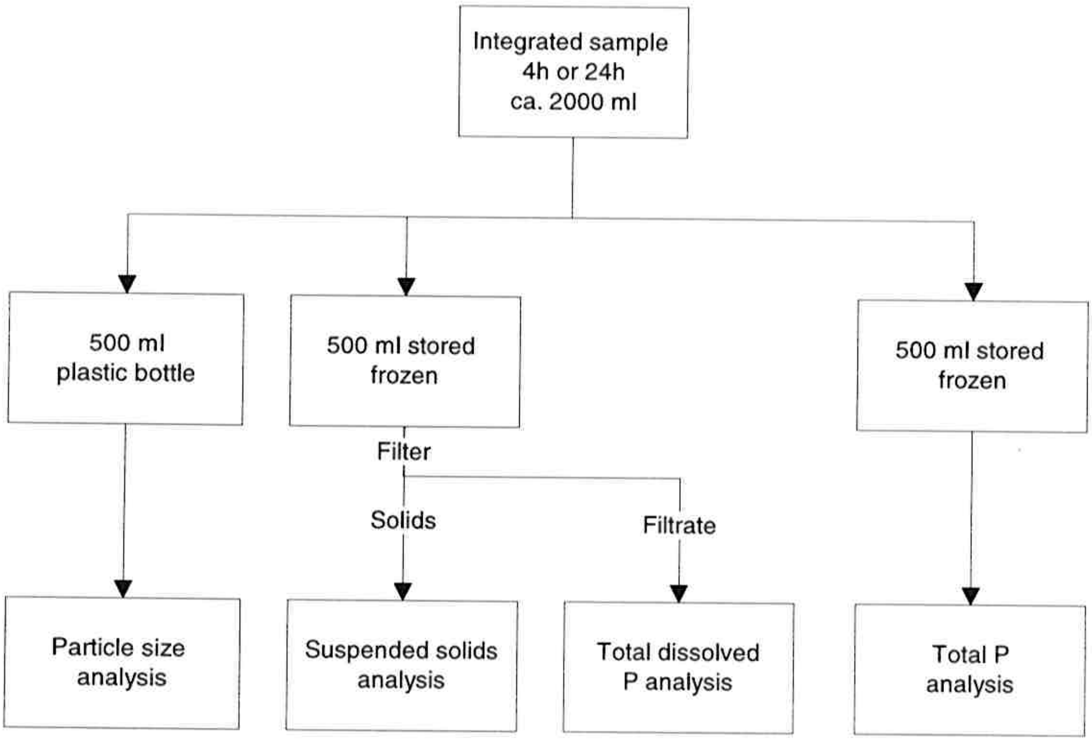

Figure 1: Analytical protocol.

Table 2: Number of samples requiring chemical or physical analysis during the main monitoring programme

Series	Day /	TP				TDP				SS				PSA			
	week	a	x	c	p	a	x	c	p	a	x	c	p	a	x	c	p
June	D	4	4	2	2	4	4	2	2	4	4	2	2	4	4	2	2
	W	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sept.	D	6	6	2	2	6	6	2	2	6	6	2	2	6	6	2	2
	W	7	7	2	-	7	7	2	-	7	7	2	-	7	7	2	-
Jan.	D	6	6	2	2	6	6	2	2	6	6	2	2	6	6	2	2
	W	7	7	2	-	7	7	2	-	7	7	2	-	7	7	2	-
April	D	6	6	2	2	6	6	2	2	6	6	2	2	6	6	2	2
	W	7	7	2	-	7	7	2	-	7	7	2	-	7	7	2	-
Total		43	43	14	8	43	43	14	8	43	43	14	8	43	43	14	8
		108				108				108				108			

a = A hall, x = X hall, p = ponds, c = control

2.3.2 Water quality analyses

TP was analysed according to Swedish Standard Method SS 02 81 27 and TN according to SIS 02 81 31.

Analyses were conducted by personnel at the accredited water quality laboratory of the Aquaculture Department of the Swedish University of Agricultural Sciences (SLU) at Umeå.

2.4 Particle characterisation

2.4.1 Equipment

PSA was conducted on replicates of all samples sent for standard water quality analyses, as described above. All particle characterisation work was conducted at the Rogaland Research operated AqvaMiljø Laboratory in Stavanger, courtesy of Elf Petroleum Norge AS.

The particle size distributions of the samples were analysed using a Coulter® Multisizer II particle analyser. The method utilises the Coulter principle (changes in electrical impedance as a particle passes through an aperture displacing a volume of the carrying electrolyte liquid) to measure particle volume, and from that, estimate individual particle sizes. The analyser was fitted with a 400 μm aperture sample tube which, after calibration using 78.9 μm diameter latex beads suspended in the sample-specific electrolyte solution, produced an analytical range of 8 - 260 μm diameter, divided into 256 size classes.

2.4.2 Sample analysis protocol

All analyses were conducted in the siphon mode so that a constant volume of suspension was analysed throughout. This ensured a consistent method was used, so reducing inter-sample procedural errors. Though a constant volume was known (6 ml), particle concentrations were not calculated because it was the distribution of sizes of the particles that was of interest rather than matter concentrations that were derived separately by SS analysis. The electrolyte was composed of 80 ml sample and 20 ml Isoton solution. The Isoton was added to prevent instrument interference inaccuracies (Cripps, 1993).

Pre-trials were conducted to determine the optimum concentration of particles required to produce a representative count and to avoid coincidence errors caused by multiple particles in a concentrated solution being counted as single large particles. A Coulter coincidence factor of less than 20 % was adopted, as recommended by the manufacturer. No further dilutions of the samples were required, as is usual for other wastewaters such as sewage, because of the low particle concentrations encountered throughout the study.

Great care was taken to ensure that representative sub-samples were analysed, so each sample was well mixed throughout the sampling and analysis procedures. Further, the maximum sample size of 2 ml was analysed and the results from each sample were accumulated 3 times, giving a total sample size of 6 ml. Additionally, all samples were analysed in triplicate or duplicate. Samples were analysed in a random order.

Triplicate controls, comprising farm inlet water, were analysed from each of the four series', to give series-specific background counts. The mean of the relevant control was subtracted from each sample mean number of particles to produce a background subtracted mean sample result. The particle data presented therefore refers only to material added to the effluent resulting from the actions of the farm, and not solids that entered the farm in the inlet water. The protocol is summarised in Figure 2.

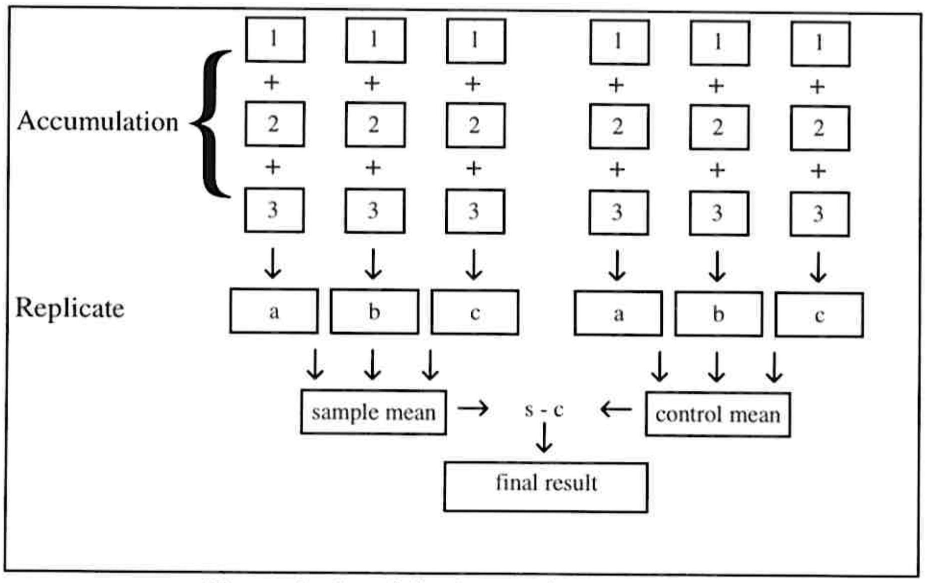

Figure 2: Particle size analysis protocol.

2.4.3 Particle data analysis

The data were analysed using the instrument specific AccuComp software.

Laser or Coulter particle analysis techniques do not directly measure particle weight and so it was not possible to accurately calculate such distributions. The Coulter method primarily counts the number of particles and calculates their individual volumes. Other parameters, such as particle diameter, are calculated from this data. Assuming a relatively constant particle density with size, weight will be proportional to volume. For consistency between the different methods, particle volume was the main parameter examined, though the distribution of the number of particles present within each size range can give a more easily comprehensible picture of the distribution. Results expressed as a percentage of the sample total were used throughout because absolute values varied with overall concentration, which was not the required parameter.

The distributions of replicate mean, background subtracted results within each group (e.g. series 2, A-hall, six 4 h integrated samples) were drawn as a figure and examined for the presence of any obvious trends. In the absence of such trends the distributions within a group were considered similar enough to justify further analysis using the mean distribution of these component distributions (see results section).

The percentage volume of particles larger than 60, 80, 100 and 200 µm diameter within each mean distribution was calculated using the dedicated AccuComp software.

3 Results

3.1 Phosphorus

Figures 3 and 4 (App. 3) indicate the diurnal fluctuations in TP, TDP and TPP in the wastewater from the A and X halls respectively during 4 h integrated periods during which water was sampled every 10 min (30 min during series 1). The greatest concentrations measured were TP: 109, TDP: 55 and TPP: 54 µg/L, though mean levels were far lower at 27, 17 and 11 µg/L in the A-hall and marginally lower at 19, 14 and 5 µg/L respectively from the X-hall. P concentrations in the effluents from both halls were then similar, excluding three high concentration periods, all from the A-hall. There was a tendency to increased P concentrations in the mornings, though this was far from clear, because in many cases fluctuations during a day were small. A greater fraction of the TP was almost always in the dissolved phase than the particulate.

Phosphorus levels from the ponds were fairly stable, fluctuating between the following extremes TP: 9 - 23, TDP: 5 - 15, TPP: 3 - 11 µg/L. These were of a similar magnitude to the P levels in the effluents from the A and X-halls.

Figures 5 and 6 (App. 3) indicate the fluctuations in TP, TDP and TPP in the A and X halls respectively during the 3 sampling weeks where wastewater was integrated over 24 h periods. The greatest concentrations measured were 90, 62 and 59 µg/L respectively, though mean levels were far lower at 19, 9 and 10 µg/L in the A-hall and slightly higher than this at 34, 17 and 19 µg/L from the X-hall. No clear P concentration trends with respect to the days of the week were evident from the A-hall, though considerably greater concentrations occurred around Friday - Saturday, from the X-hall.

The proportion of P in the particulate phase (and hence also the dissolved phase) varied greatly during the study. The average TPP, as a proportion of TP of those values falling within the range 0 - 1.00 from all sample runs and locations within the farm, was 0.39. TPP:TP was not found to vary consistently with time or location.

3.2 Suspended solids

The unadjusted SS concentrations in the effluents from the A and X-halls varied within the range 0.5 - 9.5 mg/L, with an average of 2.3 mg/L. As an indication of the contribution of the farm to the overall SS load in the effluents, the background, inlet concentrations were subtracted from the unadjusted figures, resulting a range of -2.3 - 5.8 mg/L, with a mean of 0.5 mg/L.

Figure 7 (App. 3) indicates the diurnal changes in SS in the A and X-halls. With one exception (the first sample point of the study) SS levels were fairly constant. No pronounced differences in the SS concentrations arising from the A and X-halls were evident. Negative SS values have been shown because they indicate levels originating from the farm that are lower than control, inlet levels.

SS concentrations in the effluents from the earthen ponds were low and varied little between 0.5 - 3.0 mg/L. These concentrations are at the lower end of the range of values from the A and X-halls.

Figure 8 (App. 3) indicates fluctuations in SS during the three survey weeks. Values varied between 0 - 2.0 during the September and January surveys, but varied between approximately 3.0 - 6.0 during the April survey. SS concentrations from the A and X-halls were similar. No trends with respect to the day of the week were evident. No weekly measurements were conducted during survey K1.

3.3 Nitrogen

Figures 9 and 10 (App. 3) show the nitrogen concentrations in the effluents from the A and X-halls during the survey period in April 1997. With one exception (X-hall 14-15 April 1997), TN, TDN and TPN concentrations varied between TN: 0.11 - 0.26, TDN: 0.06 - 0.28, TPN: 0.00 - 0.15 mg/l. Average concentrations were, TN: 0.17, TDN: 0.12, TPN: 0.06 mg/L.

A and X-hall N concentrations were similar. No trends in N concentration or the proportions of TDN and TPN as a proportion of TN was evident with respect to diurnal or week long fluctuations. The TPN:TN ratio varied between 0 - 0.58, with a mean of 0.30.

Mean N concentrations in the effluents from the earthen ponds were TN: 0.12, TDN: 0.11, TPN: 0.04. These were at the lower end of the range of levels of N in the effluents from the A and X-halls.

3.4 Particle characterisation

Variations in particle size distribution of each sample comprising a day or a week run from each sample location were compared and no obvious trends with time were observed (e.g. more larger particles were not seen to be produced during feeding periods or on weekdays). The data was then pooled and an average cumulative distribution for each sampling group was then calculated (Figures 11 - 13, App. 3).

Table 3 summarises the data from these distributions indicating the quantity of particles larger than four particle diameters. These values correspond to common nominal pore sizes of particle separator screens.

Table 3: Numerical summary of the particle size distributions.

Series	Location	Time scale	Proportion of particles larger than given diameter (% of sample total volume)			
			60μm	80μm	100μm	200μm
2	A-hall	24 h	77	69	61	55
2	X-hall	24 h	88	81	75	70
2	A-hall	Week	78	62	46	35
2	X-hall	Week	84	74	64	55
2	Ponds	24 h	67	61	57	42
2	Series mean		79	69	61	51
3	A-hall	24 h	80	70	63	42
3	X-hall	24 h	75	55	35	21
3	A-hall	Week	66	46	32	25
3	X-hall	Week	76	62	51	38
3	Ponds	24 h	64	43	30	20
3	Series mean		59	55	42	29
4	A-hall	24 h	53	41	33	19
4	X-hall	24 h	66	49	32	21
4	A-hall	Week	53	35	23	7
4	X-hall	Week	77	69	58	39
4	Ponds	24 h	81	62	48	37
4	Series mean		66	51	39	25

It appears that the particles in the effluent from the X-hall were usually larger than those from the A-hall. On average the difference amounted to 9.5 % in the proportion of particles larger than 100 μm (A-hall: 43 %; X-hall: 52.5 %). Changes in particle size distribution with time were possible to examine but were outside of the scope of this project.

Figure 14 (App. 3) shows the proportion of particles larger than four different particles sizes, as stated in Table 3. Data refers to particles within the analytical size range of 8 - 260 μm diameter (section 2.4). The larger gradient at the lower end of the particle size range scale indicates that larger increases in removal rate may be achieved for smaller changes in pore size at small pore sizes.

4 Discussion

4.1 Current discharges

4.1.1 Phosphorus

TP concentrations of about 20 - 30 µg/L that were shown to commonly occur during this study (section 3.1) are low compared with published data. In a review of Norwegian land-based farms Bergheim *et al.*, (1991) found average levels of 100 µg/L, which corresponded to the highest concentration measured during the current study. TP levels of up to 150 µg/L in Denmark were described by Warrer-Hansen (1982). In a more modern study, with more modern feed types, Kelly *et al.* (1994) described a mean TP of 51 µg/L, though with great variation between 5 - 1141 µg/L. It should also be noted that many modern, technically advanced farms use oxygen addition into the culture water. This greatly decreases the specific water consumption, the volume of wastewater and therefore increases the concentration of wastes. The efficiency with which such wastes can be treated is also greater than dilute wastes. At Hedens Laxodling in Boden, Cripps (1992) found a mean effluent TP concentration of 110 µg/L. A typical value, calculated from a review of many different published studies of land-based fish farms through out Europe was 125 µg/L (Cripps, 1994). These published values refer to overall levels, whereas the current study refers to the contribution of the farm to the total wasted P. Even allowing for this, levels from the Research Station appear low.

It is generally more difficult to achieve substantial reductions in levels as a result of treatment, when levels are already low. Even simple treatment produces appreciable reductions in the waste from, for example, domestic wastewater, which has TP levels of about 8000 µg/L (Tchobanoglous & Burton, 1991). A 60 % reduction in such low levels of TP would be expected at the outset to be difficult to achieve.

It was expected that there would be marked diurnal fluctuations in P levels as a result of feeding management strategies. Fish are generally fed during daylight hours and sometimes only during normal working hours. Waste feed levels, together with a time lagged input of faeces, commonly build up during the day. Levels then gradually return to an overnight low after feeding has stopped and both the tank system and the guts of the fish have had sufficient time to be flushed. There was no evidence of this occurring at Kälarne.

There are two likely reasons for this. Feeding may be maintained at such a low, yet regular and frequent level, that wastes are flushed out continuously and do not build up in the system. Alternatively, they may accumulate within the tanks or pipe-work, to be flushed out in a large plug so infrequently that a 24 hr survey does not capture them. Casual observations of the tanks and the fact that P values peaked at the end of each week at about the time of manual tank scrubbing and flushing, both indicate that the latter explanation, that of a build of material in the tanks, may be the most likely.

A common range for the proportion of P in the particulate phase is 25 - 70 %. At Hedens Laxodling, a far larger land-based farm in northern Sweden, a mean of only 25 % TPP was found (Cripps, 1992). Foy and Rosell (1991) indicated TPP levels of 30 % of the TP. So, whilst the result in this study, of 40 % TPP, may appear low, it is well within the expected range, and may even be greater than the proportion commonly found.

It is the particulate phase of P that is most susceptible to treatment. Particles can be removed by various mechanical or gravitational means, but the dissolved phase requires the implementation of extensive facilities for secondary biological filtration. Thus, even if a particle removal technique is 100 % efficient, from the outset, only 40 % of the TP will be removed. Factors such as feed characteristics, particle residence times in the water, leaching rates and mechanical agitation are thought to be factors influencing the amount of P in the particulate phase.

4.1.2 Suspended solids and particles

Similarly to the case of P, SS levels were also low at about 0.5 - 6 mg/L. This compares with 9 mg/L at 21 EIFAC farms (Alabaster, 1982), 11 mg/L at 31 UK farms (Solbé, 1982). Also at more modern farms: 3 mg/L was considered typical for Norway (Bergheim et al., 1991) and 2.6 mg/L at a Scottish farm (Kelly *et al.*, 1994). 7 mg/L was found at Boden, which had a high water flow-through rate (Cripps, 1992).

Low waste concentrations may give the impression that there is little chance of polluting the recipient, however the large flows required for the culture of fish, can lead to significant mass flows (concentration x flow rate), which may require attention.

Several of the farm SS values were negative, indicating that the control, inlet concentration was higher than the effluent concentration. Whilst this may indicate analytical or calculation errors, it may also show that the input of solids into the recipient is not greatly different to the particle load that is already there as a result of "natural", or at least non-farm, causes.

As with P, a diurnal variation in effluent SS concentrations was expected, as a result of feeding management, but this was again not evident. SS levels were fairly stable, both within a day and within each individual week. The reasons for the higher levels during the April survey is unclear, unless feeding was greater or more wasteful during that time, which is unlikely.

Particle size distribution analysis can be a useful tool within the field of wastewater treatment. It is a means of quantifying down to individual particles, which is far greater definition than standard solids analysis. A major drawback with the PSA method is that only a restricted size range of particles is analysed. In particular, particles larger than 260 μm diameter were not sampled and measured during this study. Particle distributions will be discussed in sections 4.2 and 4.3.

4.1.3 Nitrogen

Though not the main purpose of this study, as N is not normally a limiting nutrient in freshwater systems, for the sake of completeness a limited survey of N levels was conducted during the last sampling period. TN levels were exceptionally low at 0.17 mg/L as compared with 0.70 mg/L in northern Sweden (Cripps, 1992) and 0.43 - 0.70 mg/L in Norway with oxygen addition (Bergheim *et al.*, 1993).

Only 30 % of the TN was in the particulate phase, also making this a difficult parameter to treat using standard particle separation technology.

4.2 Suitable reduction strategies

4.2.1 Efficiency vs. treatment

Strategies for the reduction in waste in the effluents from land-based fish-farms fall into two categories: feed management and end-of-pipe treatment. Feed management, though largely outside of the scope of this study, is a means of reducing wastage before it occurs. This not only reduces the quantity of wastes requiring treatment, but can be a major cost saving as a result of improved feeding efficiency. End-of-pipe treatment deals with the problem after it occurs and as such is not as advantageous as feeding management. It is though widely used because it is difficult, if not impossible to reduce wastage to levels which would be suitable for direct discharge.

There is no modern type of feeding system at Kälarne. In the X-hall feed to the 200 tanks is controlled by just 4 channels, i.e. groups of 50 tanks have the same control of the time the feeders are activated or are not active. In the A-hall the 12 large tanks are controlled by 2 channels and the 42 small tanks by 4 channels.

There appears therefore to be a great need for a more modern feeding system at Kälarne, that would be expected to drastically reduce feed wastage. This would have three advantages: reduced feed costs, reduced wastes in the wastewater and an improved tank environment.

4.2.2 Commercially available treatment systems

A review of available treatment strategies is presented in Cripps and Kelly (1996). Care should be taken in transferring sewage treatment technology to the aquaculture industry as the characteristics of the wastewater are very different: aquaculture waste is far more dilute and occurs in larger flow rates.

Nutrients such as P and N compounds are known to be associated to varying extents, with the particulate fraction. It is then on this fraction that treatment facilities are focused. The dissolved fraction can be treated by biofiltration using media filters, but this is difficult at flow rates common at flow-through aquaculture facilities.

Four main types of treatment units are commonly used within the aquaculture industry: mechanical, gravitational, chemical and biological. The former two are most common in flow-through systems. Devices suitable for the treatment of aquaculture wastes have been reviewed by Wheaton (1977), Huguenin & Colt (1989), Landau (1992) and Cripps (1994).

Mechanical treatment is becoming more widespread, at the cost of sedimentation devices. A wide range of units are available, with several new models coming onto the market each year. These can be classified into three groups suitable for use in aquaculture: stationary screens, rotary screens and media filters. The latter group may also function as secondary biological filters, though are rarely used at commercial flow-through facilities.

Ulgenes (1992) tested the treatment efficiency of the Hydrotech drum filter for example, fitted with a 60 µm pore size screen. Treatment efficiency varied considerably within the ranges SS (67 - 97 %), TP (21 - 86 %) and TN (4 - 89 %). Efficiency was found to vary proportionally with the waste effluent concentration, indicating the advantages of particulate pre-concentration.

A major problem associated with currently available rotating screens is that they have been designed to stop particles, but not to remove them. The vertical nature of the screens causes large particles to be held within the units until they break down and are carried up onto the screens. Such a system is far from optimal. A band screen, in which even large particles are carried out of the water on a form of conveyor belt set at an angle of about 45^{o} is a good solution to the problem. As this method is relatively new, few independent test results are available from aquaculture facilities.

Sedimentation tanks have traditionally been used to treat the primary effluent from fish-farms. Flows are however usually far too great to allow the efficient functioning of this process. Primary treatment is now usually conducted using some form of screen separator, as described above. Sedimentation is however a valuable technique for treating lower flow rate effluents such as sludge flows, hence it can be used as a stage downstream of a mechanical separator to thicken the backwash water from the screens.

4.2.3 Treatment systems that may be suitable for Kälarne

In section 4.1.1 it was discussed that 40 % of the low TP concentration was in the particulate phase. A greater (60 %) of the TP was therefore obviously in the dissolved fraction. It would then appear advantageous to concentrate treatment effort on this dissolved fraction.

There are two main techniques available for reducing the discharge of TDP: flocculation and bio-filtration. Due to the large flows and low TP concentrations in the study effluent, flocculation using alum, as used in drinking water and sewage treatment, would require large volumes of the chemical and would be prohibitively expensive, as calculated by Cripps (1994).

Biological filtration, on the other hand, requires the use of filter units in which media is contained. This greatly increases the surface area available for bacterial attachment. The effluent water is passed through this media and the bacteria with which it contacts converts the nutrients into forms that are less available to eutrophicating organisms. There are though 3 reasons that bio-filtration is unsuitable at Kälarne: cost, facilities and environment. The cost of filters large enough to produce adequate reductions in nutrient concentrations at such high flow rates would be prohibitive. Similarly, a large land area would be required to house these facilities. Within limits, the efficiency of these filters is dependant upon, amongst various other parameters, temperature. Water temperatures at Kälarne would, for much of the year, not be warm enough to operate the filters efficiently. For these reasons, very few flow-through, land-based farms in Europe, with the exception of some Danish farms, employ biofiltration, without at least some degree of recirculation.

Treatment effort must then be focused on particle removal, as described in the previous section. Currently the most suitable method for fish-farming is screening.

Figures 11 - 13 (App. 3) show the particle size distributions of the effluent. They can also be used to predict the proportion of particles that would be separated above a defined size, e.g. if 70 % of the particles were larger than 80 µm diameter, then if a treatment technique (e.g. a screen) could remove all particles larger than 80 µm, then 30 % of the particles would be expected to remain. In practice, no commercially available system is so selective, and the particle size range analysed did not cover the whole range of particles present. The particle analysis results do however give some indication of likely treatment efficiency within broad, but un-quantified limits. It should be noted that a major problem associated with rotating screens is that the majority of current designs are unable to pick-up and collect large particles. These will therefore break down in the unit before they can be lifted onto the screen and removed. The limited analytical range may then therefore not be as inaccurate as first thought.

Figures 11 - 13 (App. 3), Table 1 and Figure 14 all show that at sizes (strictly speaking particle diameter, but as explained above also screen pore diameter) there were relatively few particles larger than 100 µm, so for a large change in treatment effort from a pore size of 200 µm down to 100 µm, little change in treatment efficiency could be expected. At size ranges smaller than 100 µm there were relatively more particles available for separation. Figure 14 shows a fairly constant gradient in size frequency from 100 µm down to the minimum particle diameter defined on the graph of 60 µm.

This size was chosen because it corresponds to the minimum pore size of a screen that is suitable for treating fish-farm effluents. Smaller pore size screens down to about 20 µm are possible, but these are used to treat the part of the influent requiring especially high quality water, e.g. the removal of parasites from hatchery inlets. It would be difficult to pass the large flows of water emanating from the Kälarne Research Station through screens with a pore size smaller than about 60 µm, because of the resulting back-pressure that would build up, or the large number (and therefore expense) of treatment units that would be required in order to achieve a sufficient flow capacity.

Particles need to be removed quickly and efficiently before they become broken down into smaller particles that may escape the screens, or have greater leaching rates as a result of their larger surface area to volume ratio. Disk screens are designed to hold back particles, not to separate and collect them. Large waste food and faecal particles are not collected until they have broken down to particles that are small enough to be lifted out of the effluent stream on the surface of the vertical screen. This is not optimal. Drum screens may be marginally better, but are also far from optimal. A band screen system that gentle lifts up the particles on a form of conveyor belt, would appear more suitable (e.g. Sobye). As the system is newly applied to the fish-farming industry, independent efficiency estimates have yet to be published, though it appears to function well (Bergheim, pers. comm., 1997). Should this system be unavailable, then drum screens, such as those manufactured by Hydrotech, may be suitable.

The pore size of the unit should be 60 µm, as a compromise between as small a pore size as possible to separate the majority of particles, and the need to maintain a workable back-head of pressure.

4.2.4 Tank design and management at Kälarne

The new generation of waste management systems are removing the particles from the water as soon as possible. This reduces the chances of breakdown and leaching. To remove the particles quickly they operate within, and immediately downstream of, the culture tanks themselves. Waste food particles and faeces settle to the bottom and are carried by carefully controlled tank hydrodynamics, to the centre-bottom of the tank. Here they are removed by a separate "sludge" flow that is commonly less than 0.1 % of the main flow. This sludge flow has a much higher SS content and lower flow rate, and so is much easier to treat. The treatment effort can be thought of as being targeted more efficiently on just that part of the effluent that requires treatment. The main flow is discharged to the recipient without further treatment.

The sludge flow can be passed through a small hydrocyclone system attached to each tank outlet (the AquaOptima system). This uses enhanced gravitational forces to efficiently separate out the particles, that can then be sent to sludge treatment. Alternatively, the small sludge flow could be passed to a series of settling ponds (as used by Hedens Laxodling) for thickening.

Whilst such tank-based techniques are undoubtedly advantageous, their applicability to Kälarne is doubtful. Both the A and X-halls have a large number of tanks. Replacement of all of them would be economically prohibitive. It may though be possible to adapt the larger tanks by the installation of within-tank separation plates, separate sludge outlets and secondary thickening devices. Such tank upgrade kits are now available from AquaOptima.

It should be noted that such a system, though expensive, has also proved to be useful in monitoring and restricting feed losses.

A more feasible solution to the management of the large number of tanks at Kälarne may be a small change in their design and management. Often even simple adaptations to the inlets and outlet of a tank can greatly improve its self-cleaning characteristics. A vertically mounted inlet pipe at the tank wall, with several holes drilled in it, and the inlet flow directed tangentially within the tank, can greatly improve the tank hydrodynamics (Tvinnereim, 1990).

4.2.5 Sludge thickening

It is often forgotten that once the wastewater has been 'treated', the separated solids will either need further treatment or will need to be disposed of. Few systems for the handling of sludge wastes in aquaculture are commercially available. Bergheim *et al.* (1997) described a system developed for Hydrotech Filter Systems in which sludge from a rotating sieve is settled in a sedimentation tank. The resulting thickened sludge is intermittently drained from the cone bottom of the tank and mixed with lime in a stabilisation tank. The lime stabilised the pH at 12 and thus prevented odours resulting from putrefaction, and killed pathogenic bacteria. The resulting thickened, stabilised sludge was then mixed with agricultural manure in a silage tank and spread on farmland as a high quality fertiliser.

It may be possible to use one of the unused extensive ponds at Kälarne to dry and store the stabilised sludge. Fish-farm sludge is usually free of harmful chemicals and other contaminants and is therefore a valuable source of plant nutrition. Assuming the flow from sludge settling facilities is not large, which it should not be, there should be no direct outflow from the earth pond into the neighbouring river.

Geographic and topographic limitations will probably result in the need for two separate primary treatment facilities: one for each hall. The small sludge flows involved, should enable the flows to be combined into one sludge treatment facility.

4.2.6 A suggested system

A combination of several systems is possible. The following recommended system however appears to have the components that are likely to give the best result. Factors such as available facilities, cost and efficiency have been considered. The system has 7 integrated stages. Each stage can be thought of as preparing the waste material for the next stage to operate as efficiently as possible. Trials will nevertheless be required to establish if all seven stages are required at one site. This is because one stage (e.g. hydrocyclone separation) may perform so well that further benefits from following stages (e.g. screen separation) may not justify the costs of implementation.

1. Feed composition. Low P feed should be used as much as possible.

2. Feeding management. Feed wastage can be reduced before it occurs by introducing independently programmable auto feeders in which both the quantity of food fed and the frequency of feeding is adjustable for each tank. Such systems are not though cheap.

3a. Tank flows. Fast removal of wastes should be attempted by altering the hydrodynamics in the culture tanks primarily by adjusting the inflow geometry.

3b. Tank outlets. If funds are available the possibility of installing AquaOptima's separate particle outlet and hydrocyclone system should be investigated.

4. The effluents from the two halls should be passed through a band screen separator (e.g. Sobye filter) with a 60 µm pore size filter screen. Alternatively, if this system is unavailable, a Hydrotech drum screen, though not optimal, may be the best that is commercially available.

5. The sludge flow from the screens should be passed to some form of sedimentation facility, possibly composed of an unused fish culture tank. The efficiency of this would though need to be tested.

6. The thickened sludge can then be intermittently drained off manually (frequency dependant on accumulation rate), mixed with lime and allowed to dry or freeze-dry in one of the Station's unused earth ponds.

7. Annually the sludge stabilisation pond can be dug up and the contents spread on agricultural or forestry land. It is not currently known if this stage will be necessary because there will be a natural breakdown of nutrients within the pond.

4.3 Predicted discharge reductions

4.3.1 Predicting discharges

It is well known in the sewage treatment field that efficiency estimates are notoriously difficult to predict. This is because of the site-specific characteristics of the wastewater and the many environmental conditions that can effect the functioning of the treatment technology employed. This study has however been able to characterise in some detail the characteristics of the effluent from the Research Station, so some tentative predictions can be proposed. It should however be stressed that no literature has been identified in which a verified prediction method has been proposed. This report may be the first attempt at such a task, using the characteristics of the water to be treated. It would be a valuable service to the fish-farming industry and environmental authorities, to follow up this study with a measurement of the treatment efficiency achieved and thus either verify the prediction model or indicate the inadequacies of the method.

4.3.2 TP removal at the feed and feeding management stages (1 & 2)

Such a quantitative prediction is outside of the scope of this project, but it is clear that reductions in wastage at this stage are particularly valuable because they not only reduce the amount of material requiring treatment at a later stage, but can also increase farm economic efficiency. Modern feeds, since about 1989, have reduced P and N contents so that they more closely match the requirements of the fish. Excess nutrients, added for the sake of safety, have been greatly reduced, leading to pronounced reductions in waste nutrients excreted by the fish. The stability of the nutrients in the feed are also marketed by the feed companies as being greater. If this is the case, then leaching from pellets would be expected to be less than from older types of feed.

The use of a feeding system that delivers only the quantity of food required by the fish, at the times they require it, will also reduce nutrient losses resulting from uneaten feed. Advanced feeding systems with some form of either manual or automatic monitoring and feedback system can reduce losses at this stage to under 1 %. The hydrocyclone system, constructed using transparent plastic, at the outlet of each tank, as developed by AquaOptima, is one such system that allows feed losses to be monitored and acted upon.

4.3.3 TP removal at the culture tank stage (3)

Rapid removal of waste material in the tanks should lead to a reduction in the quantity of nutrients that leach from the treatable particulate fraction into the dissolved fraction. No quantitative estimates of the extent of this process have been located, so removal efficiency estimates of this stage cannot be reliably made.

The efficiency of the Eco-trap system (developed by Sintef and marketed by AquaOptima) have been investigated by Twarowska *et al.* (1997). They found that a mean removal of 80 % +/- 15.8 % of the solids was possible.

TP removal = solids removal efficiency x fraction of TP in the solids

TP removal = 0.80 x 0.39 = 0.312 = 31 %

Such a method, with a large solids removal efficiency could therefore form an important part of an integrated treatment system as well as improving the culture conditions within the tanks.

4.3.4 TP removal at 60 µm pore size screen separation stage (4):

The efficiency with which particle screens can remove P can be roughly estimated knowing the proportion of particles larger than the screen pore size (66 %), the proportion of TP in the particulate fraction (39 %) and the proportion of the TDP that may be removed (25 - 50 % (Bergheim *et al.*, 1993))

66 % = study mean volume of particles larger than 60 µm

0.66 = theoretical particle treatment efficiency $= \varepsilon_p$

0.30 = proposed representative TDP treatment efficiency $= \varepsilon_d$

TP_{mean} = 19 - 34 µg/L

TP_{max} = 109 µg/L

TPP:TP = 0.39 $= \gamma_p$ TDP:TP = 0.61 $= \gamma_d$

ε_e = estimated treatment efficiency $= (\gamma_p \times \varepsilon_p) + (\gamma_d \times \varepsilon_d)$

$= (0.39 \times 0.66) + (0.61 \times 0.30)$

$= 0.26 + 0.18 = 0.44$

$PrTP_{mean}$ = predicted TP_{mean} $= TP_{mean} - (TP_{mean} \times \varepsilon_e)$

$= 19 - (19 \times 0.44)$ = 11 µg/L

$= 34 - (34 \times 0.44)$ = 19 µg/L

$PrTP_{max}$ = predicted TP_{max} $= 109 - (109 \times 0.44)$ = 61 µg/L

TP concentrations after screening would then be expected to be about 11 - 19 µg/L on average, with peak values of around 61 µg/L, i.e. only about a net 44 % reduction.

The 25 - 50 % removal rate for TDP (or soluble reactive phosphorus as used by Bergheim et al. (1993)) was thought to be due to adsorption processes from the dissolved phase onto the particles. It is also known that, as a result of a mat of material building up on the screen, particles smaller than the pore size are retained. Particles larger than about 260 μm in diameter have also not been quantified using the particle size characterisation technique described. It is then likely that the actual treatment efficiency will be greater than the very conservative figure of 44 %. There is though no reliable empirical method of predicting the final treatment efficiency. Only trials using the treatment equipment can give reliable estimates of efficiencies. The Unik screen treatment unit currently located in the T-hall may prove a useful validation method.

4.3.5 TP removal at the sludge sedimentation stage (5)

Bergheim *et al.* (1997) have shown that a realistic aim for solids removal efficiency in the sludge sedimentation system should be in excess of 90 %. Such a high efficiency can be achieved because the overflow rate (the volume of sludge water passing through the tank as a factor of the tank surface area) is low. Only a small fraction of the main wastewater flow is present in the backwash sludge water from the screens. It is at these low flow rates that sedimentation systems function best.

Almost all the TP in the sludge flow will be bound to the particles as it is only these that are separated from the farm wastewater. Only a negligible fraction of the TP may be present as TDP. It is therefore likely that TP removal will be similar to that of SS removal, at around 90 %.

4.3.6 TP removal at the sludge stabilisation and drying stage (6 & 7)

Assuming that the sludge is adequately thickened at the sedimentation stage the quantity of material produced should not be great. Bergheim *et al.* (1997) reported winter and summer sludge production quantities of 80 - 400 L/day respectively from a large Norwegian hatchery producing 1.5 M smolt: considerably in excess of the size of the Kälarne Research Station. With such low flows, transferred into a large empty pond, there should be negligible leaching of nutrients into the recipient water body.

5 Conclusions

5.1 Aim 1: Discharge quantification

1. Effluent TP concentrations were low with a mean of about 19 - 34 μg/L; TDP were 9 - 17 μg/L; and TPP were 5 - 19 μg/L.

2. Short-term peak TP, TDP and TPP concentrations encountered during the study were 109, 62 and 59 μg/L respectively.

3. About 39 % of the TP was in the particulate fraction and thus available for separation.

4. SS concentrations varied within the range 0.5 - 9.5 mg/L, with an average of 2.3 mg/L.

5. Mean TN, TDN and TPN concentrations were low at 0.17, 0.12 and 0.06 mg/L.

6. On average, 66 % of the volume of the waste particles were larger than 60 µm, 51 % larger than 80 µm, 39 % larger than 100 µm and 25 % larger than 200 µm.

7. Regular and substantial diurnal fluctuations in wastewater quality were not determined other than a tendency towards increased P levels each Friday / Saturday.

5.2 Aim 2: Suitable reduction strategy

8. The low waste concentrations, high effluent flow rates and small fraction of the TP in the particulate phase indicates that it is difficult to achieve substantial reductions in waste P levels.

9. There appears to be a need for a more modern feeding system at Kälarne, that would be expected to drastically reduce feed wastage. This would have three advantages: reduced feed costs, reduced wastes in the wastewater and an improved tank environment.

10. A seven stage integrated waste reduction system is suggested for use at Kälarne. Factors such as available facilities, cost and treatment efficiency have been considered. Trials will be required to establish if all 7 stages will be required.

11. The seven stage waste reduction system includes: 1. feed composition adjustments; 2. feeding management up grading; 3. tank collection of wastes; 4. screen separators; 5. sludge sedimentation; 6. sludge stabilisation; and 7. reuse of sludge.

5.3 Aim 3: Predicted TP reduction efficiency

12. It has been stated that it is possible to remove 80 % of the solids from the waste stream using a within-tank separation system incorporating a separate sludge outlet and tank-specific hydrocyclone separators. This corresponds to a 31 % removal of the TP at Kälarne.

13. It is tentatively estimated that 66 % of the volume of particles in the wastewater from the tanks may be separated from the main flow using a 60 µm pore size screen. This corresponds to a conservative estimate of TP removal of 44 %. Though conservative, this figure is thought to be more realistic than a previous estimate of 60 %.

14. On average, this equates with a TP removal that would produce a mean of 11 - 19 µg/L and a maximum of 61 µg/L at Kälarne.

15. It should be possible to sediment out 90 % of the solids and an approximately equivalent proportion of the TP in the sludge flow from the screen separators.

16. Negligible nutrient losses are expected at the sludge stabilisation, storage and drying stages.

17.Substantial reductions in waste nutrient discharge to the recipient should be possible if an integrated reduction strategy, such as that suggested, is adopted. An overall efficiency of TP removal of 60 % or more will however probably be difficult to achieve within sensible practical and economic constraints.

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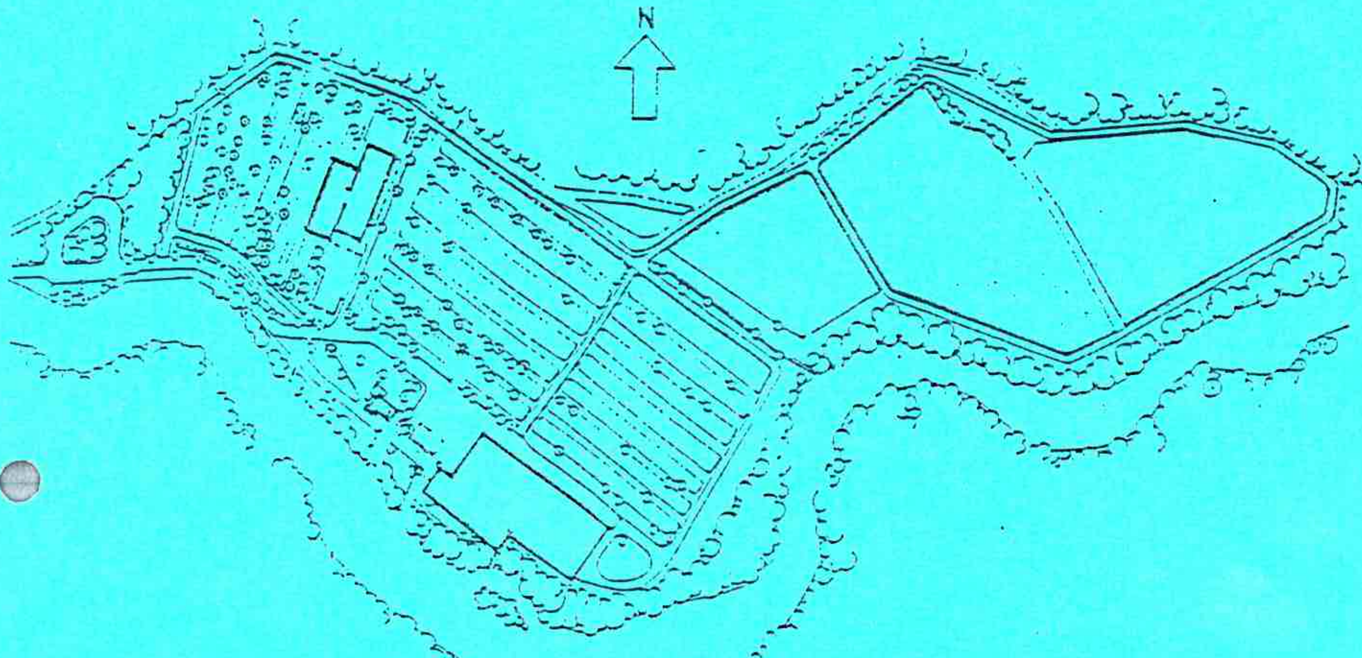
Appendix 1: Site description

FISKERIVERKET
Försöksstationen Kälarne

ANLÄGGNINGSBESKRIVNING



1991-12-16

Lars Hanell

ORIENTERING

Fiskodlingen vid Kälarneanläggningen startades redan 1909 av Jämtlands Fiskodlings AB. År 1931 köpte Lantbruksstyrelsen odlingen efter att under en period på 1920-talet ha arrenderat densamma. När Fiskeristyrelsen inrättades år 1948 övertogs driften vid anläggningen av styrelsen.
Fram till början på 1960-talet bedrevs uppfödningen i huvudsak i jorddammar och anläggningen försörjdes med vatten från Ansjöån via ett ca 200 m långt dike utan nämnvärd fallskillnad. Under 1960 talet påbörjades tråguppfödning av framförallt ensomrig fisk och behovet av bättre tryck på tilloppsvattnet ökade. I mitten av 1970-talet anlades därför en ca 850 m lång tub från Ansjön. Genom denna åtgärd hoppades man också kunna förbättra vattenkvaliteten och styra vattentemperaturen.
Under åren 1981-1983 genomfördes en omfattande till- och ombyggnad av stationen i vilken ingick bl.a. nybyggnad av två odlingshallar. Odlingen har under senare år dessutom kompleterats med en kontorsdel (1988) och hall för bl.a. uppvärmning av vatten (1991).

MÅLSÄTTNING

Vid Fiskeriverkets försöksstation i Kälarne bedrivs försök och undersökningar på fiskodlingens och fiskevårdens område.
Anläggningen står också, i mån av resurser och mot kostnadstäckning, öppen för försök från externa institutioner. Försöksstationen utgör i det sammanhanget en nationell resurs.
Vid försöksstationen skall ett långsiktigt målforsknings- och utvecklingsarbete bedrivas, som kan ge svar på väsentliga frågor för fiskevårdsarbetet och fiskodlingen i Norrland.
Den övergripande målsättningen för den biologiska försöksverksamheten kan sammanfattas under rubriken "Egenskapskartering av arter och stammar". Egenskapskarteringen syftar till att genetiskt och ekologiskt karakterisera olika arter och stammar av laxartad fisk framför allt från Norrland. Syftet är att höja kvaliteten på sättfisk som används inom fiskevård och konsumtionsodling. Målet är att nå fram till en produktion av kvalitetsdeklarerad fisk, dvs en produkt som är känd vad beträffar genetiskt ursprung, odlingshistoria, miljökrav och prestanda. Genom kontrollerade utsättningar av fisk i sjöar och rinnande vatten ökas kunskapsunderlaget för fiskevårdsarbetet.

Ett annat viktigt område för försöksstationen är att utarbeta program för avelsarbete vid fiskodling, baserade på modern populationsgenetisk kunskap. Avelsarbetet bedrivs med olika metoder beroende på om målet för verksamheten är bevarande, nyintroduktion, förstärkningsutsättning eller konsumtionsodling.
Frågor om odlingsteknik och metodik står också på programmet.
Försöksstationen skall kunna bistå med information, rådgivning och utbildning inom tillämpad fiskodling och fiskevård.

1. BYGGNADER

Anläggningen har fyra byggnader (se situationsplan bil. 1).

1. Huvudbyggnad (A-hall)
2. Tråghall för experimentell odling (X-hall)
3. Hall för uppvärmning av vatten (T-hall)
4. Personalutrymme med smittskyddskläckeri (Röda stugan)

1.1 HUVUDBYGGNAD (A-hall)

Omfattar kontor, seminarierum, laboratorier, förråd, verkstad, kylrum, foderrum, uppfödningshall, yngelhall, kläckeri, märkrum, vattenberedningsrum med reservkraftaggregat samt avelshall (bil. 2)

1.2 TRÅGHALL FÖR EXPERIMENTELL ODLING (X-hall)

Innehållande 200 st 1 m^2 tråg, mindre kontorsutrymme, foderrum samt märkrum (bil. 3).

1.3 HALL FÖR UPPVÄRMNING AV VATTEN (T-hall)

Innehållande 4 st 12 m^2 betongbassänger, experimentrum; hjulfilter för rening av till- och avloppsvatten, värmeväxlare, vattenluftare syrgasgenerator, pumpar för vattenförsörjning och värmeväxling; datoriserat styr- och övervakningssystem för vatten, syrgas och temperatur; uppvärmningsanläggning med oljepanna samt ljusstyrningssystem (bil. 4).

1.4 PERSONALUTRYMME MED KLÄCKERI (Röda stugan)

Omfattar 2 övernattningsrum i övre plan, kombinerat kök och matplats, vardagsrum samt tork och tvättutrymme med bastu i nedre plan. I källaren finns ett kläckeri (smittskyddsenhet) med utrustning för behandling av avloppsvatten. Kläckeriet består av 20 st kläckskåp med vardera 10 st kläckbackar. I kläckeriet finns dessutom en elpanna för uppvärmning av personalutrymmen och vatten för romavdelning.

2. PRODUKTION

Produktionsplan och åläggande enligt dom saknas och produktionsnivån bestäms från år till år beroende på försöksinriktning. Stationens totala odlingskapacitet uppgår till ca 32 ton fisk och 5 miljoner ögonpunktad rom. Ungefär 50% av odlingsutrymmet utnyttjas för hållande av avelsfisk varför den årliga försöks- och sättfiskproduktionen uppgår till endast 15-20 ton.

3. VATTENFÖRSÖRJNING

I dom av den 27 dec 1971 (A15/71) medgavs fiskeriförsöksstationen rätt att från Ansjön via tub avleda maximalt 500 l vatten/s. I två senare behandlade mål Va 5/80 och Va 12/82 fick sökanden rätt att i Ansjöns utlopp renovera en Kälarnesågen tillhörig damm, samt att reglera Ansjöns vattenyta mellan höjderna 288.10 m och 287,50 m. Den ca 850 m långa tuben har en diameter på 90 cm och ger vid full dämningshöjd ca 500 l/s. När vattenytan är i nivå med sänkningsgränsen minskar flödet genom tuben till ca 400 l/s. Vid full dämning uppnås fallhöjden 4,10 m mellan Ansjön och A-hallens golvplan. I omedelbar anslutning till Ansjön finns en regleringsbrunn i vilken tuben mynnar. Till denna kan vatten ledas in antingen från en drygt 300 m lång ledning belägen på 10 m djup i Ansjön eller via ett ytvattenintag (3-4 m)beläget ca 100 m från sjöns strand. Vattnet i tuben leds till ett vid stationen beläget vattentorn. Från detta kan vattnet via reglerventiler fördelas ut till de olika odlingsenheterna. Förbrukningen i enheterna varierar med årstid och odlingsinriktning. I bilaga 5 redovisas den generella vattenförbrukningen i varje enhet.

3.1 VATTENKVALITÉ

Under extremt varma somrar kan temperaturen i Ansjöns ytvatten överstiga 20 °C. Genom reglering via botten- eller ytintag kan temperaturen i viss mån styras. Under vinterhalvåret sker tappningen i allmänhet via bottenintag vilket möjliggör en temperatur på 1,0-3,0 °C. I bilaga 6 redovisas medeltemperaturen på inkommande sjövatten för åren 1982-1986, samt år 1991.

pH-värdet ligger med små variationer vid 7,0. Från 1990-10-30 finns följande analysvärden på vatten uppströms tubintag. Färg PT, 25 mg/l; Turbiditet, FTU, 0,30; COD mn 6 mg/l; totalkväve 185 mg/l; totalfosfor 14 mg/l.

3.2 FILTRERING

Vattnet från Ansjön är förhållandevis fritt från grumlande partiklar under hela året och vattnet kräver därför ingen rening. Under vissa år har stationen besvärats av höga angrepp av larver av cestoden Triaenophorus på framförallt ensomrig och ettårig fisk. I samband med nybyggnad av T-hall installerades därför ett s.k hjulfilter, typ Unik, för filtrering av inkommande vatten till X- och T-hall.

Filtret har vid duktätheten 120 my en kapacitet på ca 6000 l/min. Filtret är i drift under perioden maj-september då risken för inströmning av infekterade copepoder bedöms som störst.

Före avloppsvärmeväxlarna finns ett filter för att rena uppvärmt returvatten från X- och T-hall. Filtret är av samma typ som ovan men med något lägre genomrinningskapacitet, 2000 l/min, vid duktätheten 150 my.

3.3 LUFTNING

Luftning av vatten förekommer endast under uppvärmd period. Luftare av Inkatyp finns i A-hall och smittskyddsenhet för avluftning av vatten till yngelhall och kläckerier. I T-hall finns två luftare av genomrinningstyp.

3.4 SYRGAS

Vid stationen finns en gemensam syrgasgenerator för T- och X-hall samt en syrgasgenerator för A-hallens yngelavdelning och kläckeri. Till förstnämnda generator är kopplat 6 st syrgasinlösare som reglerar syreinlösningen vid 6 oberoende temperaturer. Syreförsörjningen till A-hallens yngelavdelning och kläckeri sker via gemensam syreinlösare. Reservsyrebatteri, som automatiskt kopplas in vid för låg syrenivå är anslutna till båda syrgasalstrarnas tryckkärl. I T-hall och X-hallen är reservsyret kopplat till larm och övervakningssystemet.

3.5 VÄRMEVÄXLING

Värmeväxlingen i T- och X-hall sker i två steg.
För återvinning av energi ur uppvärmt avloppsvatten finns två växlare typ Alfa Laval A15-BFM. Dessa har var för sig en kapacitet motsvarande normalt driftflöde från X-hallen (1200 l/min). För rengöring (bakspolning) av den växlare som ej är i drift finns en högtryckspump som kan kombineras med spolning av uppvärmd eller kall lutlösning. Energiåtervinningen beräknas uppgå till 70-75%.
Från avloppsväxlarna leds det förvärmda tilloppsvattnet till två växlare (steg 2) där vattentemperaturen höjs till förutbestämd nivå. Energin till dessa växlare erhålles från en oljepanna.

3.6 TILLOPP OCH AVLOPP

Tillflödet till jorddammarna sker via öppna diken och utflödet genom munkavlopp. Vattnet genomrinner två efter varandra liggande dammar (bil. 1).
Vattenförsörjningen till A-hallens betongtråg och plastråg sker via öppna rännor. I betongtrågen regleras utflödet via avlopp av munktyp och i plastrågen med avlopp av teleskoptyp. I X-hallen sker tillflödet via rör, kallvattenflödet genom självtryck och varmvattentillförseln med pumptryck. Avloppen är centrumplacerade, med utanförliggande reglerventil som medger individuell reglering av kall- eller varmvattenflödet. Kallvattnet avbördas via öppna rännor och varmvattnet genom rör, som står i förbindelse med T-hallens värmeåtervinning.

3.7 ALARMANORDNINGAR

Inom anläggningen finns två typer av larmövervakning. A-larmet går via en larmpanel till LAC i Östersund som i sin tur ringer upp personalen enligt uppgjord telefonlista. B-larmet bevakas internt. Vattnet går sommartid via självtryck ut till de olika odlingsenheterna och saknar larmövervakning. Under vinterperioden, då delar av driften upprätthålls genom uppvärmning, luftning, filtrering och vattennivåreglering, är driften kopplad till larmsystemet. Till detta är knutet ett antal automatiska säkerhetssystem. Vid anläggningen finns bl.a. ett dieseldrivet elaggregat på 90 KW. Vid strömbortfall tar detta med ca 10 s varsel över favoriserade funktioner. På tilloppssidan finns 3 pumpar varav 2 st automatiskt ersätter varandra vid ev pumphaveri.
I X- och T-hallens tråg finns separata tilloppsrör för kallt och varmt vatten. Under varmvattendrift står kallvattenkranarna av säkerhetsskäl alltid öppna. Som en sista säkerhetsåtgärd släpps med viss inprogramerad fördröjning kallvatten in i trågen med sälvtryck. Styrningen av reglerventiler sker i detta fall via syrgastryck.

4. ODLINGSUTRYMMEN

För intensivuppfödning finns följande tråg och dammar :
220 st plasttråg á 1 m^2, 36 st plasttråg á 4 m^2, 2 st plasttråg á 16 m^2, 12 st betongtråg á 25 m^2, 4 st betongtråg á 12 m^2, 10 st betongtråg (avelsbassänger) á 7,5 m^2, 12 st jorddammar á 600 m^2, 6 st jorddammar (sommardammar) á 180 m^2.
För extensiv uppfödning finns 3 st jorddammar á totalt ca 2 ha.

5. KRAMNING OCH ROMINLÄGGNING

Kramningen sker i särskilt rum i anslutning till avelshallen. Målsättningen vid allt avelsarbete som inte omfattas av speciella försök är att söka bibehålla genetisk bredd. Varje hona befruktas därför med en slumpmässigt vald hane. Antalet föräldrar hålls högt, helst minst 25 st av vardera könet.Efter svällning och sköljning slås rommen från alla honor ihop och sammanblandas före inläggning i kläckeri. Inläggningsmängden beräknas med hjälp av Brofeldts skala. Vid uppmätning av besättningar och vid romförsäljning användes romräkningsbricka.

5.1 KLÄCKNINGSANORDNINGAR

I A-hallens kläckeri finns 8 st kläcningsstativ, typ EWOS 2003, uppbyggda i 5 våningar med vardera 40 kläckbackar. Totalt omfattar kläckeriet 320 rominläggningsenheter.
I smittskyddsenheten finns 20 st kläckskåp, med vardera 10 st kläckbackar. Totalt 200 kläckbackar.

5.2 APPARATUR FÖR PLOCKNING

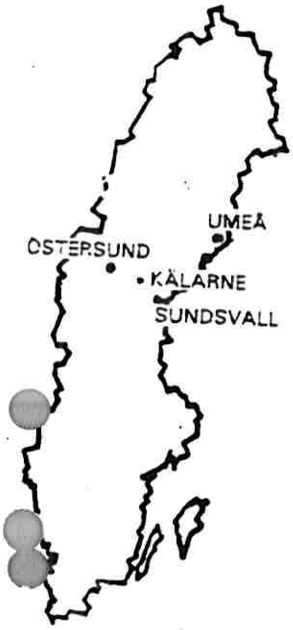
All grovplockning av ögonpunktad rom sker med romplockningsmaskin AD Vinter, typ WB8. Efterplockning sker med hävert och pincett.

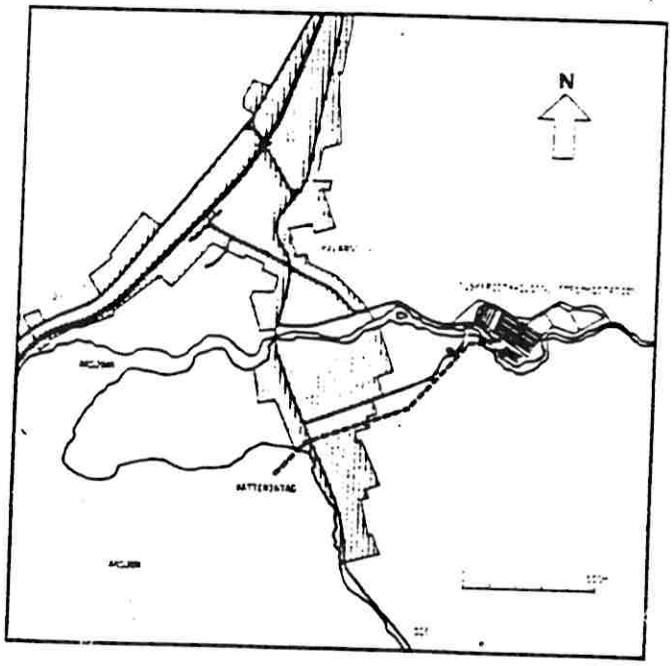
6. FODER - UTFODRING

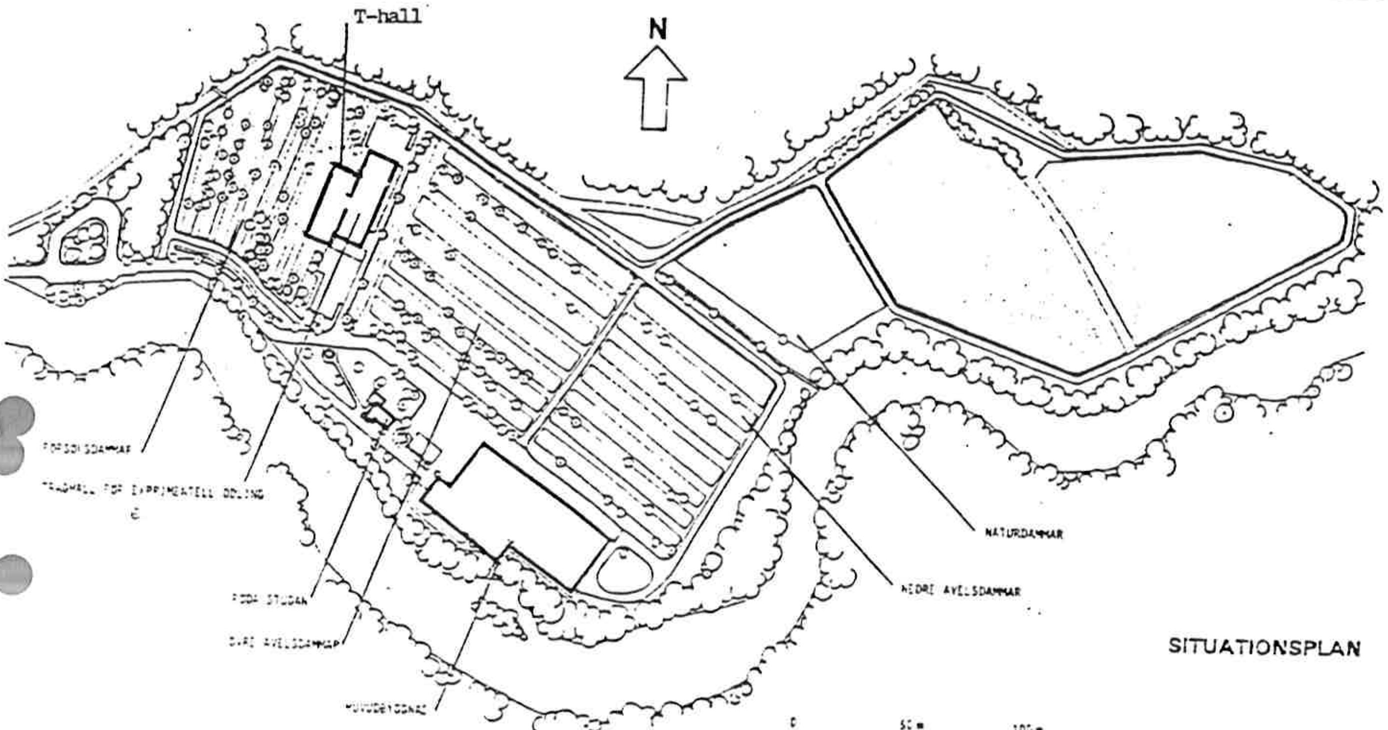
Endast torrfoder används. Utfodring i samtliga tråg sker med olika typer av EWOS automater. Utfodringen styrs med EWOS fyrkanaliga centraler, typ multi 2. I jorddammarna används Spinny foderslungor med separata styrcentraler.

7. TRANSPORTER

Interna transporter sker i transporttankar av varierande storlek. För att underlätta lastning av mindre fisk (<0.5 kg) vid transporter mellan dammar och övriga odlingsenheter användes fiskpump av modell Dati.
Externa transporter sker i huvudsak med hyrda transportmedel.

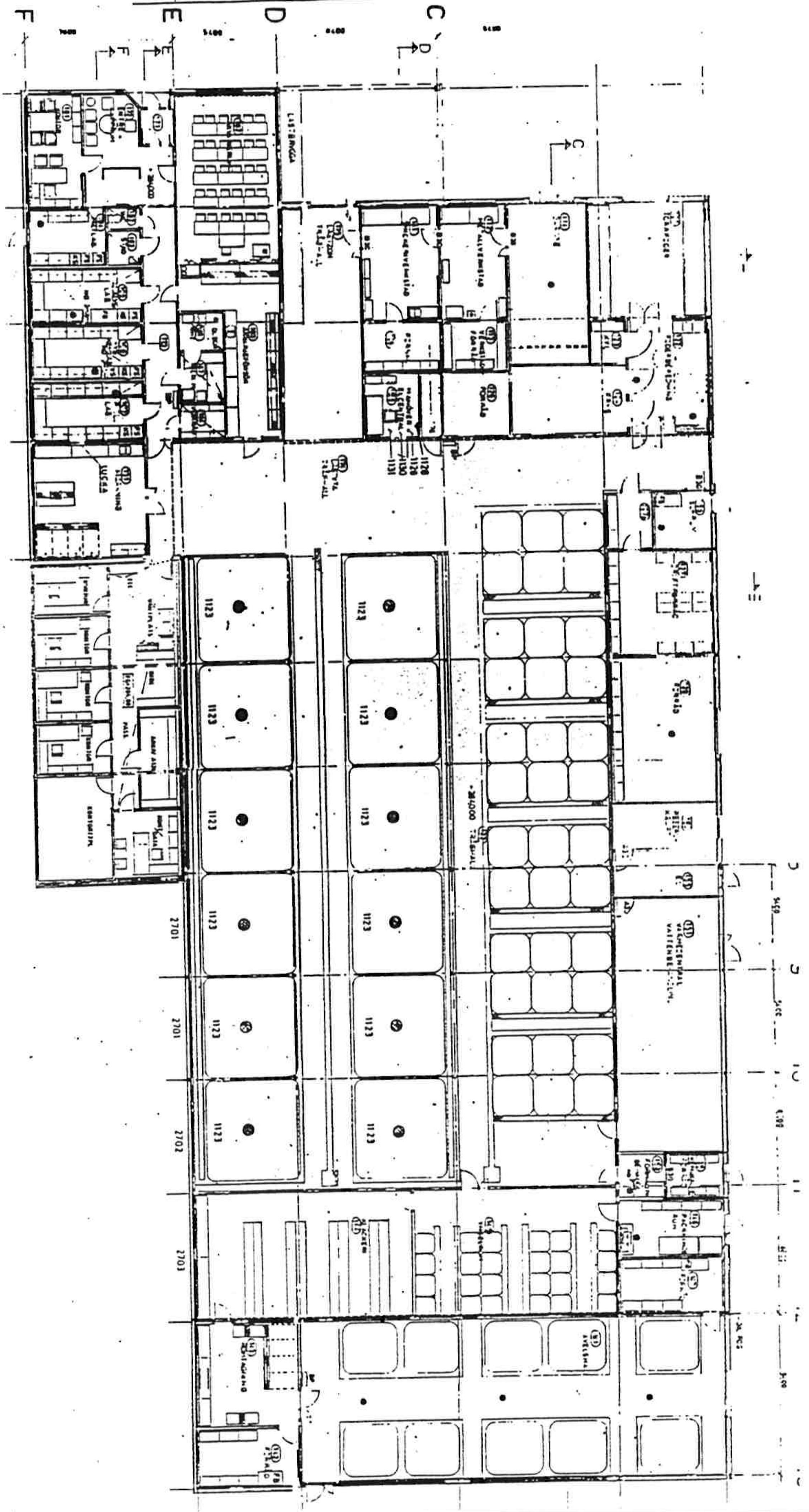

UMEÅ
ÖSTERSUND
KÄLARNE
SUNDSVALL

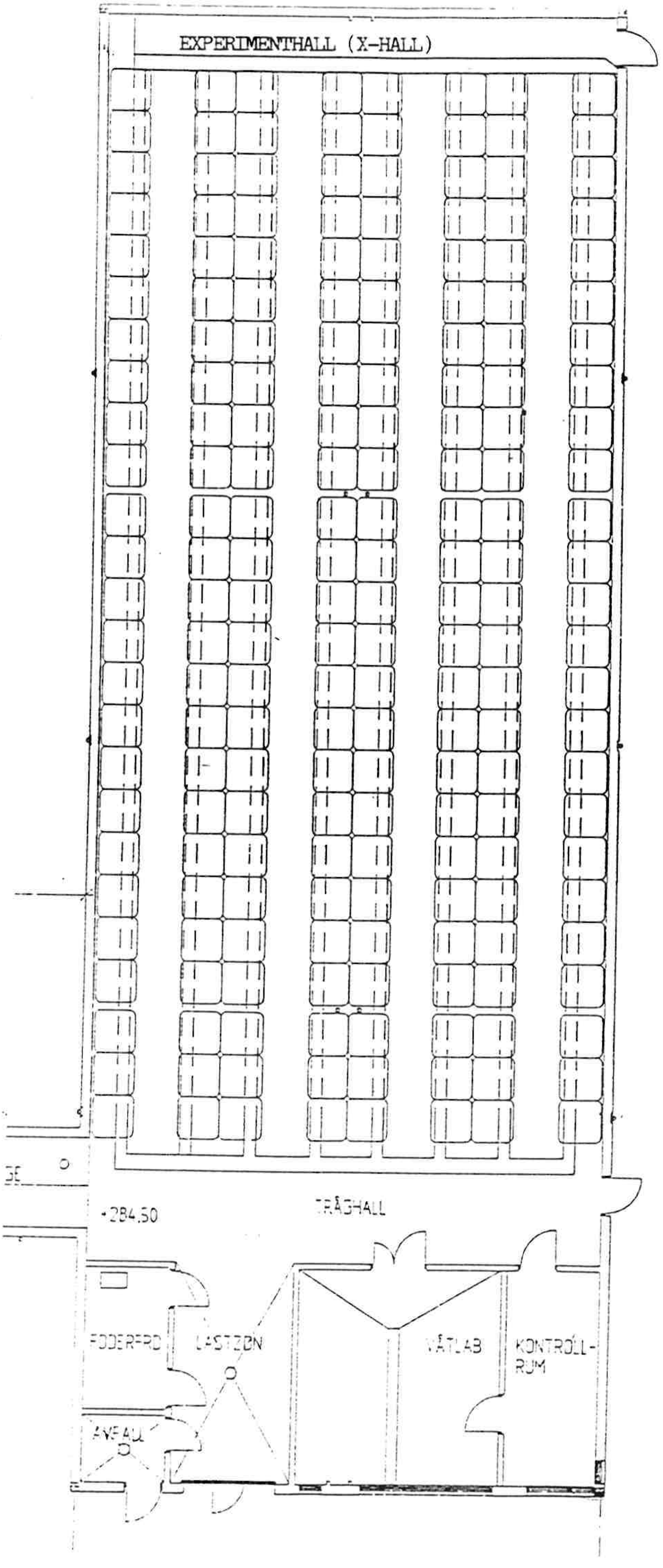

N


T-hall
N
NATURDAMMAR
SITUATIONSPLAN

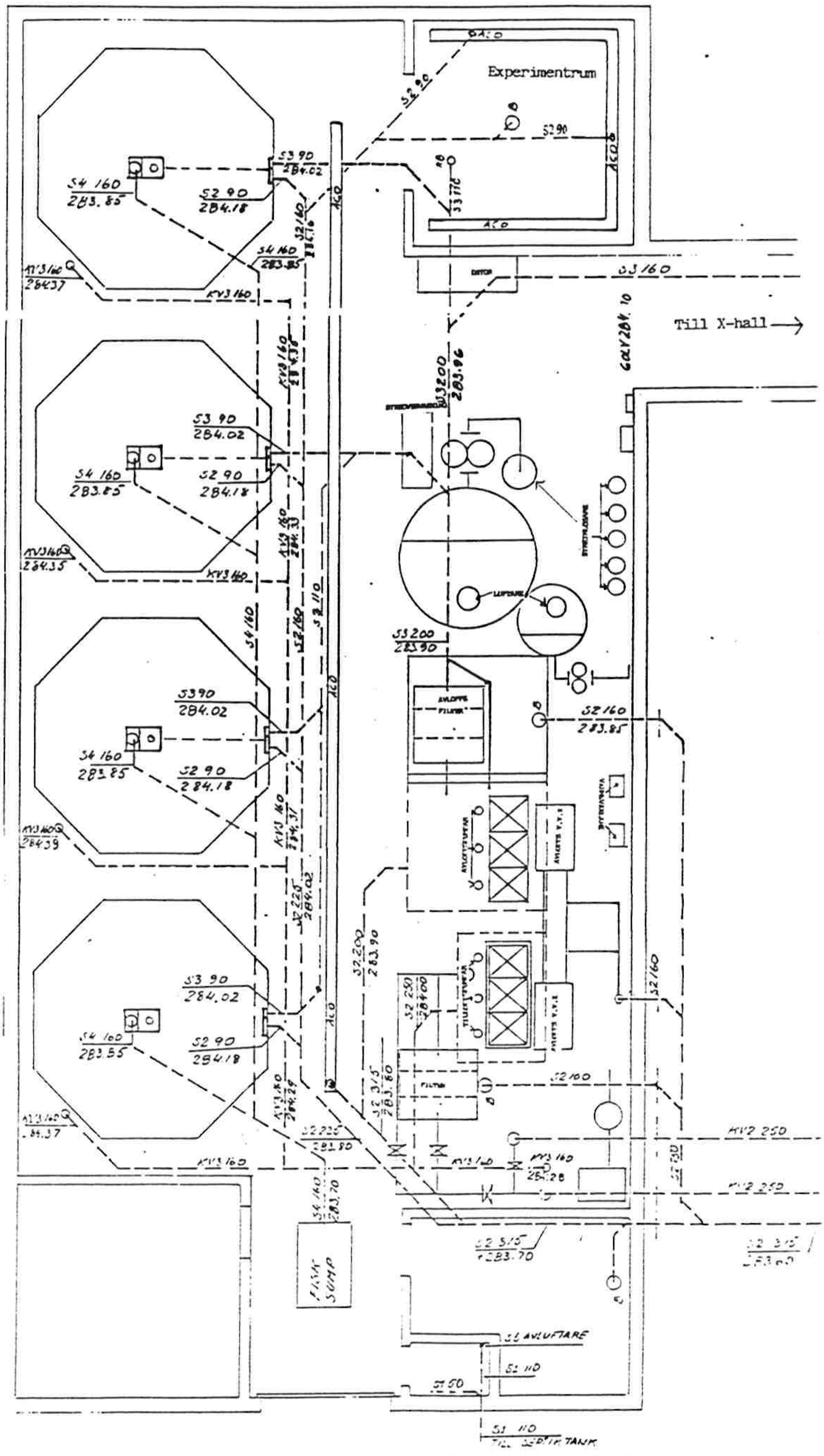
Bil. 2

HUVUDBYGGNAD (A-HALL)




EXPERIMENTHALL (X-HALL)
+284.50
TRÅGHALL
FODERFRD
LASTZON
AVFALL
VÅTLAB
KONTROLL-
RUM

T-HALL


Experimentrum
Till X-hall
FLASK SUMP
S4 160
2B3.85
S2 90
2B4.18
S3 90
2B4.02
KV3 160
S2 110
S3 200
2B3.90
S2 160
2B3.85
KV2 250
S2 315
2B3.70
S2 AVLUFTARE
S2 110
S2 50
S1 110
TILL SEPTIK TANK

VATTENFÖRBRUKNING l/min

ODLINGSAVDELNING

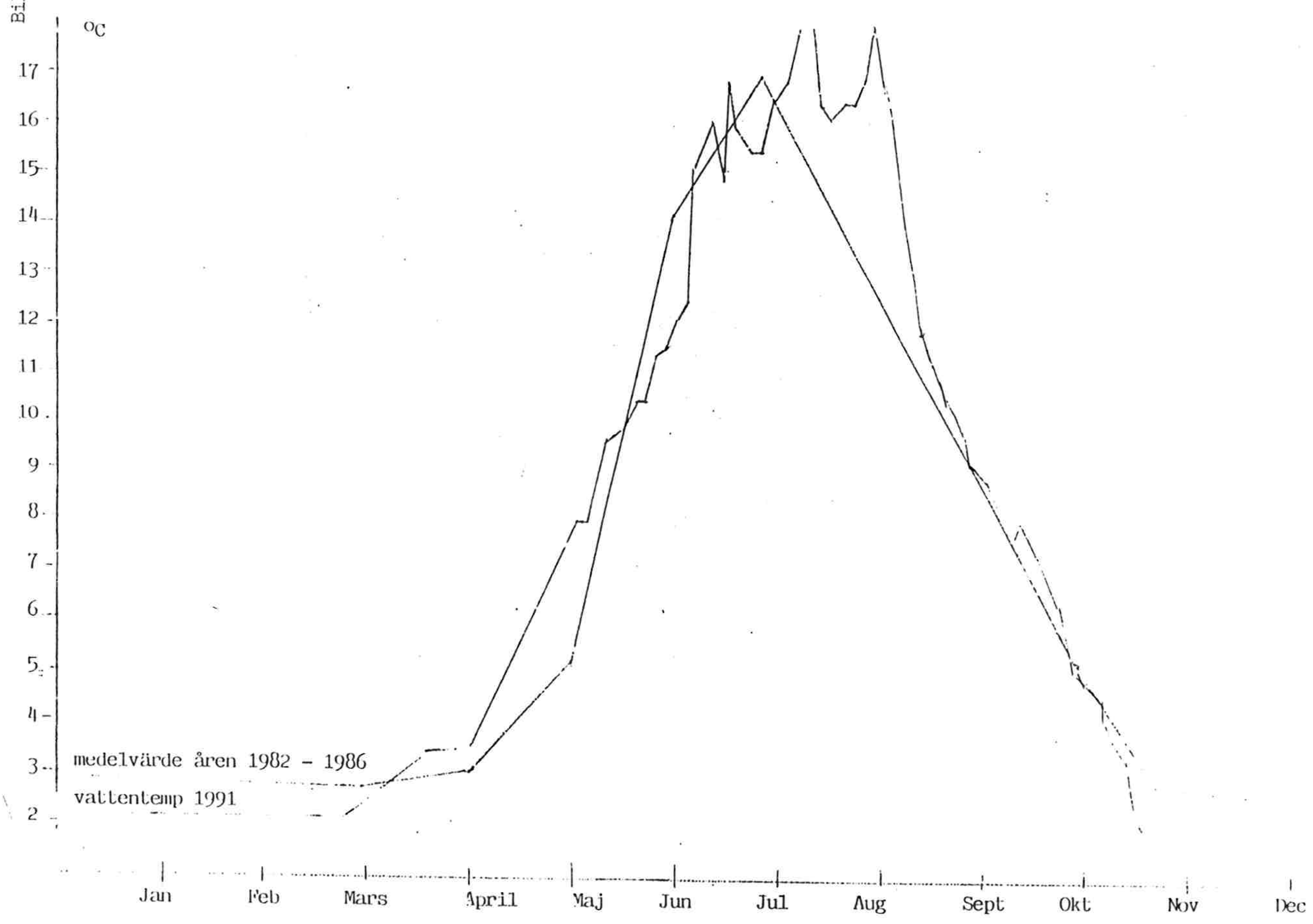
Avelsdammar	15.000 l/min	naturvatten
Experimenthall	4.000 "	"
"	1.200 "	tempererat
T-hall	1.000 "	naturvatten
"	400 "	tempererat
A-hall	10.000 "	naturvatten
Smittskydd	60 "	"

ENHET

Avelsdamm	600 m^2	2.150 l/min	naturvatten
T-tråg	12 m^2	250 "	"
"	"	100 "	tempererat
B-tråg	25 m^2	250 "	naturvatten
P-tråg	16 m^2	160 "	"
P-tråg	4 m^2	40 "	"
X-tråg	1 m^2	20 "	"
"	"	6 "	tempererat
Y-tråg	1 m^2	20 "	naturvatten

Bil. 6

VA[illegible]EMPERATUR



Appendix 2: Water quality data

Appendix 2: Wastewater quality data

Series	Time scale	Location	Date	Time	Sample mark	TP mg/l	TPfarm µg/l	TDP mg/l	TDPfarm µg/l	TPPfarm µg/l	TPP/TPf prop.	PO4 mg/l	SS mg/l	SS farm mg/l	TN mg/l	TN farm mg/l	TDN mg/l	TDNfarm mg/l	TPNfarm mg/l	TPN/TN prop.
	Week	A	97/01/28-29	13:15-13:15	K3AW1	0.019	6	0.015	0	6	0.96	--	1.0	0.5	--	--	--	--	--	--
			97/01/29-30	13:15-13:15	K3AW2	0.019	5	0.016	2	3	0.67	--	1.5	1.0	--	--	--	--	--	--
			97/01/30-31	13:15-13:15	K3AW3	0.028	15	0.021	7	8	0.52	--	3.0	2.5	--	--	--	--	--	--
			97/01/31-02/01	13:15-13:15	K3AW4	0.018	5	0.014	-1	6	1.17	--	2.0	1.5	--	--	--	--	--	--
			97/02/01-02	13:15-13:15	K3AW5	0.016	3	0.016	1	1	0.49	--	1.5	1.0	--	--	--	--	--	--
			97/02/02-03	13:15-13:15	K3AW6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
			97/02/03-04	13:15-13:15	K3AW7	0.028	14	0.019	5	9	0.65	--	1.5	1.0	--	--	--	--	--	--
		X	97/01/28-29	12:20-12:20	K3XW1	0.016	2	0.014	-1	3	1.32	--	1.0	0.5	--	--	--	--	--	--
			97/01/29-30	12:20-12:20	K3XW2	0.015	2	0.013	-1	3	1.80	--	1.0	0.5	--	--	--	--	--	--
			97/01/30-31	12:20-12:20	K3XW3	0.016	2	0.015	0	2	0.78	--	1.5	1.0	--	--	--	--	--	--
			97/01/31-02/01	12:20-12:20	K3XW4	0.068	54	0.053	39	15	0.28	--	1.5	1.0	--	--	--	--	--	--
			97/02/01-02	12:20-12:20	K3XW5	0.017	3	0.015	0	3	0.88	--	2.0	1.5	--	--	--	--	--	--
			97/02/02-03	12:20-12:20	K3XW6	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
			97/02/03-04	12:20-12:20	K3XW7	0.023	9	0.013	-2	11	1.18	--	2.5	2.0	--	--	--	--	--	--
			97/02/04-05	12:20-12:20	K3XW8	0.018	5	0.015	1	4	0.81	--	1.0	0.5	--	--	--	--	--	--
	Single	St2			K3ST2	0.014	1	--	--	--	--	0.008	--	--	--	--	--	--	--	--
		St3			K3ST3	0.014	1	--	--	--	--	0.001	--	--	--	--	--	--	--	--
		St8			K3ST8	0.020	7	--	--	--	--	0.013	--	--	--	--	--	--	--	--
		St10			K3ST10	0.016	2	--	--	--	--	0.007	--	--	--	--	--	--	--	--
		St11			K3ST11	0.018	4	--	--	--	--	0.009	--	--	--	--	--	--	--	--
4 - late winter	Diurnal	A	97/04/21-22	13:42-17:32	K4AD1	0.021	21	0.013	13	8	0.36	--	4.0	0.5	0.438	0.143	0.650	0.284	-0.140	-0.98
				17:42-21:32	K4AD2	0.021	21	0.015	15	7	0.32	--	3.0	-0.5	0.438	0.143	0.508	0.141	0.002	0.02
				21:42-01:32	K4AD3	0.022	22	0.014	14	8	0.35	--	2.0	-1.5	0.487	0.192	0.583	0.216	-0.024	-0.13
				01:42-05:32	K4AD4	0.109	109	0.055	55	54	0.50	--	2.5	-1.0	0.474	0.179	0.473	0.107	0.072	0.40
				05:42-09:32	K4AD5	0.026	26	0.015	15	11	0.43	--	2.0	-1.5	0.492	0.197	0.452	0.085	0.112	0.57
				09:42-13:32	K4AD6	0.024	24	0.022	22	2	0.07	--	1.5	-2.0	0.468	0.173	0.484	0.117	0.056	0.32
		X	97/04/21-22	14:06-17:56	K4XD1	0.028	28	0.021	21	7	0.26	--	2.0	-1.5	0.451	0.156	0.493	0.126	0.029	0.19
				18:06-21:56	K4XD2	0.021	21	0.015	15	6	0.29	--	1.5	-2.0	0.429	0.134	0.450	0.083	0.051	0.38
				22:06-01:56	K4XD3	0.021	21	0.015	15	7	0.32	--	2.5	-1.0	0.406	0.111	0.427	0.060	0.051	0.46
				02:06-05:56	K4XD4	0.022	22	0.015	15	7	0.32	--	3.0	-0.5	0.419	0.124	0.426	0.059	0.065	0.52
				06:06-09:56	K4XD5	0.029	29	0.013	13	16	0.54	--	3.5	0.0	0.445	0.150	0.476	0.109	0.040	0.27
				10:06-13:56	K4XD6	0.020	20	0.015	15	5	0.27	--	4.0	0.5	0.446	0.151	0.485	0.119	0.032	0.21
	(day)	P	97/04/22-23	14:03-17:53	K4PD1	0.023	23	0.014	14	9	0.39	--	6.5	3.0	0.415	0.120	0.443	0.077	0.043	0.36
				06:03-13:53																
	(night)			18:03-24:00	K4PD2	0.021	21	0.015	15	6	0.30	--	4.5	1.0	0.405	0.110	0.502	0.136	-0.026	-0.23
				00:00-05:53																
		C	97/04/21	10:25	K4C1	0.000	--	0.000	--	--	--	--	3.0	--	0.295	--	0.378	--	--	--
			97/04/22	14:45	K4C2	0.000	--	0.000	--	--	--	--	4.0	--	0.295	--	0.355	--	--	--
					mean C	0.000	--	0.000	--	--	--	--	3.5	--	0.295	--	0.366	--	--	--
	Week	A	97/04/14-15	13:17-12:47	K4AW1	0.021	21	0.013	13	9	0.40	--	4.0	0.5	0.455	0.160	0.501	0.135	0.025	0.16
			97/04/15-16	13:17-12:47	K4AW2	0.017	17	0.013	13	3	0.21	--	4.5	1.0	0.408	0.113	0.478	0.112	0.002	0.01
			97/04/16-17	13:17-12:47	K4AW3	0.040	40	0.014	14	26	0.65	--	3.5	0.0	0.426	0.131	0.467	0.101	0.030	0.23
			97/04/17-18	13:17-12:47	K4AW4	0.028	28	0.019	19	10	0.34	--	2.5	-1.0	0.463	0.168	0.522	0.155	0.013	0.07
			97/04/18-19	13:17-12:47	K4AW5	0.030	30	0.014	14	16	0.54	--	3.5	0.0	0.474	0.179	0.451	0.084	0.095	0.53
			97/04/19-20	13:17-12:47	K4AW6	0.020	20	0.012	12	7	0.38	--	3.0	-0.5	0.428	0.133	0.486	0.119	0.014	0.11
			97/04/20-21	13:17-12:47	K4AW7	0.024	24	0.011	11	13	0.54	--	3.0	-0.5	0.472	0.177	0.467	0.101	0.076	0.43
		X	97/04/14-15	13:30-13:00	K4XW1	0.045	45	0.000	0	45	1.00	--	4.0	0.5	0.811	0.516	0.580	0.214	0.302	0.59
			97/04/15-16	13:30-13:00	K4XW2	0.062	62	0.014	14	47	0.77	--	3.0	-0.5	0.420	0.125	0.499	0.133	-0.008	-0.06
			97/04/16-17	13:30-13:00	K4XW3	0.023	23	0.015	15	8	0.35	--	5.5	2.0	0.430	0.135	0.448	0.082	0.053	0.39
			97/04/17-18	13:30-13:00	K4XW4	0.031	31	0.016	16	16	0.50	--	4.0	0.5	0.490	0.195	0.448	0.082	0.113	0.58
			97/04/18-19	13:30-13:00	K4XW5	0.089	89	0.062	62	27	0.31	--	2.5	-1.0	0.550	0.255	0.475	0.108	0.147	0.57
			97/04/19-20	13:30-13:00	K4XW6	0.023	23	0.013	13	10	0.42	--	4.0	0.5	0.425	0.130	0.431	0.065	0.065	0.50
			97/04/20-21	13:30-13:00	K4XW7	0.024	24	0.018	18	6	0.25	--	2.5	-1.0	0.480	0.185	0.461	0.094	0.091	0.49
	Single	St2			K4ST2	0.012	12	--	--	--	--	0.011	--	--	0.432	0.137	--	--	--	--
		St3			K4ST3	0.012	12	--	--	--	--	0.010	--	--	0.348	0.053	--	--	--	--
		St8			K4ST8	0.016	16	--	--	--	--	0.010	--	--	0.480	0.185	--	--	--	--
		St10			K4ST10	0.011	11	--	--	--	--	0.011	--	--	0.355	0.060	--	--	--	--
		St11			K4ST11	0.013	13	--	--	--	--	0.010	--	--	0.368	0.073	--	--	--	--

Appendix 2: Wastewater quality data

Series	Time scale	Location	Date	Time	Sample mark	TP mg/l	TPfarm µg/l	TDP mg/l	TDPfarm µg/l	TPPfarm µg/l	TPP/TPf prop.	PO4 mg/l	SS mg/l	SS farm mg/l	TN mg/l	TN farm mg/l	TDN mg/l	TDNfarm mg/l	TPNfarm mg/l	TPN/TN prop.
1 - Summer	Diurnal	A	96/6/5	07:00-10:30	K1A1	0.024	9	0.024	8	1	0.16	--	6.0	2.2	--	--	--	--	--	--
				11:00-14:30	K1A2	0.021	7	0.021	6	1	0.13	--	2.5	-1.3	--	--	--	--	--	--
				15:00-18:30	K1A3	0.022	8	0.024	8	0	-0.06	--	3.0	-0.7	--	--	--	--	--	--
				19:00-22:30	K1A4	0.037	23	0.023	7	15	0.68	--	1.5	-2.2	--	--	--	--	--	--
		X	96/6/5	07:00-10:30	K1X1	0.061	47	0.041	25	22	0.46	--	9.5	5.8	--	--	--	--	--	--
				11:00-14:30	K1X2	0.034	20	0.033	17	3	0.15	--	1.5	-2.3	--	--	--	--	--	--
				15:00-18:30	K1X3	0.036	21	0.034	19	3	0.12	--	3.0	-0.8	--	--	--	--	--	--
				19:00-22:30	K1X4	0.035	21	0.034	18	2	0.10	--	1.5	-2.3	--	--	--	--	--	--
		C	96/6/5		K1C1	0.015	--	0.016	--	--	--	--	4.0	--	--	--	--	--	--	--
					K1C2	0.014	--	0.015	--	--	--	--	3.5	--	--	--	--	--	--	--
					mean C	0.014	--	0.016	--	--	--	--	3.8	--	--	--	--	--	--	--
2 - Autumn	Diurnal	A	96/09/10-11	12:00-15:50	K2AD1	0.042	25	0.033	16	9	0.37	--	2.0	1.0	--	--	--	--	--	--
				16:00-19:50	K2AD2	0.041	24	0.040	23	2	0.07	--	2.0	1.0	--	--	--	--	--	--
				20:00-23:50	K2AD3	0.024	7	0.024	7	0	0.00	--	1.5	0.5	--	--	--	--	--	--
				24:00-03:50	K2AD4	0.026	10	0.027	10	0	-0.05	--	1.5	0.5	--	--	--	--	--	--
				04:00-07:50	K2AD5	0.079	62	0.050	33	30	0.47	--	1.5	0.5	--	--	--	--	--	--
				08:00-11:50	K2AD6	0.091	75	0.042	25	50	0.67	--	2.5	1.5	--	--	--	--	--	--
		X	96/09/10-11	12:00-15:50	K2XD1	0.025	9	0.025	8	1	0.11	--	1.5	0.5	--	--	--	--	--	--
				16:00-19:50	K2XD2	0.031	15	0.030	13	2	0.11	--	1.5	0.5	--	--	--	--	--	--
				20:00-23:50	K2XD3	0.040	23	0.035	18	6	0.24	--	2.0	1.0	--	--	--	--	--	--
				24:00-03:50	K2XD4	0.039	22	0.035	18	4	0.20	--	2.0	1.0	--	--	--	--	--	--
				04:00-07:50	K2XD5	0.037	20	0.034	17	3	0.17	--	2.0	1.0	--	--	--	--	--	--
				08:00-11:50	K2XD6	0.038	21	0.032	15	6	0.28	--	1.5	0.5	--	--	--	--	--	--
		P			K2PD1	0.039	22	0.028	11	11	0.49	--	3.0	2.0	--	--	--	--	--	--
					K2PD2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
		C	96/09/10	09:00	K2C1a	0.014	--	0.021	--	--	--	--	1.0	--	--	--	--	--	--	--
				09:00	K2C1b	0.016	--	0.015	--	--	--	--	1.0	--	--	--	--	--	--	--
				09:30	K2C2a	0.014	--	0.016	--	--	--	--	1.0	--	--	--	--	--	--	--
				09:30	K2C2b	0.022	--	0.015	--	--	--	--	1.0	--	--	--	--	--	--	--
					mean C	0.017	--	0.017	--	--	--		1.0	--		--		--	--	--
	Week	A	97/01/28-29	13:15-13:15	K2AW1	0.038	21	0.026	9	12	0.57	--	2.0	1.0	--	--	--	--	--	--
			97/01/29-30	13:15-13:15	K2AW2	0.025	9	0.025	8	1	0.08	--	1.5	0.5	--	--	--	--	--	--
			97/01/30-31	13:15-13:15	K2AW3	0.035	19	0.025	8	10	0.55	--	1.5	0.5	--	--	--	--	--	--
			97/01/31-02/01	13:15-13:15	K2AW4	0.037	20	0.024	6	14	0.68	--	1.0	0.0	--	--	--	--	--	--
			97/02/01-02	13:15-13:15	K2AW5	0.027	11	0.024	6	4	0.39	--	1.5	0.5	--	--	--	--	--	--
			97/02/02-03	13:15-13:15	K2AW6	0.028	11	0.024	7	4	0.38	--	2.0	1.0	--	--	--	--	--	--
			97/02/03-04	13:15-13:15	K2AW7	0.054	37	0.027	10	27	0.73	--	2.0	1.0	--	--	--	--	--	--
		X	97/01/28-29	12:20-12:20	K2XW1	0.067	50	0.046	29	22	0.43	--	2.5	1.5	--	--	--	--	--	--
			97/01/29-30	12:20-12:20	K2XW2	0.042	26	0.036	19	7	0.27	--	2.0	1.0	--	--	--	--	--	--
			97/01/30-31	12:20-12:20	K2XW3	0.037	21	0.027	10	10	0.51	--	1.5	0.5	--	--	--	--	--	--
			97/01/31-02/01	12:20-12:20	K2XW4	0.049	33	0.026	9	24	0.74	--	1.5	0.5	--	--	--	--	--	--
			97/02/01-02	12:20-12:20	K2XW5	0.106	90	0.048	30	59	0.66	--	2.5	1.5	--	--	--	--	--	--
			97/02/02-03	12:20-12:20	K2XW6	0.037	20	0.027	10	10	0.51	--	1.5	0.5	--	--	--	--	--	--
			97/02/03-04	12:20-12:20	K2XW7	0.038	22	0.035	18	4	0.18	--	1.5	0.5	--	--	--	--	--	--
3 - Winter	Diurnal	A	97/01/27-28	11:57-15:57	K3AD1	0.024	11	0.025	11	0	0.03	--	1.0	0	--	--	--	--	--	--
				15:57-19:57	K3AD2	0.023	9	0.024	10	-1	-0.07	--	1.5	1.0	--	--	--	--	--	--
				19:57-23:57	K3AD3	0.019	6	0.022	7	-2	-0.29	--	1.0	0.5	--	--	--	--	--	--
				23:57-03:57	K3AD4	0.019	5	0.020	6	-1	-0.13	--	1.5	1.0	--	--	--	--	--	--
				03:57-07:57	K3AD5	0.021	7	0.023	9	-2	-0.26	--	1.0	0.5	--	--	--	--	--	--
				07:57-11:57	K3AD6	0.022	9	0.025	11	-2	-0.21	--	1.5	1.0	--	--	--	--	--	--
		X	97/01/27-28	11:09-15:09	K3XD1	0.019	5	0.019	5	0	0.08	--	1.5	1.0	--	--	--	--	--	--
				15:09-19:09	K3XD2	0.019	5	0.020	6	0	-0.06	--	1.5	1.0	--	--	--	--	--	--
				19:09-23:09	K3XD3	0.023	10	0.025	10	0	-0.03	--	2.0	1.5	--	--	--	--	--	--
				23:09-03:09	K3XD4	0.019	5	0.021	7	-1	-0.24	--	1.0	0.5	--	--	--	--	--	--
				03:09-07:09	K3XD5	0.018	5	0.019	5	0	-0.06	--	1.0	0.5	--	--	--	--	--	--
				07:09-11:09	K3XD6	0.021	8	0.021	6	2	0.21	--	2.0	1.5	--	--	--	--	--	--
		P	97/01/04-05	14:25-01:55	K3PD1	0.022	9	0.019	5	4	0.44	--	1.0	0.5	--	--	--	--	--	--
				02:25-13:55	K3PD2	0.024	11	0.022	8	3	0.25	--	2.0	1.5	--	--	--	--	--	--
		C	97/01/27	15:15	K3C1	0.014	--	0.014	--	--	--	--	0.5	--	--	--	--	--	--	--
			97/01/28	08:50	K3C2	0.013	--	0.015	--	--	--	--	0.5	--	--	--	--	--	--	--
					mean C	0.014	--	0.014	--	--	--	--	0.5	--		--		--	--	--

Appendix 3: Results figures

Figure 3: *Diurnal phosphorus fluctuations in A hall effluent*

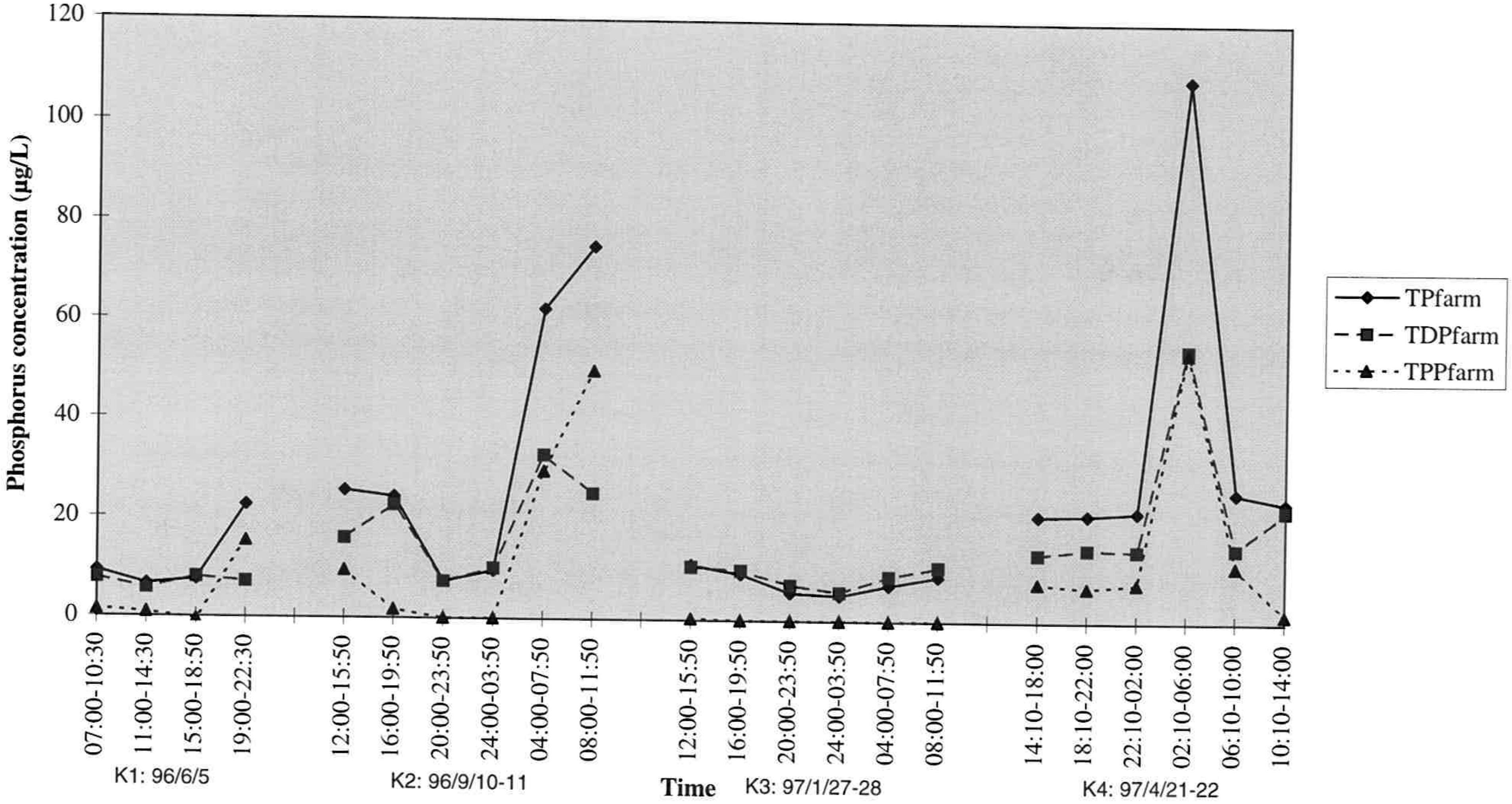


Figure 4: Diurnal phosphorus fluctuations in X hall effluent

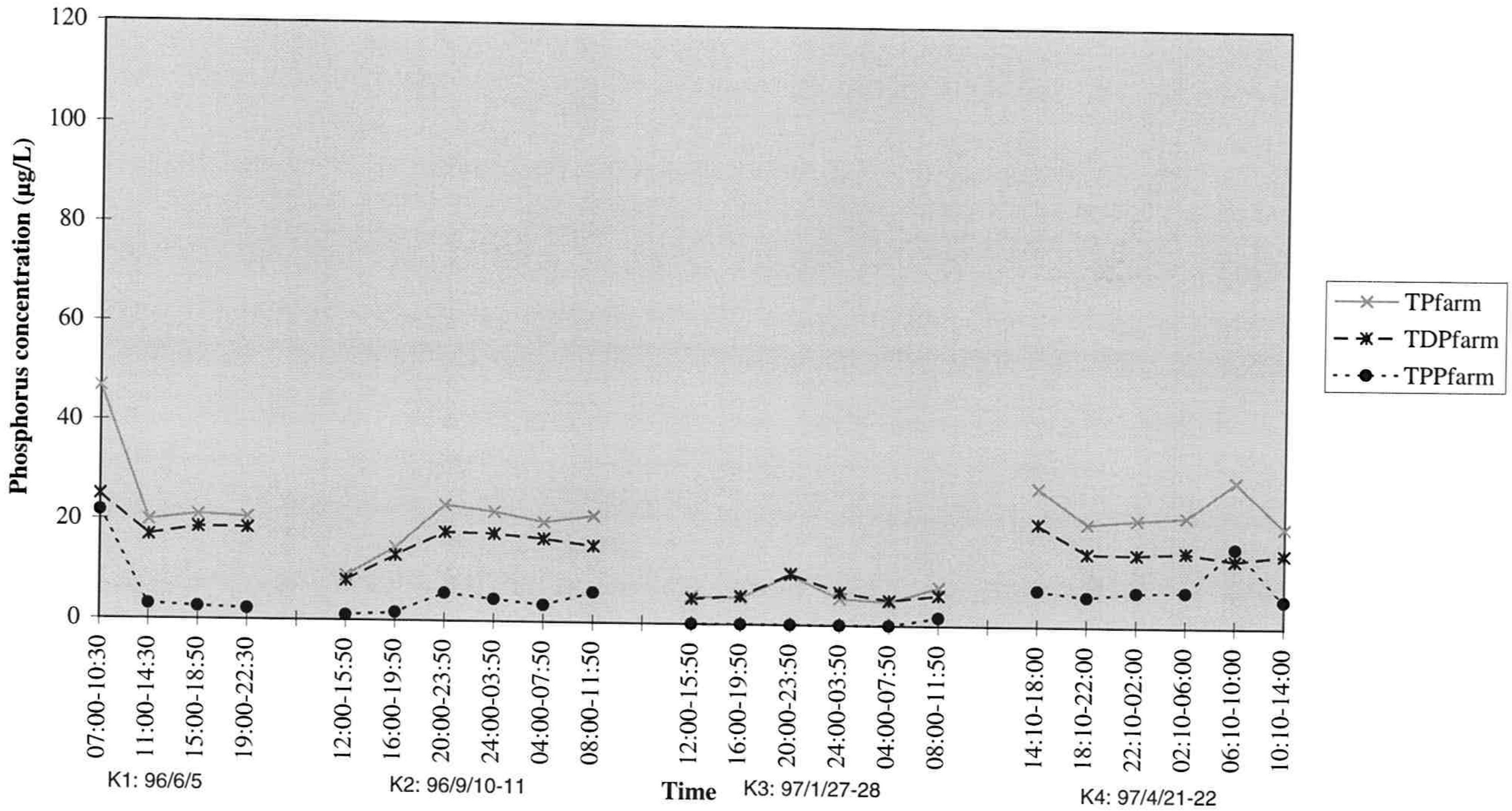


Figure 5: *Fluctuations in phosphorus concentrations in A-hall effluent during three one week periods*

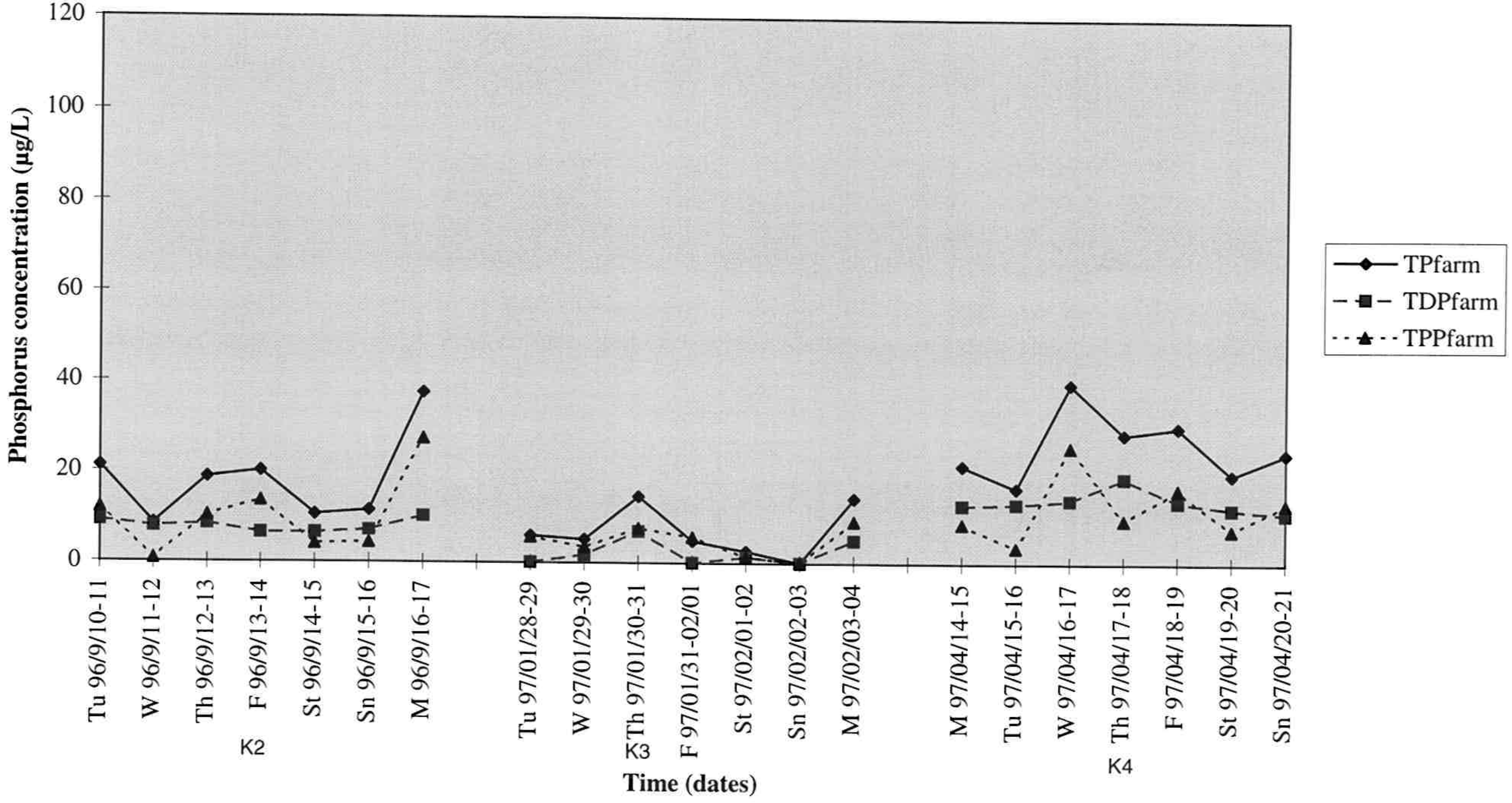


Figure 6: *Fluctuations in phosphorus concentrations in X-hall effluent during three one week periods*

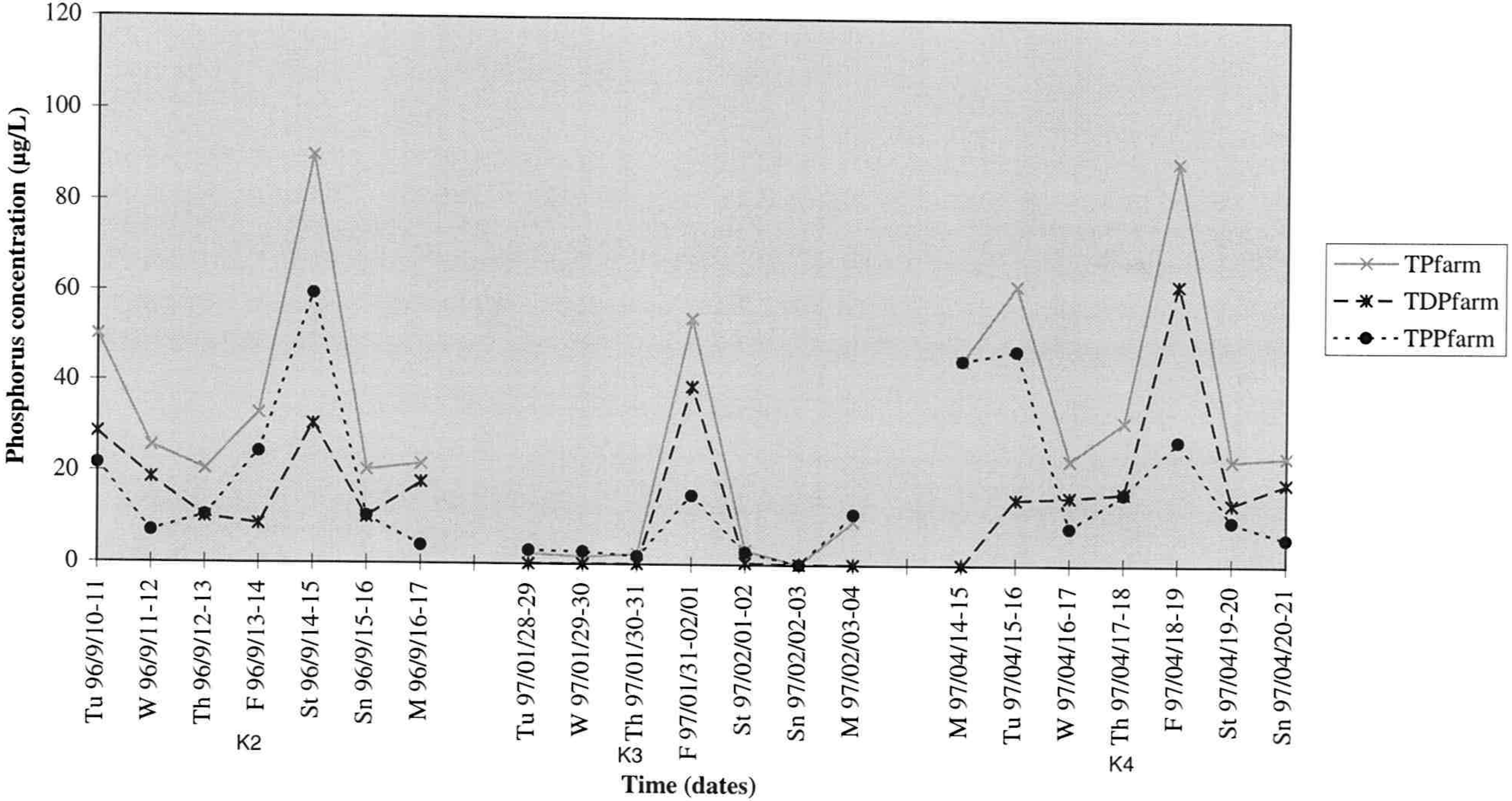


Figure 7: *Diurnal suspended solids fluctuations - A & X halls*

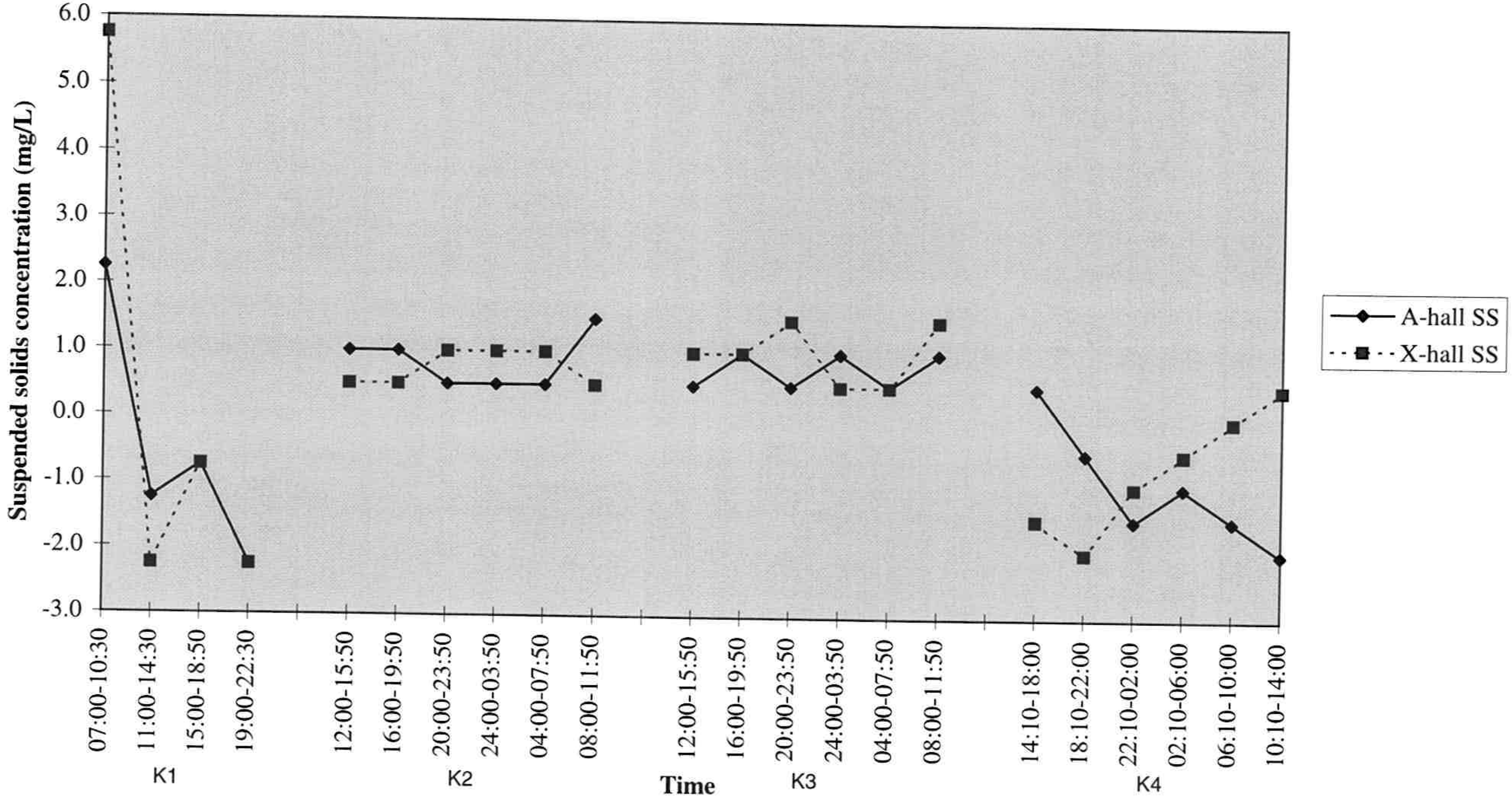


Figure 8: *Suspended solids fluctuations in the effluents from the A and X-halls during 3 one week periods*

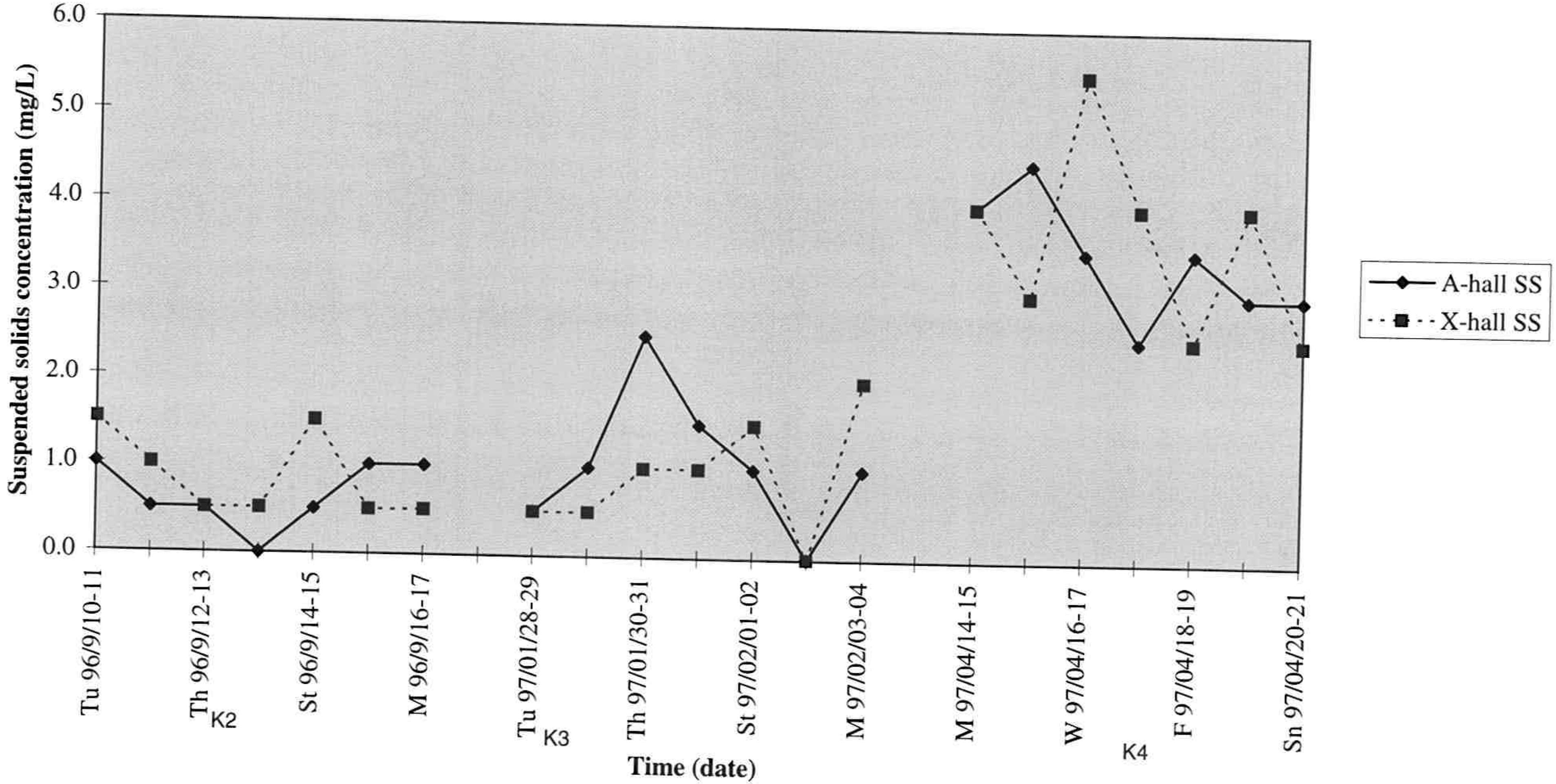


Figure 9: *Diurnal nitrogen concentration fluctuations - K4 April 1997*

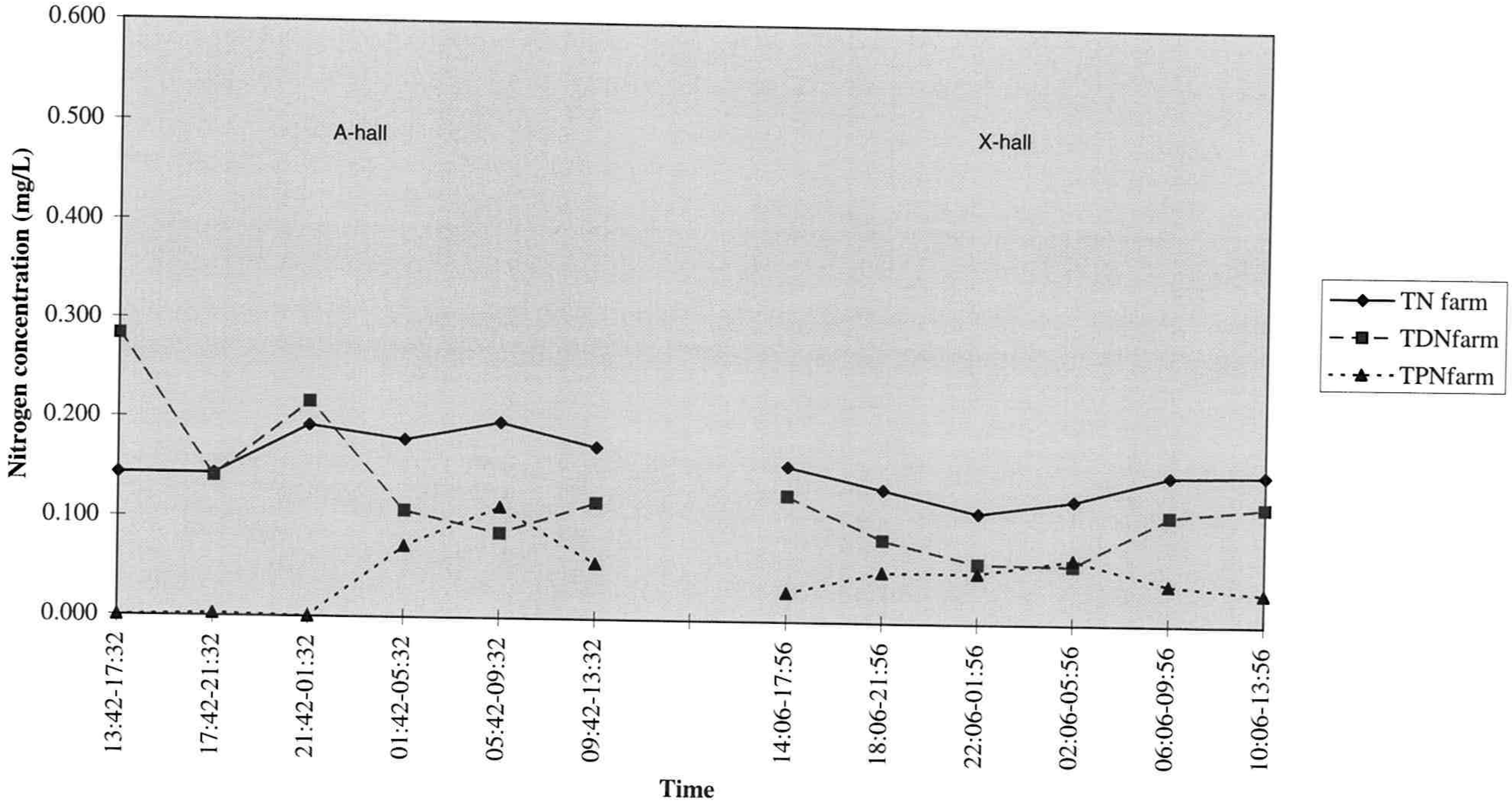


Figure 10: *Nitrogen concentration fluctuations during a week - K4 April 1997*

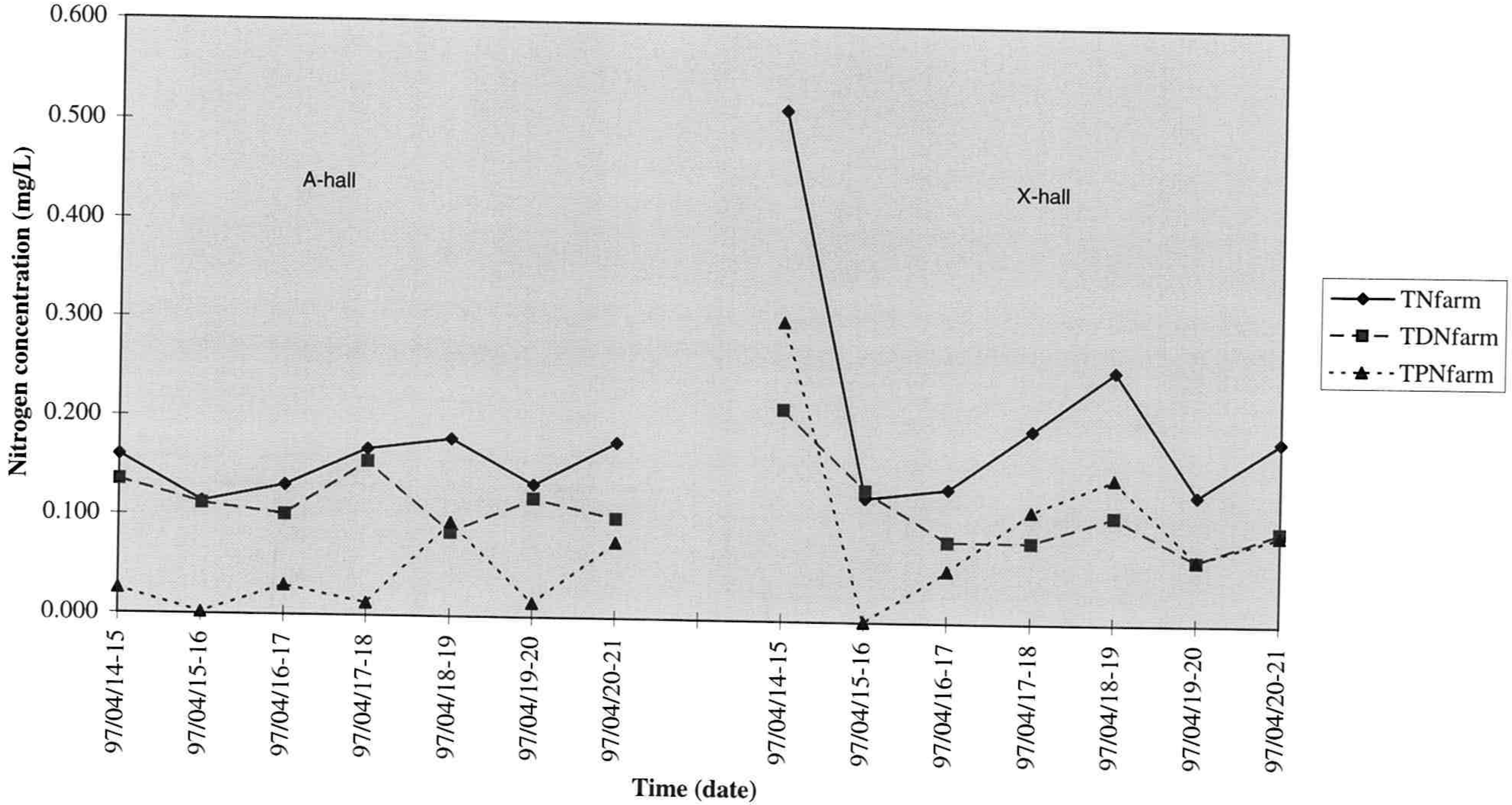


Figure 11: *Mean particle volume distribution - K2, Sept. 1996*

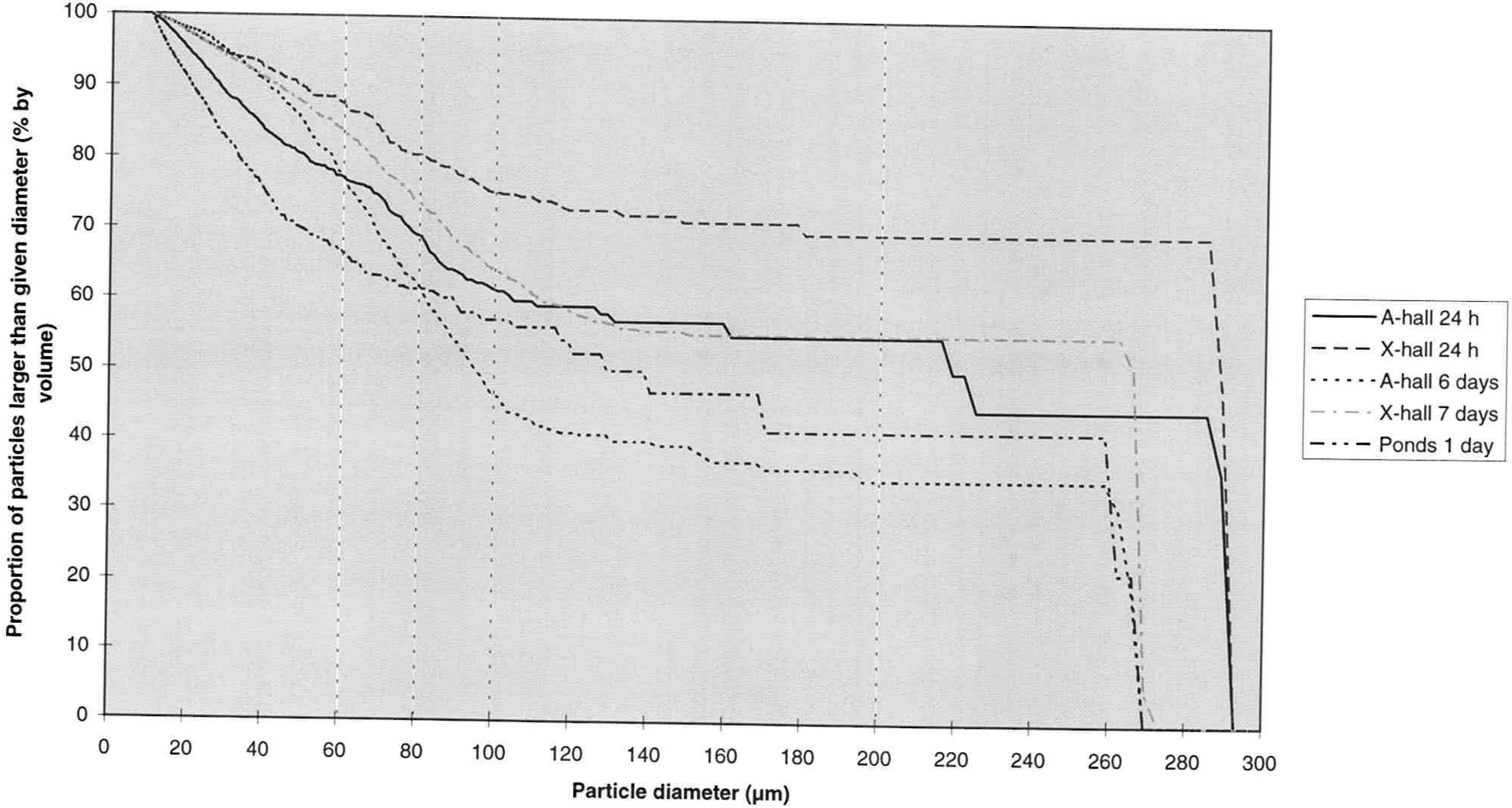


Figure 12: *Mean particle volume distribution - K3, Jan/Feb. 1997*

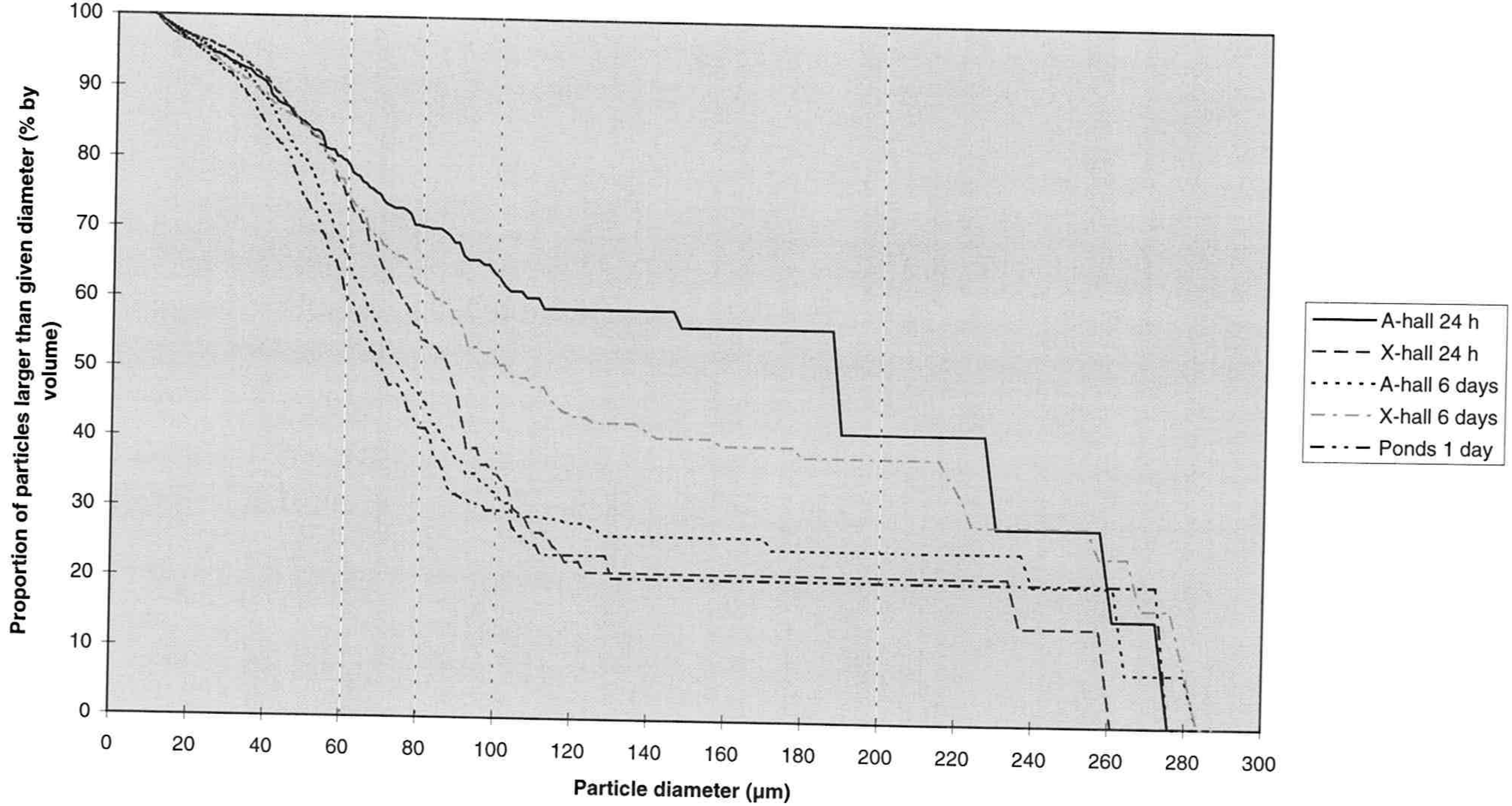


Figure 13: *Mean particle volume distribution - K4, April 1997*

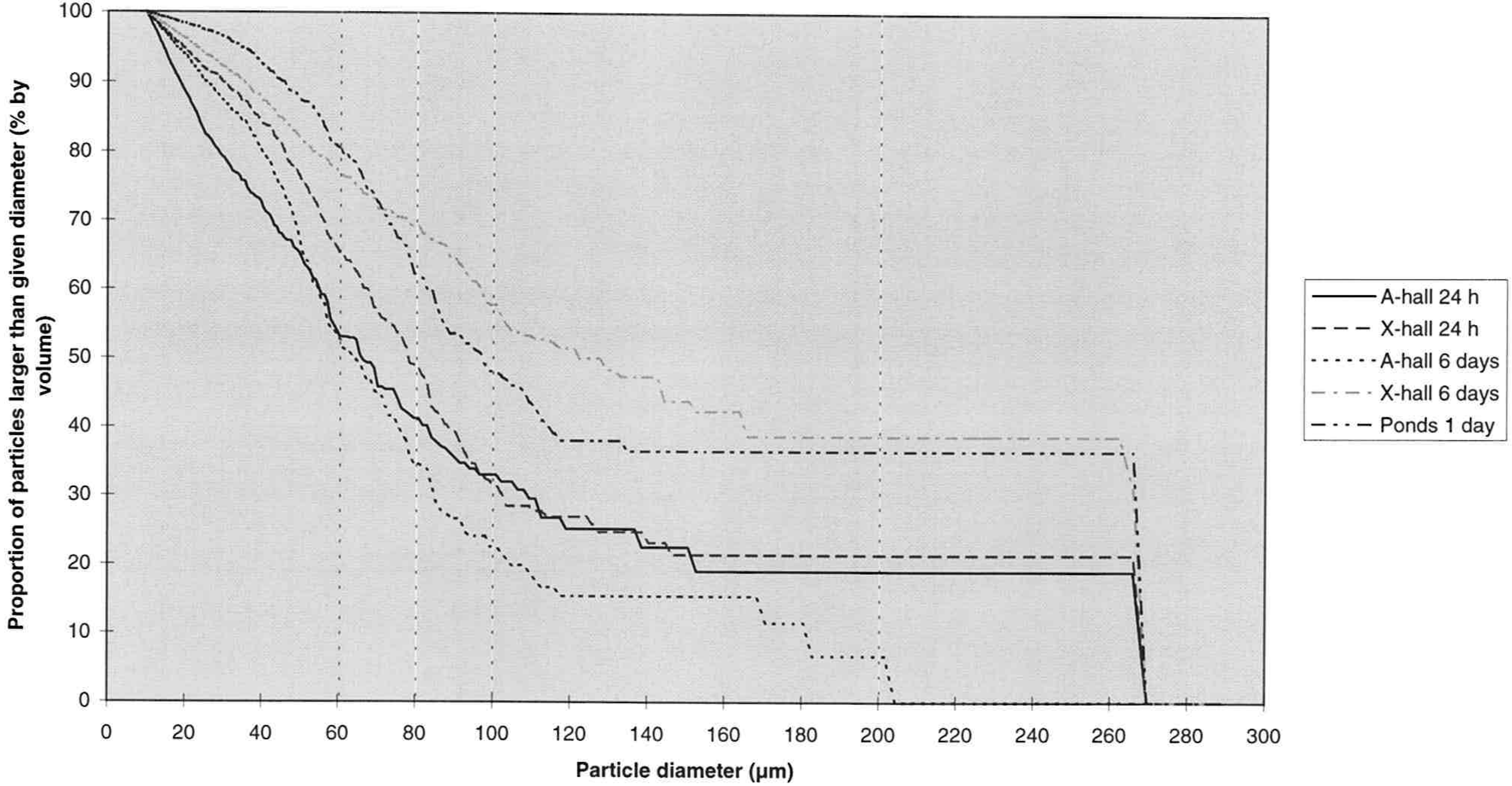


Figure 14: *Predicted particle removal rates*