FINAL

REPORT ON THE REHABILITATION, OPERATION AND TREATMENT PERFORMANCE OF MPIRA/BALAKA MAIN WATER TREATMENT WORKS

FOR

THE DEPARTMENT OF WATER
MINISTRY OF WORKS, REPUBLIC OF MALAWI.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

cu.m/h	-	cubic metres per hour
l/c.d.	-	litres per capita and day
l/sec.	-	litres per second
m	-	metre
mg/l	-	milligrams per litre
m/h	-	metres per hour
ppm	-	parts per million

ABBREVIATIONS

CWQ	-	Central Water Quality Laboratory, Lilongwe
DF	-	Downstream of the farm
D.O.	-	Dissolved Oxygen
DRF	-	Downflow Roughing Filter(s)/Filtration
DRFI	-	Downflow Roughing Filter Inlet
NTU	-	Nephelometric Turbidity Units
PVC	-	Poly-vinyl Chloride
RF	-	Roughing Filter
RFI	-	Roughing Filter Inlet
RFO	-	Roughing Filter Outlet
SSF	-	Slow Sand Filter/Filtration
SSFO	-	Slow Sand Filter Outlet
TNTC	-	Too Numerous To Count
UDSM	-	University of Dar es Salaam
UF	-	Upstream of the farm
WD	-	Water Department, Malawi
WHO	-	World Health Organization

LIST OF APPENDICES

ACKNOWLEDGEMENTS

I am grateful to the Government of Malawi, Ministry of Works and specifically the Controller of Water Services, Water Department, Mr. E.H. Msolomba for inviting me to review the performance of Mpira/Balaka main water works after my earlier visit in 1990. I take this opportunity to thank Mr. N. Chaya for coordinating my trip, the DANIDA TAT staff, the Project Engineer Mr. J.M. Kumwenda and his staff for their excellent support during my stay in Malawi. I should like to thank Miss. M. Mangulama for her assistance in typing the draft report. Finally, I wish to extend my sincere thanks to my colleagues in the Faculty of Engineering who assisted me in the production of this final report, especially Messrs. J. Mmbaga and R.Litto.

Dr. T.S.A. Mbwette (Consultant)
Dar es Salaam, Tanzania.
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1. TREATMENT PLANT REHABILITATION

Following my visit to the project in April 1990, I made a number of recommendations which were included in the brief report to the Water Department dated 12th April 1990. I will now present my observations in three main groups. The schematic layout of the treatment plant indicated on Appendix.1 will be used for the description of the units.

1.1 Downflow Roughing Filters (DRF) Rehabilitation

1.1.1 The vee-notch weirs have been installed at the inlets to all the five DRF which have been modified.

1.1.2 The suggested increase of the net length of flow from 5.60 to 6.60m was effected.

1.1.3 In an attempt to improve the performance of the under drainage system, instead of the two 400mm diameter ductile iron pipes proposed to be installed in each fraction, the following have now been provided:

DRF 6 & 1: One 355mm PVC pipe in each gravel compartment with Gate Valves.

DRF 2-5 :
- i) Two 250mm PVC pipes in the coarse fraction with butterfly valves.
- ii) Two 250mm PVC pipes running through the medium and fine fractions.

  Both pipes are spaced at approx. 5.0 metres centre to centre.

a) It is important to note that the use of PVC pipes was based on the need to minimize capital costs. However,to avoid or minimize chances of damage of PVC pipes due to exposure to sunrays, all the valve chambers with exposed PVC pipes should be covered at once. The consultant does not see the need to change these pipes to Ductile Iron to be of any urgency now if the exposed portions of The pipes can be kept covered all the time.

b) The operators are aware of how to use the system to quickly flush the DRF units. Generally it takes between 20 to 30 minutes for the dirty water to cease flowing out.

c) The 160 mm diameter filtered water collection main pipe provided should in future designs be increased to 200mm and also be kept above the drainage pipe or channel in order to reduce chances of draining dirty water if the underdrainage pipe is not frequently drained. In

fact, the provision of such a collection pipe underdrainage system is optional as water can be collected by other means. Unlike in the modified DRF 2-5, future designs should also ensure that the water collection pipes are spread across the whole plan area of the DRF compartments in order to minimize chances of formation of dead zones. A typical design of such a DRF with a sloping floor and a false bottom channel ending in a pipe just before the wall is shown in Appendix.2 to this report. Such a design ensures complete removal of the deposited sludge. It is a good engineering practice to provide washout pipes to drain water from every filter box compartment.

1.1.4 During the time of my visit, the DRF were being operated at 60 cu.m/h which is just below its original design capacity of 72 cu.m/h. This discharge corresponds to a filtration rate of approximately 0.92 m/h. This rate is still slightly on the high side of the conventional average of between 0.6 and 0.8 m/h (ref. 1,2,3) and at present does not allow one to increase the rate of the other DRF if any unit is under major repair.

1.1.5 During the first visit to the plant on the 16th Feb. 1992 it was noted that the third compartment of the DRF2 commissioned on the 12th February 1992, was submerged. The possible cause for this was the installation of an 110mm in place of an 160mm equal tee on the water collection main pipe. The technician responsible should replace this with an 160mm equal-tee soon in order to avoid such an operational condition which will ultimately result in encouraging algal growth on the gravel.

1.1.6 Regarding the condition of the filter media for DRFs, the raw crushed aggregates brought to the treatment plant site appear to have a lot of dust. Apart from having to sieve it into 3 fractions, (i.e 50-25mm, 25-12mm, 12-6mm), its important to ensure that the initial washing is done properly so as to minimize the flushing to waste period initially. Furthermore, current design guidelines (3) require that RF media size should range from 30mm to 5mm, future DRF designs should observe this requirement.

1.1.7 The Rehabilitation of the DRF1 should be speeded up so that the raw water influenced by the current rainy season can pass through a fully modified treatment works so that the system can be tested without any interruptions. Such an operation will provide the Water Department with reliable data on a fully operational system during its first year of proper operation.

1.2 Overall Treatment Plant Layout

1.2.1 It has been observed that as a follow up on my comments (1990 visit) regarding the non-flexible layout of the units, a number of additional valves have now been included in the pipe network in order to ease isolation of any of the units should this be necessary in future.

A new layout plan should be drawn at a bigger scale in order to show positions of all the valves if none is available at the moment.

2. TREATMENT PLANT PERFORMANCE AND OPERATION

2.1 Treatment Plant Operation

The operation of the treatment plant between January 1991 and todate has been scrutinized. One has to note that while the SSF3-6 have been fed with Roughing Filtered water as of June 1991, prior to then, the DRF were commissioned in stages as indicated below:

DRF 5 .... On 09/01/91
DRF 4 .... On 19/03/91
DRF 6 .... On 12/05/91
DRF 3 .... On 25/05/91

The SSF2 was connected to the DRF2 system very recently, i.e. on 12/02/1992 and hence for most of the time it was operating with un-prefiltered water. As at the time of writing this report, the SSF1 was the only one filtering raw water from the dam directly.

2.1.1 Filter run times

Apart from operating under the above explained conditions, the SSF (in this case SSF3-6) showed a substantial improvement in its operational conditions by increasing the filter run time from 3 days to 2 weeks reported in April 1990 to an average of about <u>one month</u>. This average included filter run times of up to just over two months. Moreover, even the minimum filter run times recorded during the heavy rains went up to at least 10 days (with 2 weeks as the typical minimum). This clearly proves the merits of the modified DRFs.

2.1.2 Schedule of Cleaning of SSF

In the longrun, a well planned schedule of start-up of the SSF will have to be prepared in order to ensure that the chances of any two SSF requiring cleaning at the same time is eliminated. Such a planning can be ensured when typical filter run times of all SSF are recorded over a period of at least one year. Its therefore important that the data on this continues to be kept until at least the end of 1992.

2.1.3 Hygiene Considerations During Cleaning

On the basis of occurrence of a few unusual bacteriological analysis results which for example, show a high level of contamination in the SSF outlet while

the Roughing Filter outlet shows none, a discussion was held with the resident Senior Technical Officer at the plant regarding the conduct of the workers during the cleaning of SSF. It was very clear that there is a need for all the involved staff members to be enlightened on the importance of observing hygiene. If possible, the workers involved should be provided with boots for wearing strictly only while doing the SSF cleaning work and for no other use (including going to the toilets with them). The need for a specialized in-house training of the workers is very evident.

2.1.4 Changes of the SSF Filtration Rates

In August 1991 the SSF were found to have been operating at a low rate (approx. 0.06 m/h). It was then decided to increase it to the usual rate of approx. 0.11 m/h. This brought sudden increase in the filtration rate to nearly double within a short spell. The effect of this was the occurrence of short-term deeper penetration of impurities which is narrated in section 2.3.2 of this report. The need to keep the filtration rate as constant as possible cannot be over-emphasized.

2.1.5 Inadvertent Opening of the Bottom Intake Pipe

During routine troubleshooting at the intake of the ~~main treatment works~~ dam carried out by the WD in the first week of January 1992, it was discovered that the bottom intake pipe (i.e. 20m deep) was kept open for an unspecified time. The pipe was closed on that occasion. However, this must have caused continuous delivery of poor quality water to the treatment plant for quite some time.

2.2 Treatment Performance

2.2.1 Treatment Works Laboratory Data

The results cover the period between April 1991 and January 1992 and are grouped into three main sections. The first section summarizes the sulphate, Nitrate, Nitrite, total Iron, Ammonia and Dissolved Oxygen data attached as Appendix.3.

In general, the treatment plant consistently shows a very good removal efficiency of Iron and Ammonia. The sulphate removal is also very notable. On two occasions when Dissolved Oxygen (D.O.) was analyzed (i.e June & July 1991 only), the filtrate D.O. was a bit low. This might have been partially caused by the use of the bottom intake pipe which usually delivers water that is nearly anaerobic in deep reservoirs. In order to check the intensity of biochemical activities in the DRF and to avoid anaerobic

conditions in the distribution lines, it is proposed that D.O. should be monitored bi-weekly for RFI, RFO and SSFO during a period of at least six months.

A summary of Turbidity removal and Bacteriological improvement results is given in Appendices 4 and 5 for the period of April 1991 to January 1992. Appendix 6 shows the graphs corresponding to this period. In general the improvement of both Turbidity and the Bacteriological quality was very good and kept on improving with time with the exception of occurrence of a few undesired incidences. Upon comparing the turbidity removal with the Local Standards (of 25 NTU), with the exception of some periods in the months of April & December 1991 and January 1992, during the rest of the times, the SSF outlet turbidity was within acceptable levels. In fact, at no time did the monthly mean turbidity exceed 29.5 NTU. This was so inspite of the inadvertent use of the bottom intake pipe at the dam site.

Regarding bacteriological quality, its clear that more care has to be taken to supervise the workers when they are cleaning the SSF. Any supporting staff asked to take bacteriological analysis samples has to be made very conscious of the need to maintain absolute sterility of any equipments used. It may be a good idea to secretly counter-check the first few samples which they take on their own. The need for formal short-term training of supporting staff in health education is very clear.

The most important observations from these results are that any increases in the filtration rates of the SSF have to be done gradually and should be done under supervision of Engineers. The shock chlorination of the DRF and SSF done for purposes of identifying the source of algae in November 1991 is not desirable. At no time should one consider dosing chlorine in either the DRF or the SSF again because that is detrimental to the bio-chemical processes taking place in both units.

2.2.2 Results from the Danish Laboratory

The parameters analyzed by the Danish Laboratory between January and December 1991 for water samples from some nine locations within the catchment of Mpira/Balaka project are summarized in Appendix.7. These included the main treatment works and four depths of the dam reservoir which are shown on the schematic sketch on Appendix.8. The pattern of Total Iron, Aluminium and Total Phosphorus is described in detail in this report.

2.2.2.1 Total Iron

From the graphs on Appendix.9, it can be seen that the total Iron distribution in the reservoir showed a distinct increase in concentration with depth with the highest recorded value of 43.1 ppm at 20m depth in January 1991. This by

chance led to the highest level of total Iron in the SSFO recorded of 6.54 ppm on the same date. Otherwise, during the rest of the time, the level of total Iron in the SSFO was within the average value of 1.64 ppm that is also well within the allowable local temporary standard of 2.0 mg/l. The SSFO ranged from 0.022 to 6.54 ppm total Iron during this period. The effect of use of the bottom intake water is very apparent from the results and if one examines the total Iron level at the depth of 5.0m one clearly sees that the maximum never exceeded 11.6 ppm instead of the 43.1 ppm reported.

2.2.2.2 Aluminium

The graphs in Appendix.10 show that the level of Aluminium in the reservoir and along the treatment plant followed a similar trend to the total Iron. The highest level of Aluminium recorded was in the reservoir and at a depth of 20m which was 50 ppm and resulted in a high (inexplicable) RFO of 63 ppm that was nevertheless brought down to only 9.2 ppm in the SSFO. By chance the latter was to become the highest value of the SSFO which generally ranged from 0.011 to 9.2 ppm with an average value of 1.96 ppm that is well within the local temporary standards of 2.0 mg/l. Inspite of using the bottom intake pipe, the DRF/SSF system coped very well with the high Aluminium load in the reservoir water. It is fair to comment that although the Aluminium levels do increase in the reservoir during the rains especially between February and April, the levels in the SSFO are not alarming at all. It is important to also note that orally ingested Aluminium compounds at such low concentrations do not have any deleterious health effects to most human beings with the exception of kidney dialysis patients. Even the WHO guideline value of 0.2 mg/l was set on compromise basis purely by considering non-health related matters associated with discoloration. Finally, one can note that if the 5.0m depth intake was the one used, the maximum Aluminium level recorded would have been only 12.0 ppm in place of the 50 ppm currently observed.

2.2.2.3 Total Phosphorus

The graphs on Appendix.11 clearly show that in the reservoir, there was a very clear tendency of the total phosphorus increasing with depth. However, in the treatment plant, one can observe the existence of a moderate capacity to remove the total Phosphorus. While the maximum RFI total Phosphorus was 0.62 ppm, the SSFO value ranged from 0.027 to 0.19 ppm. In general, the total phosphorus levels in the RFI was fairly similar to the same for the 20m depth in the reservoir.

The rainy season led to some increase in total Phosphorus concentration thus reinforcing the validity of the theory of leaching from nearby farmlands. The shifting of most of the farmers from the Mpira river catchment which was largely completed in August 1991 is expected to reduce even further the effect of nutrients like Phosphorus and Nitrogen on algae growth in the reservoir in

the near future. In fact, there were fewer algae related problems in 1992 than 1990.

2.2.2.4 **Other Parameters Analyzed**

Apart from Silica and to some extent pH, the results of the other compounds analyzed are of no immediate interest due to the delay between the time of sampling and analysis involved.

2.2.3 **Results from the Central Water Quality Laboratory, Lilogwe (CWQ)**

Due to the tendency to leave water samples for long durations before analysis, the results of most samples taken to the CWQ were of very limited use. The most useful data was that of total suspended solids concentration which albeit did not distinguish the volatile from the non-volatile proportion. The data is presented in Appendix.12 and shows that the maximum recorded suspended solids concentration was 465 mg/l for a water sample taken from a depth of 20m in the reservoir. Once again, an increase of the concentration of the suspended solids with depth is apparent with the quality of the RFI being closely related to that of the 20m depth samples. The level of suspended solids concentration in the SSFO remained fairly low at between 3.0 to 32 mg/l with an average of 11.35 mg/l.

The DRF and SSF jointly contributed for suspended solids removals of between 62 and 95%. It is proposed that this parameter be monitored intensively for at least during the whole of the current rainy season for the RFI, RFO and SSFO and should include both the volatile and non-volatile components.

2.2.4 **Analysis Data from the University of Malawi (ICU)**

At the time of writing this report, only two sets of data were received from the Chancellor College for the samples taken on the 24th July 1991 and of the 10th September 1991. However, with the exception of the total Iron results, the data on the other parameters was so different from those reported by the Danish Laboratory which has a better quality control that one has to get further information on the methods of analysis used there prior to making any comment. In addition, the consultant was informed of the delays in analyzing the samples which originated from bureaucratic bottlenecks. These must have partially contributed to the mentioned differences. The Water Department should follow up this matter with the relevant authorities.

2.3 Overall Treatment Plant Assessment

While bearing in mind the operational constraints faced during the year 1991 together with the continuation of the task of modifying the DRF expected to be finished soon, the treatment works operation and treatment ability has improved tremendously. The merits of the modification of the DRF have been established in this review report.

The consultant is recommending that the WD should concentrate its efforts in finishing the modification of the DRF1 as soon as possible so that the treatment works can be run under the long-term conditions with six SSF and DRF1. The exclusion of the bottom intake pipe will also ensure delivery to the water works water of better quality throughout the year.

In an attempt to improve even further the monitoring of the treatment plant capacity, the laboratory at the treatment plant should be strengthened and expanded to carry out a few more relevant routine tests (including suspended solids and D.O.) in order to ensure existence of the local capacity to handle this matter. The laboratory might also be useful for monitoring the water quality in the distribution mains apart from also serving any nearby water supply schemes in future. Complicated tests will however, still have to be carried out at the Central Water Quality Laboratory in Lilongwe (CWQ).

3. TREATMENT PLANT CAPACITY OF THE MAIN WORKS

3.1 Introduction

There are six Slow Sand Filters and five modified Downflow Roughing Filters (DRF) which are operational. The Downflow Roughing Filter is nearing completion but still needs to be filled with media. The modifications to the DRF proposed by the consultant in April 1990, have been carried on four DRF (which became operational by the end of May 1991 (i.e. DRF3-6). In May 1992, water analysis of a complete year of operation with the four modified DRF will be available. However, the results will be largely based on the use of the bottom intake (20m deep) which was found to have been inadvertently left open until during the first week of January 1992 when it was closed. It is difficult to guess when this pipe was actually opened for the first time.

3.2 Projected Capacity for the Year 2005

To establish the required plant capacity at any time, apart from the plant filtration ability, a number of operational factors have to be considered.

3.2.1 Operational Factors Considered

The first operational factor considered is SSF cleaning, records collected between January 1991 and 1992 show that it usually takes two (up to three) days to clean the SSF bed because prior to scraping the top 20 - 30mm, the filter has to be drained and then refilled up to the operational level before restarting. For a DRF protected SSF unit, this operation is done on average once a month. Assuming ten SSF are provided and considering the worst circumstances, one filter will be out of operation permanently for cleaning purposes.

Regarding resanding, if its assumed that the average scraping thickness of sand is 25mm, for an average filter run time of one month and with an initial sand depth of 1200mm, in two years, the net scraping depth will be 600mm to bring the sand depth to the minimum of 600mm. Experience at Balaka has shown that it takes approximately three months to complete the resanding of one unit. Again considering that ten only SSF are provided, another SSF unit will also be permanently inoperational for purposes of resanding.

Current operational experience has shown that the DRF can operate at up to 60 cu.m/h without any problems. This corresponds to a filtration rate of about 0.9 m/h. This in turn corresponds to a SSF filtration rate of about 0.12 m/h. However, the average operational flow is usually set at between 50 and 55 cu.m/h thus leading to an average flow of 15 l/sec. The capacity of the six

SSF units now constructed has thus been shown to be about 90 l/sec. at a rate of just under 0.1 m/h if all are operational at the same time. Considering a specific domestic water consumption of 27 l/c.d., the total water demand for the project area by the year 2005 when excluding Balaka town expected to have its own supply and including other miscellaneous requirements will be 120 l/sec.

Since each SSF unit can treat about 15 l/sec., in order to treat 120 l/sec., at least eight SSF units are required. Considering that two units are permanently out of operation, 10 SSF units are required in order to provide standby capacity for both cleaning and resanding of the SSF.

4. CONCLUSIONS

The following conclusions can be made regarding the current status of Mpira/Balaka Water treatment works:

4.1 The water treatment plant which now comprises of the modified DRF and SSF is capable of improving the raw water quality from Mpira dam reservoir to an acceptable level even under the most difficult operational conditions explained in this report.

4.2 The SSF filtrate from the water works is safe for human consumption after addition of minimum of chlorine for final disinfection and for prevention of recontamination.

4.3 The merits of the modifications of the DRF have been shown in the form of a much improved operational conditions in terms of the SSF filter run times.

4.4 In order to meet the future (year 2005) water demands excluding Balaka Town without any difficulties, the water works should be expanded to have four more DRF and 4 more SSF units.

4.5 To improve further the performance of the works, a comprehensive in-house training of the lower cadre personnel involved with routine operation of the treatment plant should be effected as soon as possible.

4.6 The Laboratory facilities at the water works should be upgraded in order to improve its routine monitoring capability.

4.7 There is no need to go for full scale chemical treatment in this project as the current treatment system is suitable especially when one considers the aspect of long-term sustainability which is critical for future success of any rural water supply scheme.

4.8 Assessment of failure or success of any water treatment plant should be based on the quality of final filtrate and not on the raw water quality as such.

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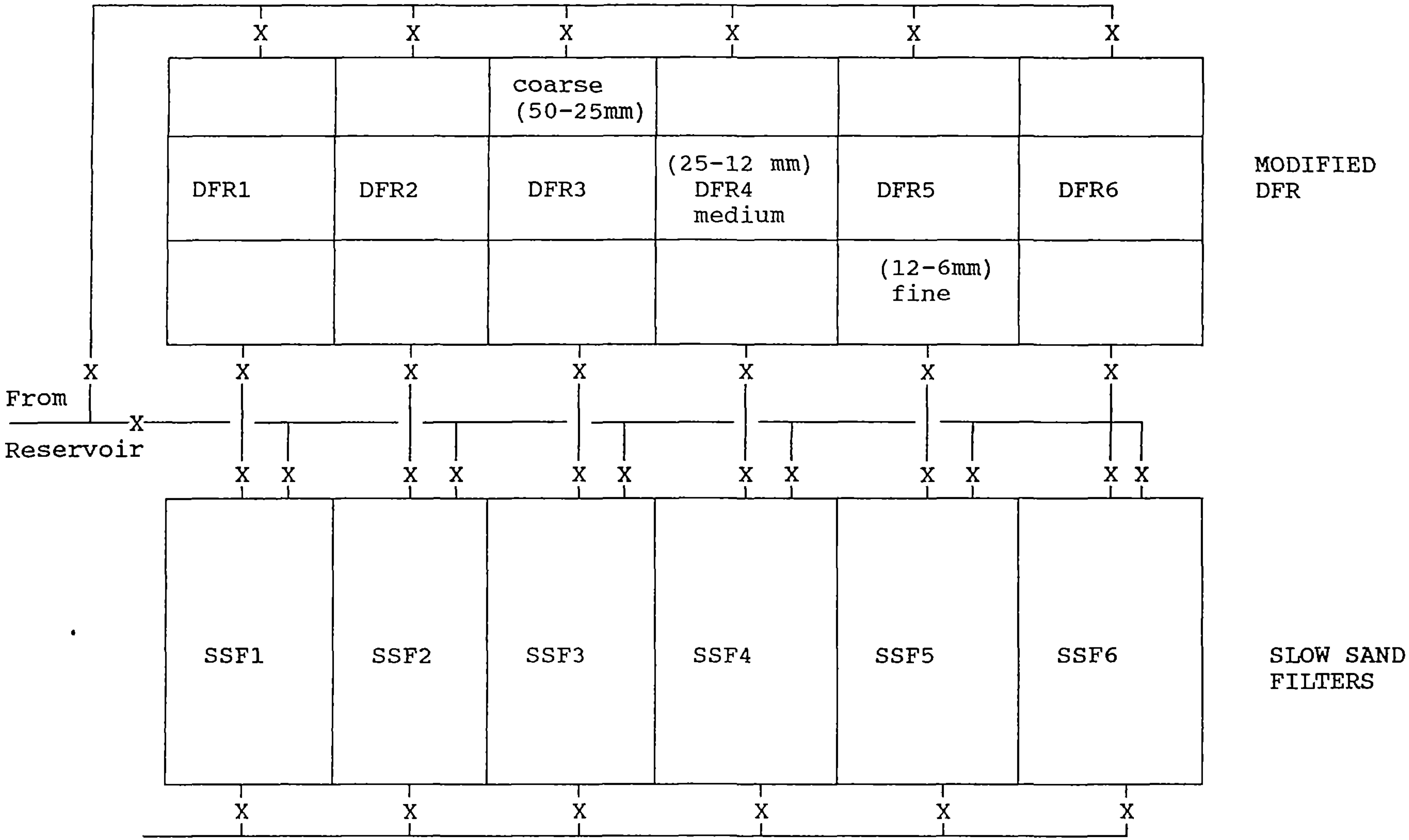
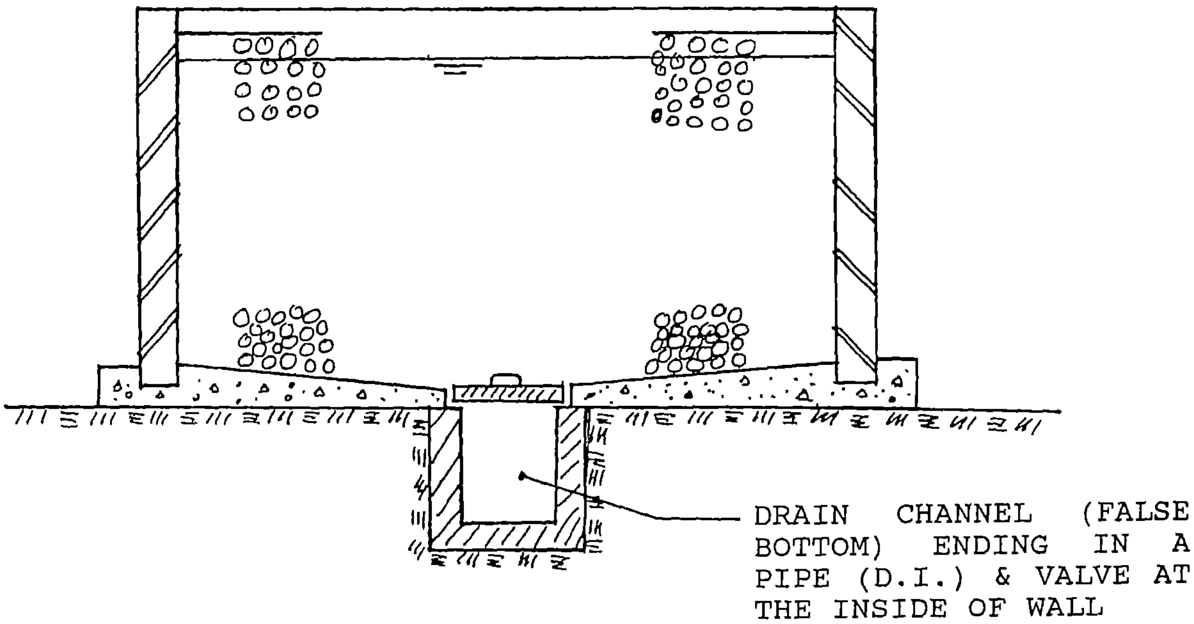


THE SCHEMATIC LAYOUT PLAN OF MPIRA/BALAKA WATER WORKS

APPENDIX 1



NOTE: FILTERED WATER COLLECTION PIPES ARE OPTIONAL

A TYPICAL CROSS-SECTION OF A DRF PROVIDED WITH A DRAIN CHANNEL (FALSE BOTTOM TYPE)

TREATMENT WORKS LABORATORY ANALYSIS RESULTS

Date	Sulphate (mg/l)		Nitrate (mg/l)		Nitrate (mg/l)		Total Iron (mg/l)		Ammonia (mg/l)		Dissolved oxygen (mg/l)	
	RFI	SSFO	RFI	SSFO	RFI	SSFO	RFI	SSFO	RFI	SSFO	RFI	SSFO
April 1991	7.20	4.75	0.31	0.38	0.20	0.03	0.26	0.07	0.31	0.32	-	-
June 1991	5.83	3.33	0.15	0.45	0.02	0.01	0.20	0.08	0.05	0.00	6.70	5.88
July 1991	4.75	2.63	0.12	0.70	0.02	0.04	0.14	0.04	0.00	0.00	6.45	4.99
August 1991	2.67	1.29	0.25	0.50	0.02	0.01	0.20	0.05	0.05	0.05	-	-
September 1991	3.40	1.20	0.36	1.40	0.12	0.03	0.14	0.04	0.15	0.17	-	-
October 1991	3.86	2.14	0.05	1.48	0.02	0.21	0.32	0.03	0.68	0.21	-	-
November 1991	2.67	2.83	0.01	1.69	0.00	0.37	0.49	0.04	1.30	0.25	-	-
December 1991	6.00	2.72	0.04	0.64	0.09	0.08	0.68	0.06	1.01	0.34	-	-

APPENDIX 3

TURBIDITY (NTU)

Date	Results		EXPLANATIONS
	DRFI	SSFO	
April 1991	48 - 157	31 - 132	i) Generally Turbidity removal low, sometimes an increase in SSF Outlet observed. ii) Only DF4&5 commissioned by 19/03/91. Flushing just finished on DF4 and most of the water is not pretreated.
June 1991	54 - 70	23 - 33.8 Mean = 29.5 NTU	i) Average SSF filtrate quality is better and very stable. (See graph, Appendix. 6.1)
July 1991	28 - 60	17 - 32	i) Average SSF filtrate turbidity is within local standards for most of the time. ii) On a number of occasions, slightly higher SSF filtrate than DRF outlet turbidity observed. This could either be caused by cleaning of the two SSF or unusually fine algae penetration which is not unusual in a SSF. If the latter is the cause, "Chlorophyl-a" analysis could confirm it. (See graph, Appendix. 6.2)

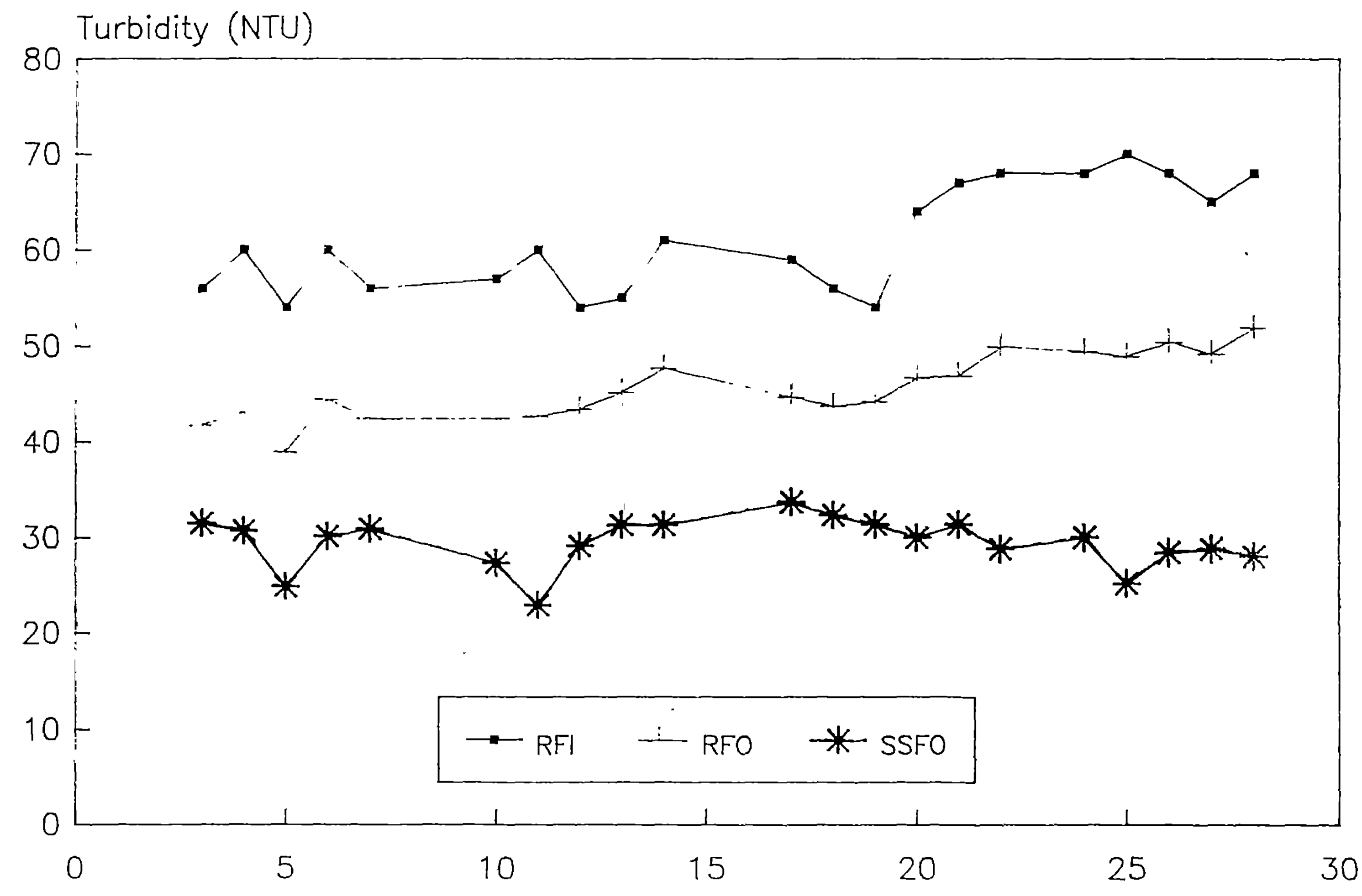
August 1991	19 - 28	9.4 - 19.2 Mean = 15.2 NTU	i) DRF outlet ranged from 9.4-19.2 NTU. The SSF outlet was for sometime slighty higher that the SSF outlet. ii) Possible cause of higher turbidity is deep penetration of impurities caused by uprating as a result of increase in flow from 25 - 30 to 60 cu. m/h. Exact date not known but increase not affected gradually. (See graph, Appendix.6.3).
Sept. 1991	15 - 21	2.6 - 7.8 Mean 4.9 NTU	i) DRF outlet ranged from 3-7.5 NTU. The SSF outlet was for a short period higher than the DRF outlet. (See graph, Appendix. 6.4) - Other reasons as in August 1991.
Oct. 1991	13 - 21	0.8 - 3.0	i) DRF outlet turbidity, 3.7- 9.0 NTU ii) SSF outlet quality is very good and stable. The incoming turbidity is fairly similar to September. (See graph, Appendix.6.5)
Nov. 1991	11 - 23	1 - 4.5 Mean = 2.2 NTU	i) DRF outlet turbidity, 3 - 10.3 NTU. ii) However, the overall performance was very good with SSFO < 10 NTU. (See Appendix 6.6)
Dec. 1991	27 - 229	0.6 - 58.3 Mean = 7.9 NTU	i) The SSF outlet is only from SSF3 - 6. ii) Very high inlet water turbidity on 27th and 30th, the shock load led to low removals in the DRF but the SSF took the majority of the load. (See Appendix 6.7)
January 1992	12 - 180	3.4 - 74.5 Mean = 20.5 NTU	i) During the first week of january 1992, the bottom intake pipe which had been open was closed. Note the decrease of RFI the next day from 87 to 15 NTU. SSFO value down to < 10 NTU. (See Appendix 6.8)

BACTEREOLOGICAL QUALITY (No./100 ml)

Date	Faecal Coliforms (FC)		Faecal Streprococci (FS)		EXPLANATIONS
	DRFI	SSFO	DRFI	SSFO	
April 1991	4 - TNTC	0 - 51	0 - 32	0 - 9	i) Performance is Average/Moderate. ii) Some unsatisfactory results obtained even when DRF Inlet quality is good, Suspect Analysis. Possible causes are: 1) Sample contamination 2) Poor hygiene during cleaning of SSF. e.g. SSF 3,4 & 5 cleaned on 13th, 15th, and 17th.
June 1991	0 - 42	0 - 4	0 - 2	0	i) Bacteriological quality good.
July 1991	0 - 4	0 - 2	0 - 1	0 - 1	i) Performance generally goo, pollution load low.
Aug. 1991	0 - 12	0 - 4	0 - 1	0	i) Results were good but suprisingly no problems associted with increase in the rate of filtration. ii) The explanation is plausible if one considers the difference in the nature of the particles i.e. colloids and bacteria
Sept. 1991	2 - 26	0 - 10	0 - 2	0 - 1	i) Performance is good inspite of the filtration rate increase
Oct. 1991	0 - 60	0 - 2	0 - 2	0	i) Bacteriological quality improvement is very good
Nov. 1991	6 - 56	0 - 9	0 - 12	0 - 2	i) Performance is good although the shock chlorination of DRF and SSF done in Nov. 1991. ii) Slight reduction in removal of bacteria noted.
Dec. 1991	13 - TNTC	0 - 33	0 - TNTC	0 - 26	i) Below average performance and hence chlorination is compulsory after SSF.
Jan. 1992	11 - TNTC	0 - 3	4 - 37	0	i) The performance is better than normal inspite of the worse inlet water quality.

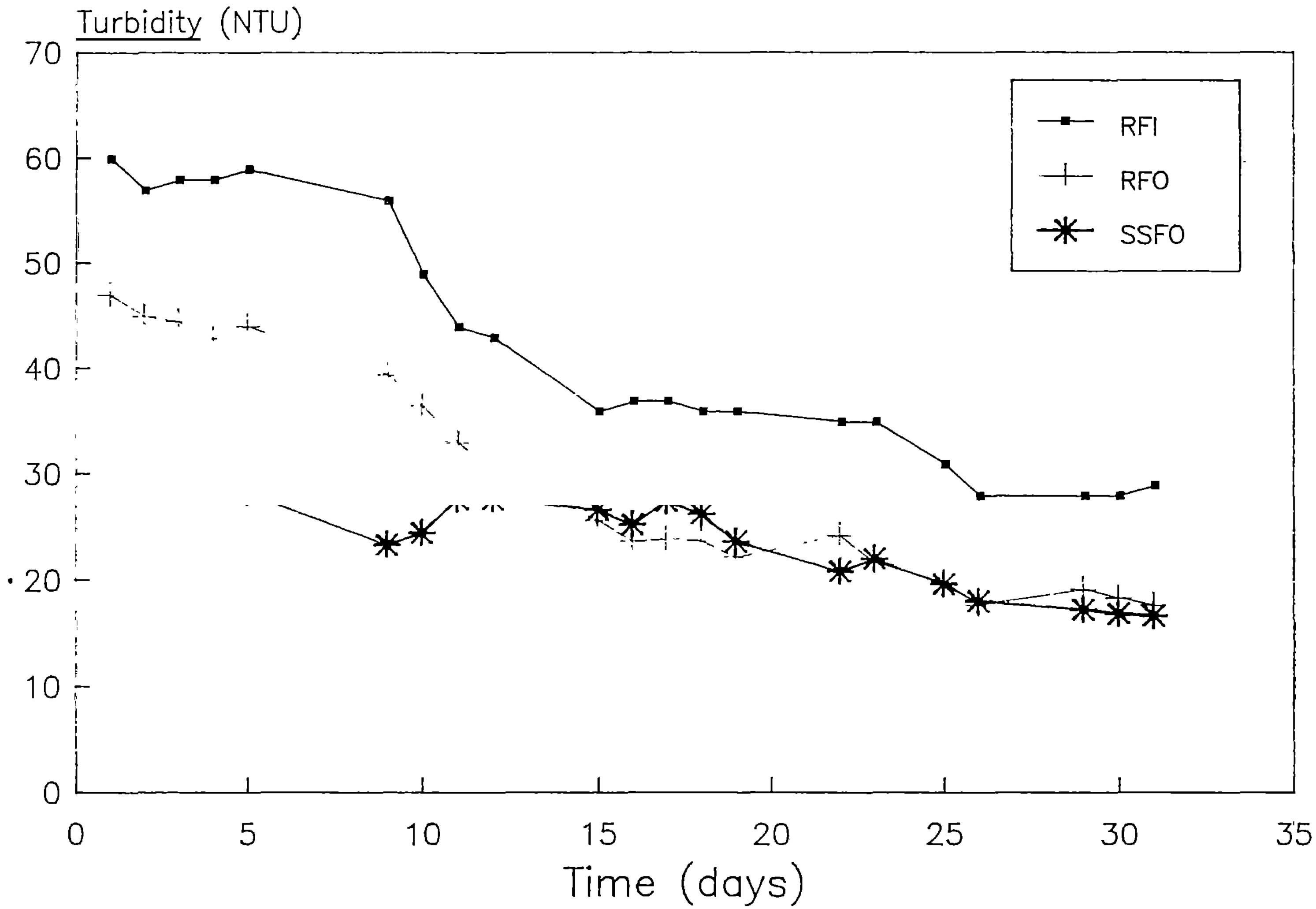
Note: TNTC = Too Numerous To Count

APPENDIX 5



MAIN TREATMENT WORKS TURBIDITY VARIATION, JUNE 1991

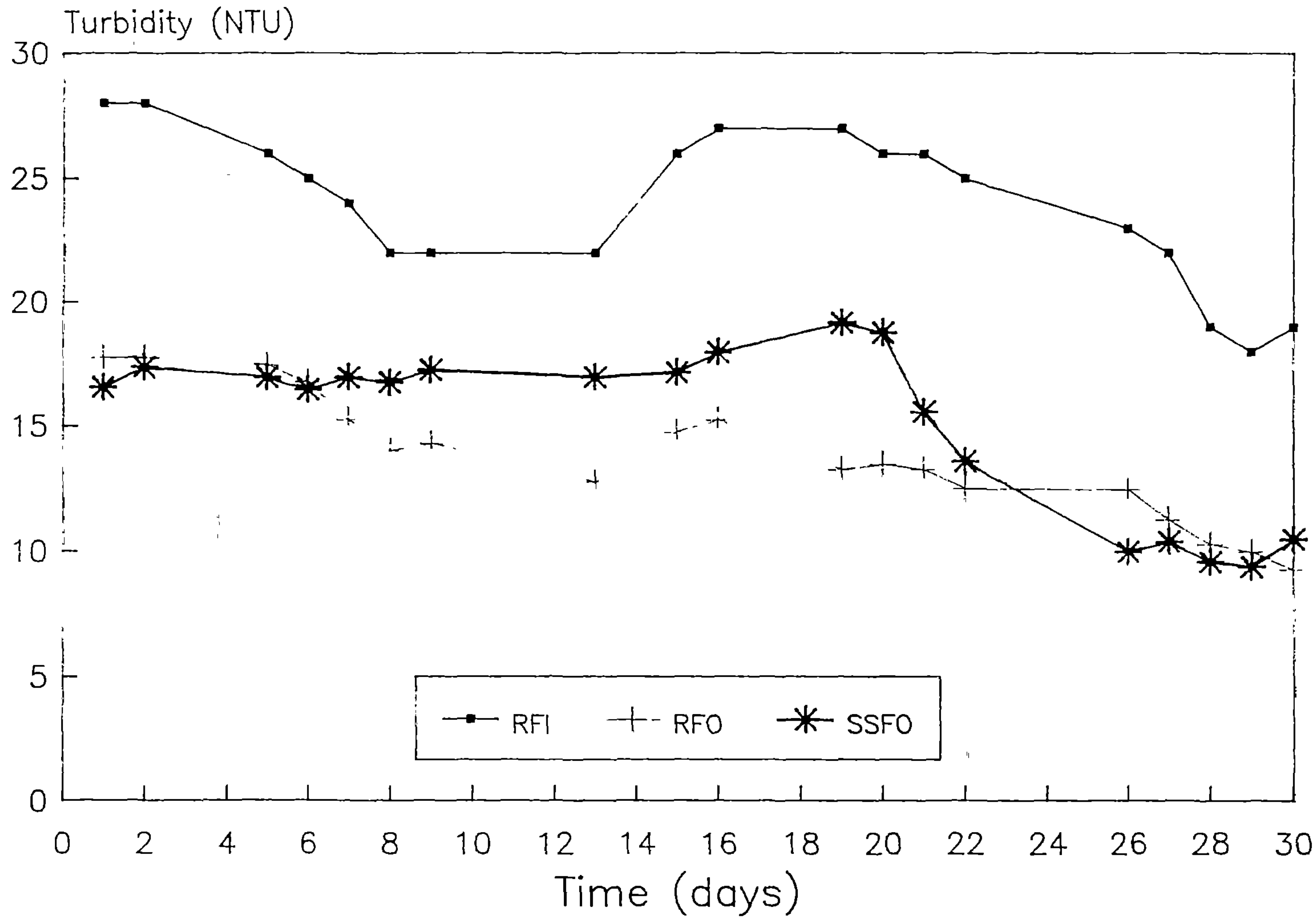
APPENDIX 6.1



MAIN TREATMENT WORKS TURBIDITY VARIATION, JULY 1991

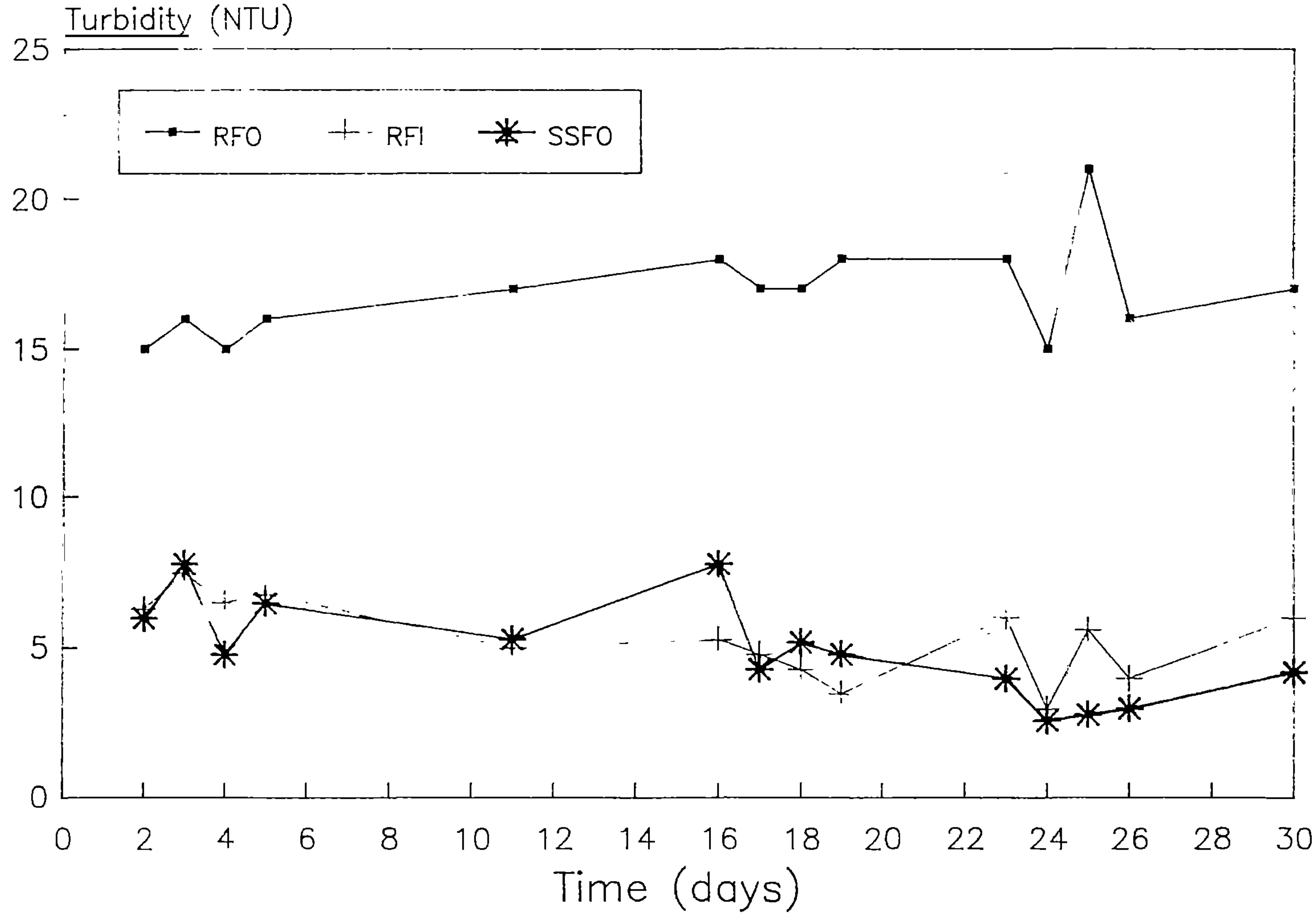
APPENDIX 6.2

APPENDIX 6.3

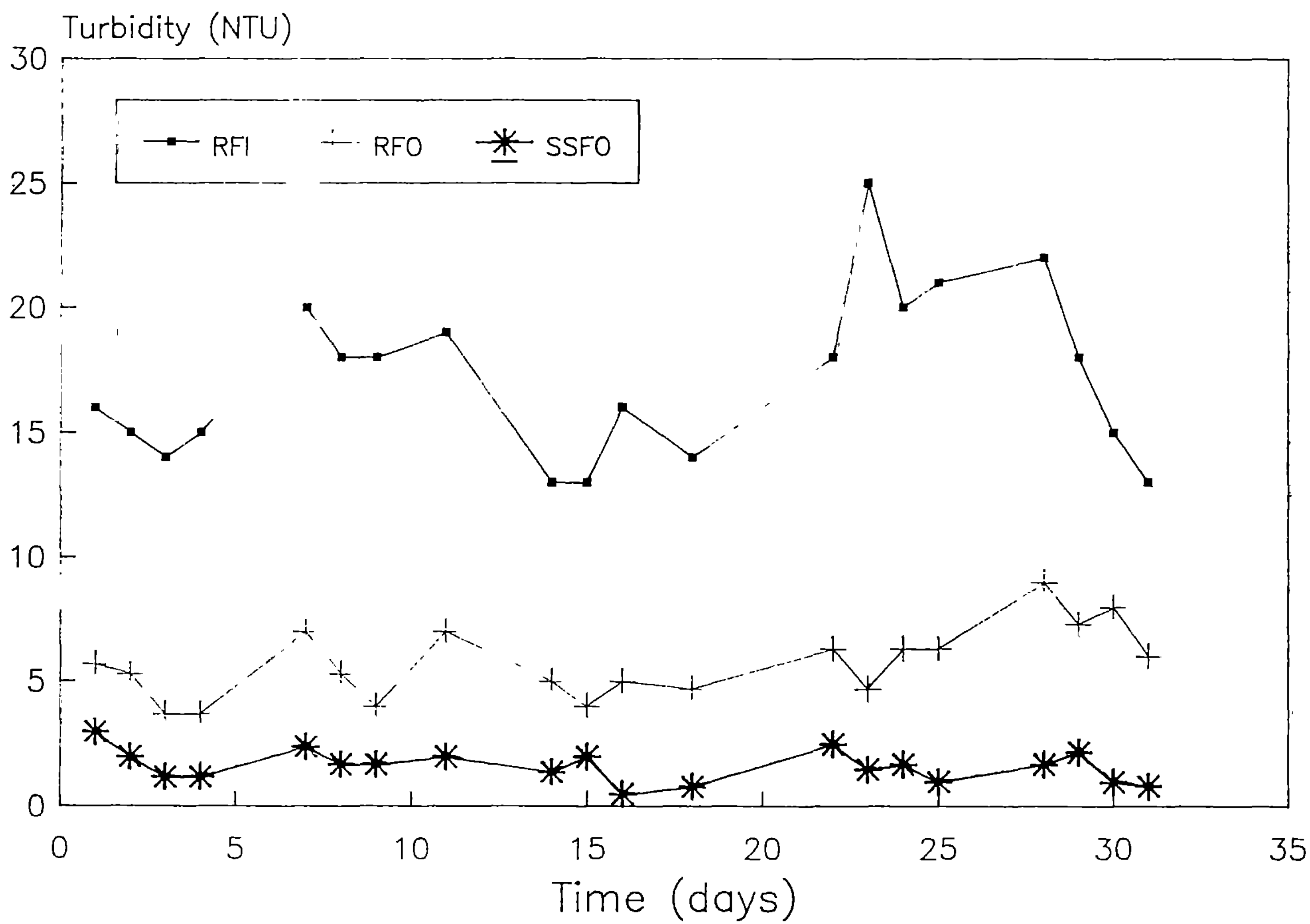


MAIN TREATMENT WORKS TURBIDITY VARIATION, AUGUST 1991

APPENDIX 6.4

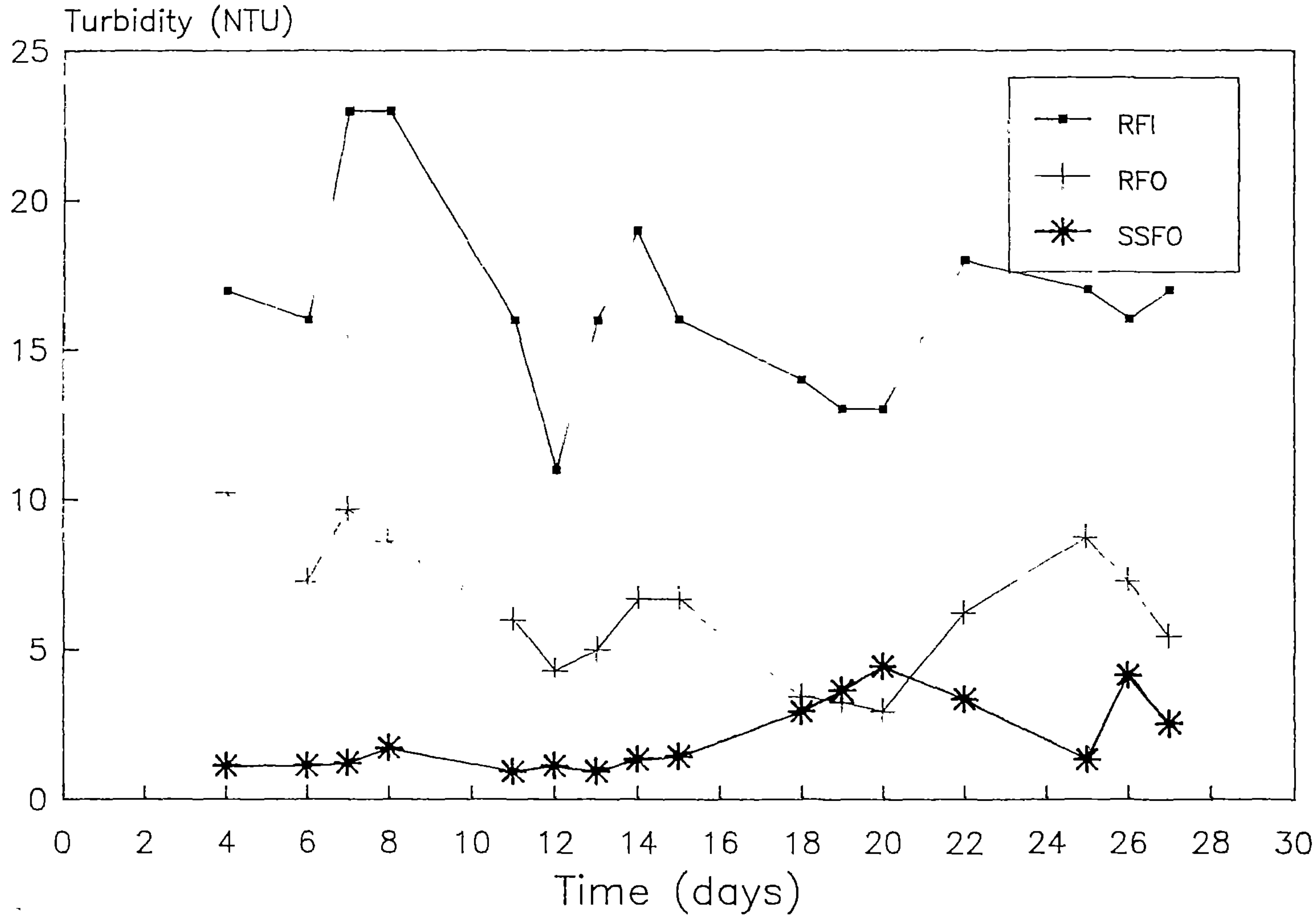


MAIN TREATMENT WORKS TURBIDITY VARIATION, SEPTEMBER 1991



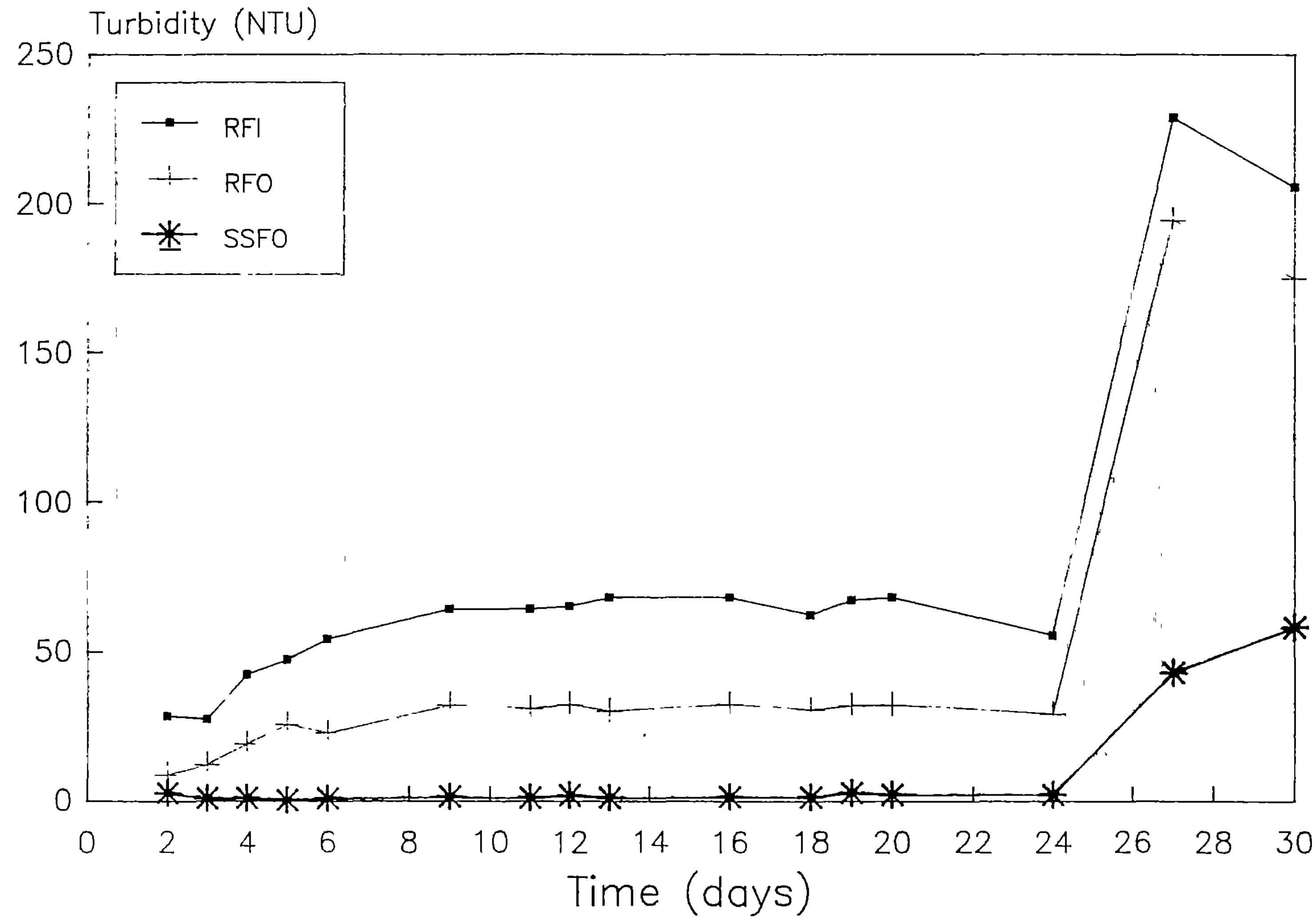
MAIN TREATMENT WORKS TURBIDITY VARIATION, OCTOBER 1991

APPENDIX 6.5



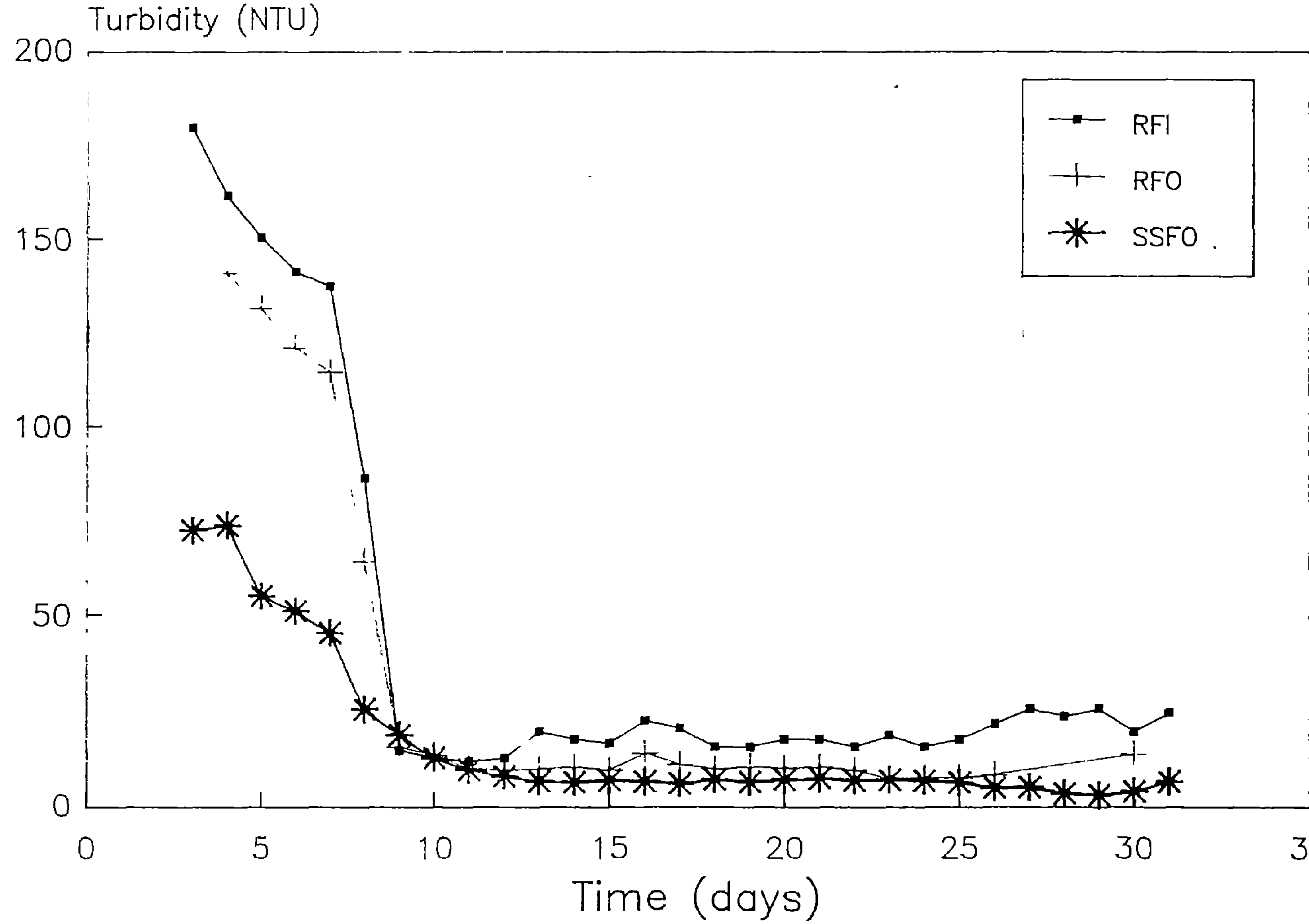
MAIN TREATMENT WORKS TURBIDITY VARIATION, NOVEMBER 1991

APPENDIX 6.6



MAIN TREATMENT WORKS TURBIDITY VARIATION, DECEMBER 1991

APPENDIX 6.7



MAIN TREATMENT WORKS TURBIDITY VARIATION, JANUARY 1992

APPENDIX 6.8

A SUMMARY OF THE DANISH LABORATORY RESULTS

PARAMETER	DATE	DAY No.	SAMPLING POINTS								
			UF	DF	SURFACE	5 m	10 m	20 m	RFI	RFO	SSFO
Iron, Total (ppm)	29/1/91	29	3.00	-	2.03	11.6	-	43.1	-	24.5	6.54
	10/1/91	10	0.66	2.8	1.53	2.10	3.9	3.53	1.23	0.51	0.022
	28/2/91	59	4.12	18.9	2.70	4.16	12.3	30.5	19.7	17.7	3.87
	11/4/91	101	0.56	0.53	2.60	2.56	2.59	2.30	3.42	3.44	2.71
	16/5/91	136	0.54	0.89	1.62	1.93	1.95	3.64	2.66	1.77	1.12
	18/6/91	169	0.70	0.46	2.25	1.77	1.97	4.36	2.82	1.55	1.26
	24/7/91	207	0.33	0.36	1.13	1.01	1.01	1.01	1.00	0.74	0.72
	10/9/91	255	0.22	0.17	0.48	0.53	0.71	0.93	0.39	0.14	0.064
	21/10/91	296	1.13	0.12	0.17	0.20	0.50	1.90	2.65	0.052	0.022
	28/11/91	334	0.91	0.88	0.031	0.097	1.05	2.41	0.65	0.008	0.12
	17/12/91	353	2.04	8.20	0.23	0.26	3.10	7.45	3.95	0.65	-

Day 0 = 31/12/90

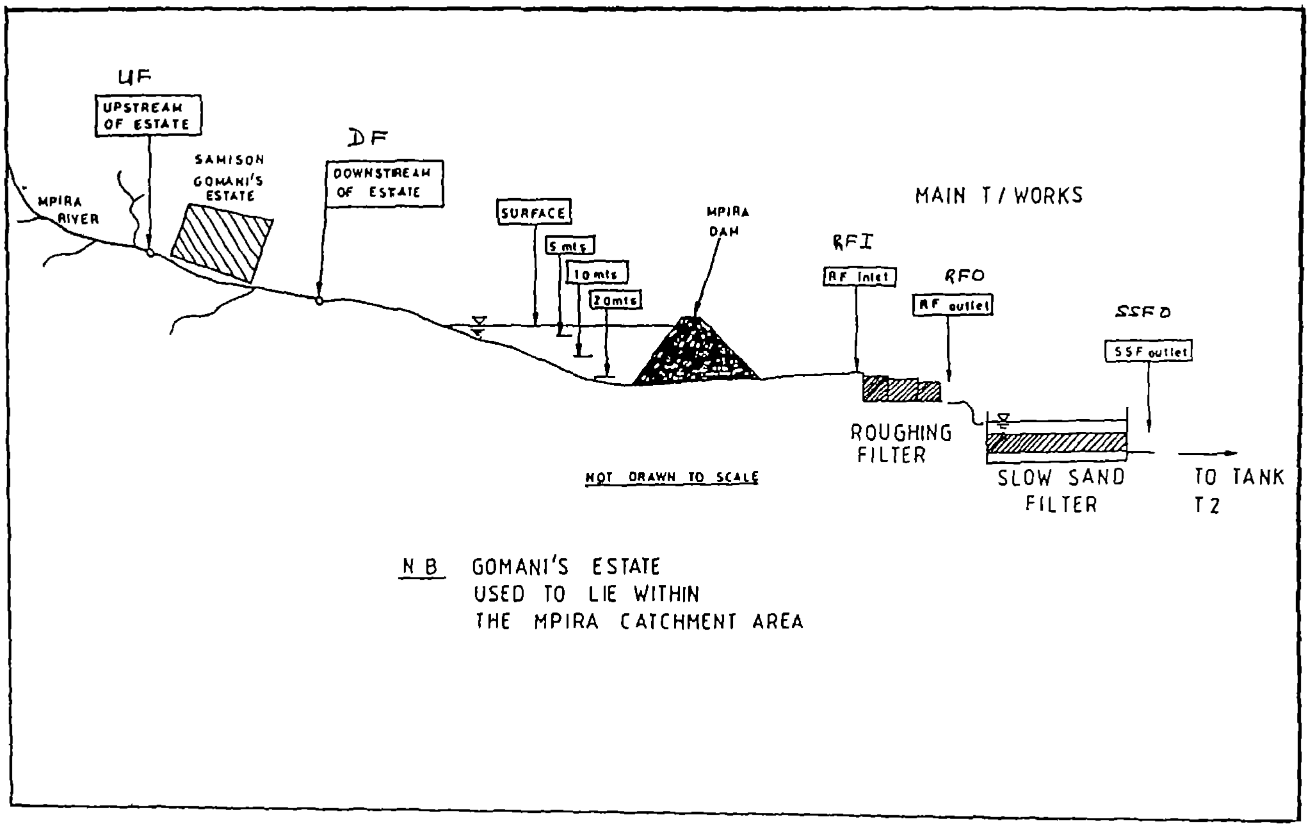
PARAMETER	DATE	DAY No.	SAMPLING POINTS								
			UF	DF	SURFACE	5 m	10 m	20 m	RFI	RFO	SSFO
Aluminium Total (ppm)	29/1/91	29	5.0	-	6.9	0.97	-	2.0	-	2.2	0.64
	10/1/91	10	0.99	0.73	1.2	1.7	4.4	1.6	0.97	0.37	0.041
	28/2/91	59	8.4	25.0	6.4	12.0	23.0	50.0	46.0	63.0	9.2
	11/4/91	101	0.60	0.39	6.1	7.0	6.4	8.2	8.4	8.5	6.0
	16/5/91	136	0.68	0.94	3.3	3.2	3.8	5.1	5.1	3.1	2.2
	18/6/91	169	0.68	0.21	2.63	2.41	2.69	5.31	3.62	2.34	2.10
	24/7/91	207	0.29	0.093	1.84	1.58	1.70	1.53	1.36	1.15	1.21
	10/9/91	255	0.098	0.057	0.70	0.77	0.79	1.1	0.46	0.17	0.095
	21/10/91	296	0.12	0.10	0.18	0.18	0.086	0.10	0.22	0.061	0.11
	28/11/91	334	0.82	1.0	0.095	0.073	0.17	0.12	0.11	0.11	0.027
	17/12/91	353	3.8	20.5	0.26	0.39	2.8	6.6	2.3	0.44	0.02

Day 0 = 31/12/90

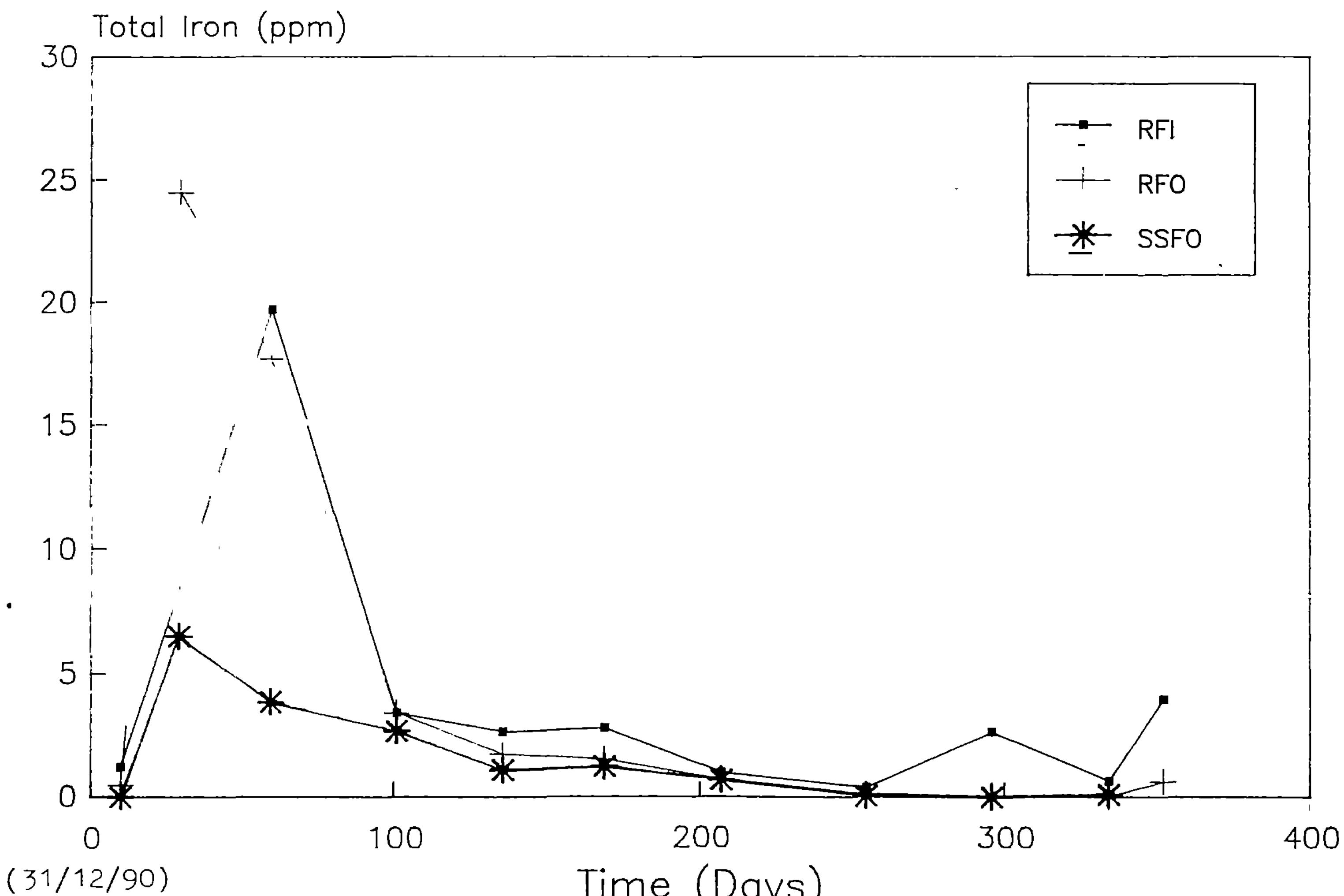
APPENDIX 7.3

PARAMETER	DATE	DAY No.	SAMPLING POINTS									
			UF	DF	SURFACE	5 m	10 m	20 m	RFI	RFO	SSFO	
Phosphorous Total (ppm)	29/1/91	29	0.14	-	0.28	0.31	-	0.77	-	0.74	0.18	
	10/1/91	10	0.66	2.8	0.15	0.12	0.21	0.18	0.087	0.077	0.044	
	28/2/91	59	0.15	0.78	0.14	0.22	0.43	0.78	0.62	0.51	0.18	
	11/4/91	101	0.036	0.085	0.14	0.13	0.14	0.22	0.20	0.16	0.19	
	16/5/91	136	0.038	0.10	0.084	0.095	0.096	0.15	0.13	0.096	0.10	
	18/6/91	169	0.037	0.065	0.30	0.11	0.11	0.19	0.15	0.092	0.073	
	24/7/91	207	0.029	0.060	0.091	0.063	0.071	0.071	0.074	0.051	0.061	
	10/9/91	255	0.041	0.11	0.14	0.088	0.067	0.081	0.066	0.35	0.028	
	21/10/91	296	0.29	0.13	0.086	0.056	0.074	0.18	0.19	0.044	0.027	
	28/11/91	334	0.069	0.15	0.039	0.040	0.098	0.20	0.20	0.14	0.034	
	17/12/91	353	0.17	0.43	0.062	0.063	0.22	0.48	0.27	0.053	0.035	

Day 0 = 31/12/90

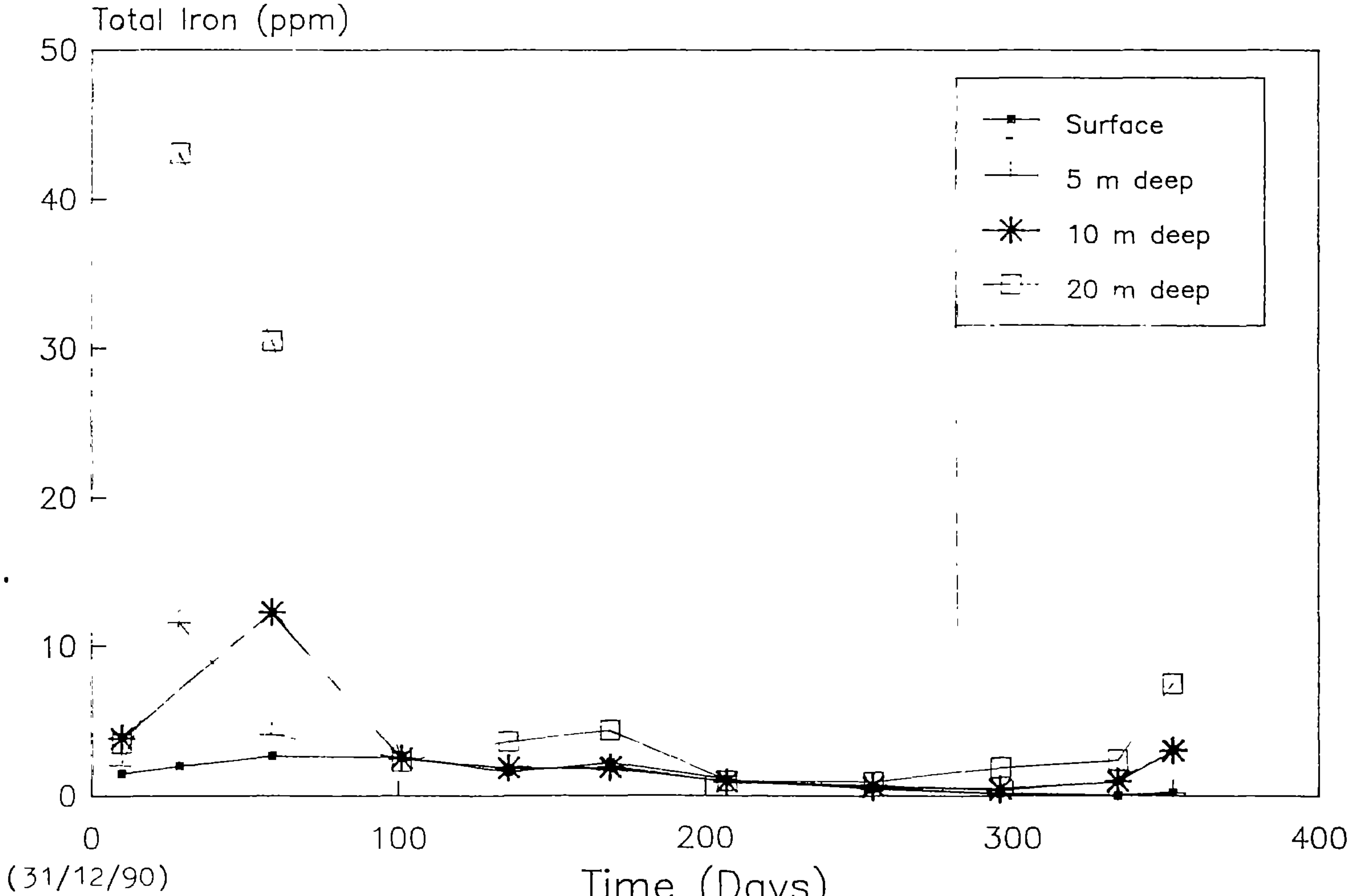


A SCHEMATIC LONGITUDINAL SECTION OF THE LOCATIONS WHERE WAT ER SAMPLES WERE TAKEN



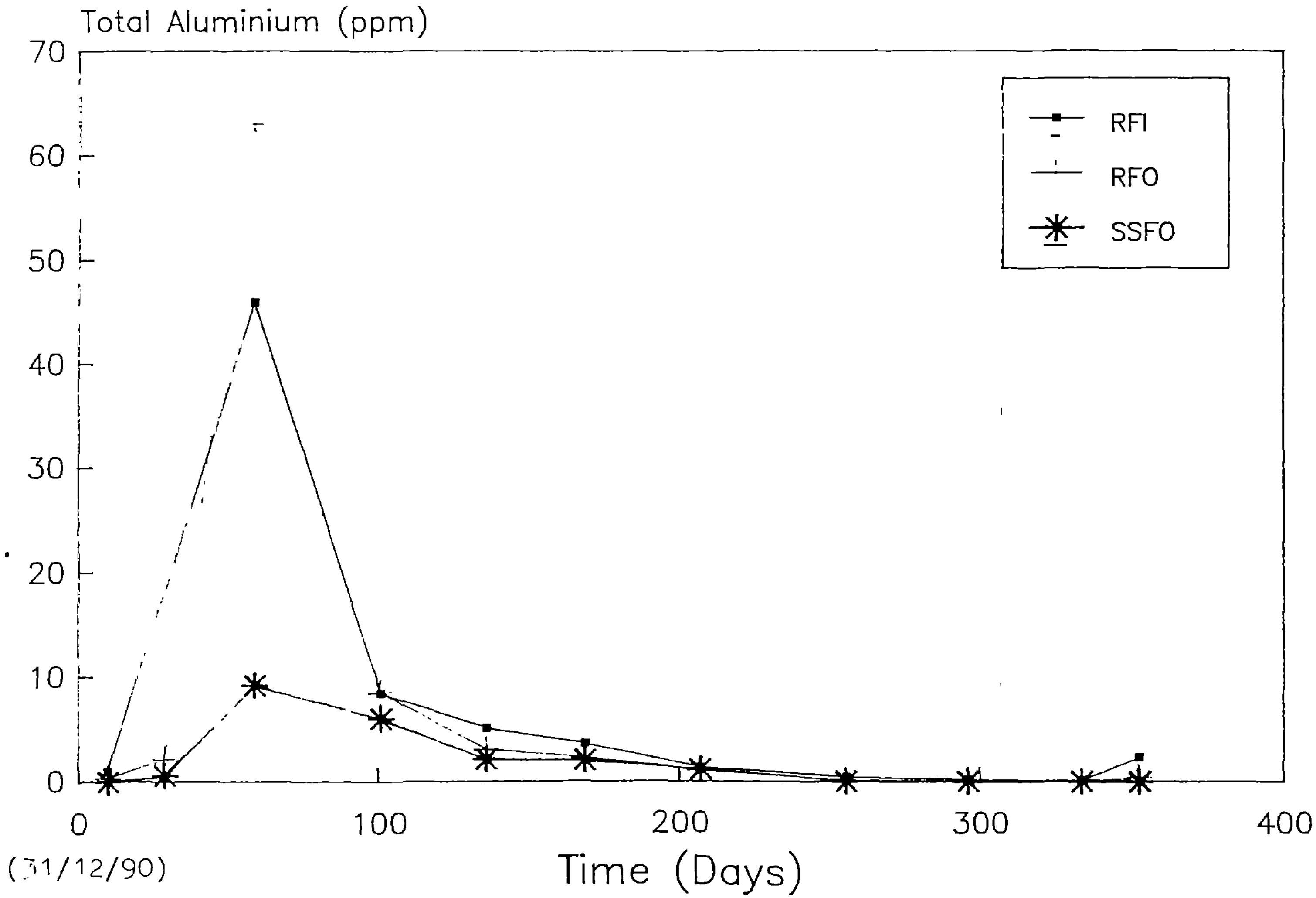
MAIN TREATMENT PLANT TOTAL IRON CHANGES

APPENDIX 9.1



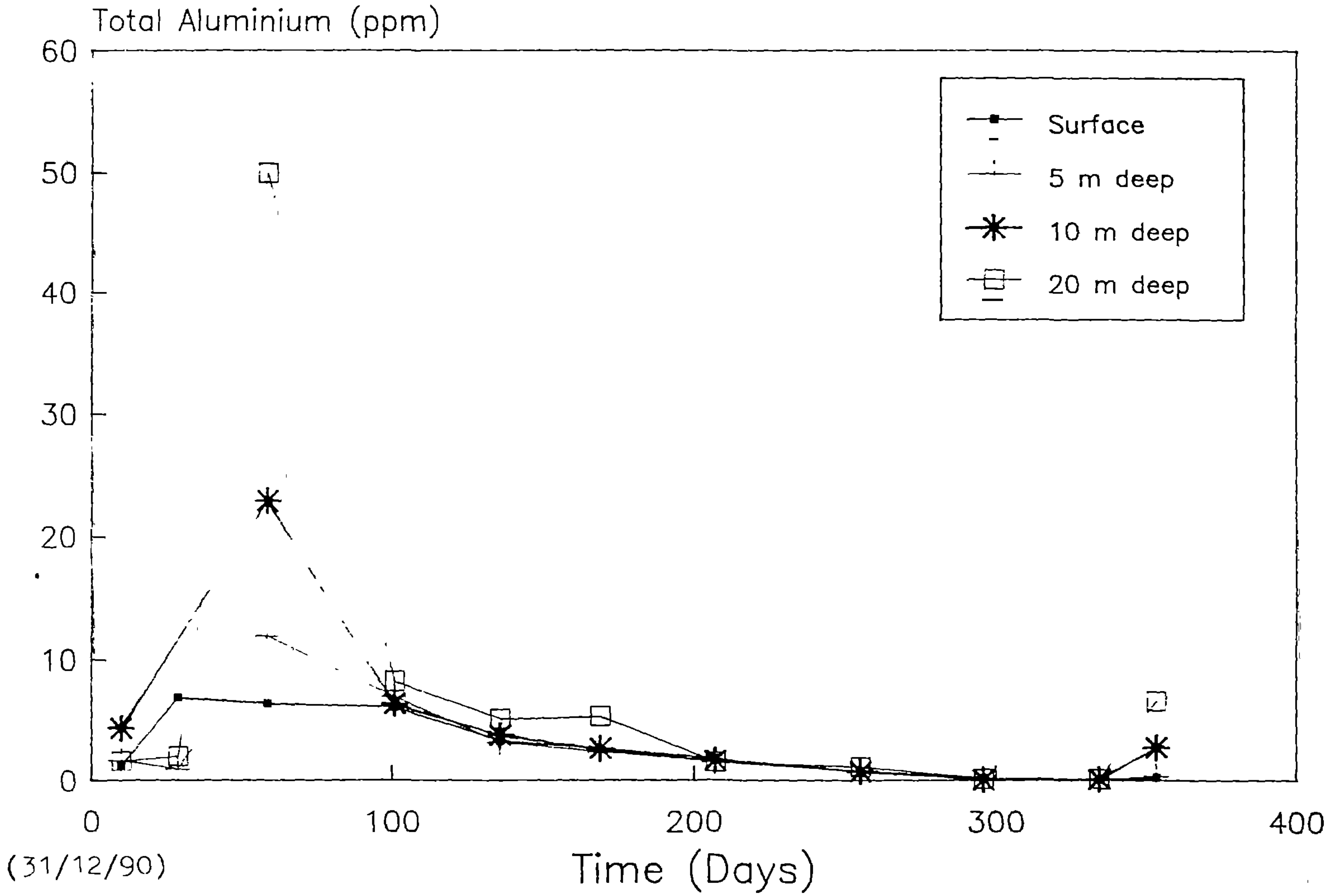
MPIRA DAM: TOTAL IRON VARIATION WITH DEPTH

APPENDIX 9.2



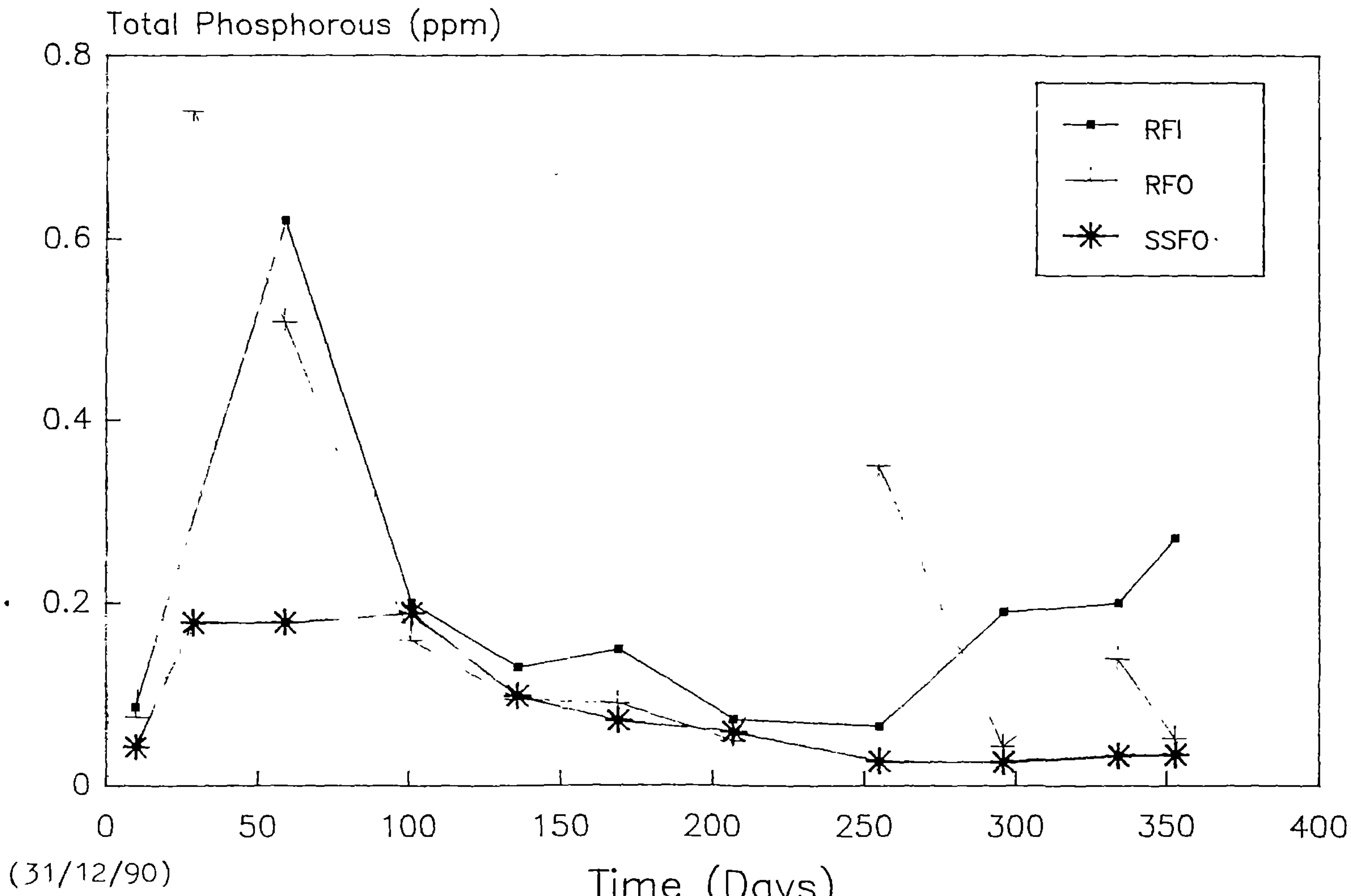
MAIN TREATMENT PLANT ALUMINIUM CONCENTRATION CHANGES

APPENDIX 10.1

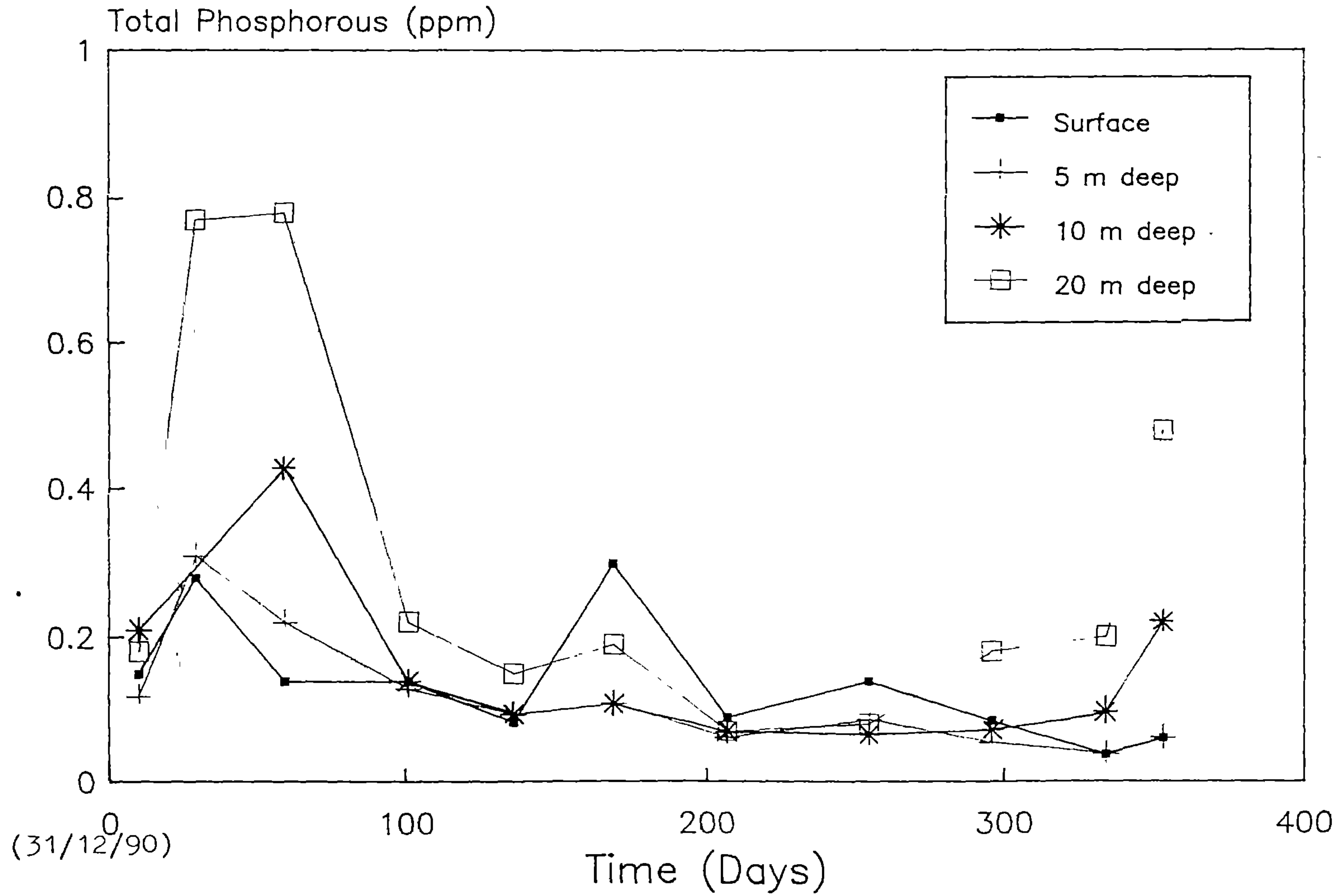


MPIRA DAM: VARIATION OF ALUMINIUM CONCENTRATION WITH DEPTH

APPENDIX 10.2



MAIN TREATMENT PLANT TOTAL PHOSPHOROUS CHANGES



MPIRA DAM: TOTAL PHOSPHOROUS VARIATION WITH DEPTH

APPENDIX 11.2

TOTAL SUSPENDED SOLIDS CONCENTRATION

Date	Concentration (mg/l)						Removal * %
	Mpira River (UF)	Mpira Dam Surface	Mpira Dam 20 m	RFI	RFO	SSFO	
28/02/91	67.0	8.0	465.0	310.0	131.0	17.0	94.5
11/04/91	21.0	42.0	89.0	46.0	22.0	9.0	80.4
02/05/91	-	-	-	22.0	7.0	3.0	86.4
16/05/91	4.0	14.4	36.0	24.0	2.8	6.8	71.7
30/05/91	8.4	-	-	22.0	12.0	6.8	61.9
18/06/91	12.0	59.0	65.0	44.0	11.0	14.0	72.7
Undated	27.0	16.0	353.0	321.0	65.0	32.0	91.6

APPENDIX 12