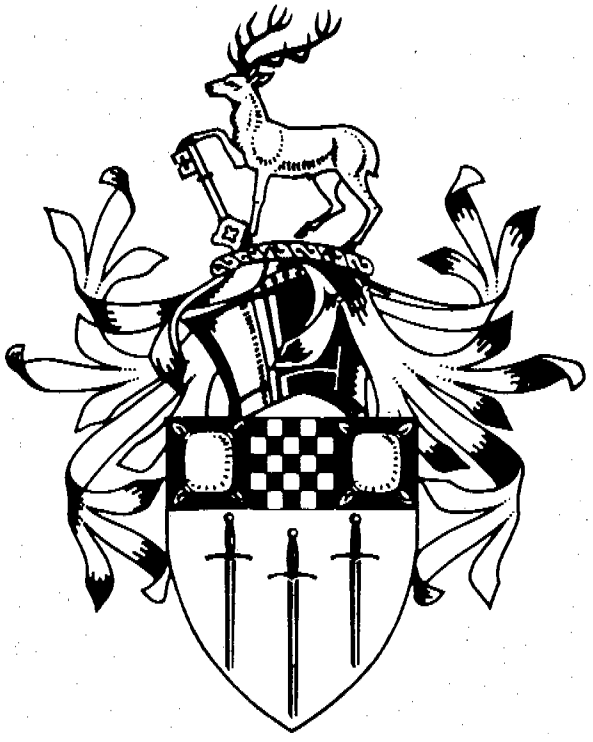

University of Surrey
Department of Civil Engineering

Evaluation of Fabric Enhanced Reduced Depth Slow Sand Filters

Research Scheme R4648

PROGRESS REPORT - OCTOBER 1991

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Evaluation of Reduced Depth Slow Sand Filters

Department of Civil Engineering
University of Surrey

Reporting Period: April 1991 - October 1991

Aim of the Project

The aim of the project is to investigate by how much the depth of conventional slow sand filters can be reduced by the application of synthetic fabrics whilst maintaining the treated water quality.

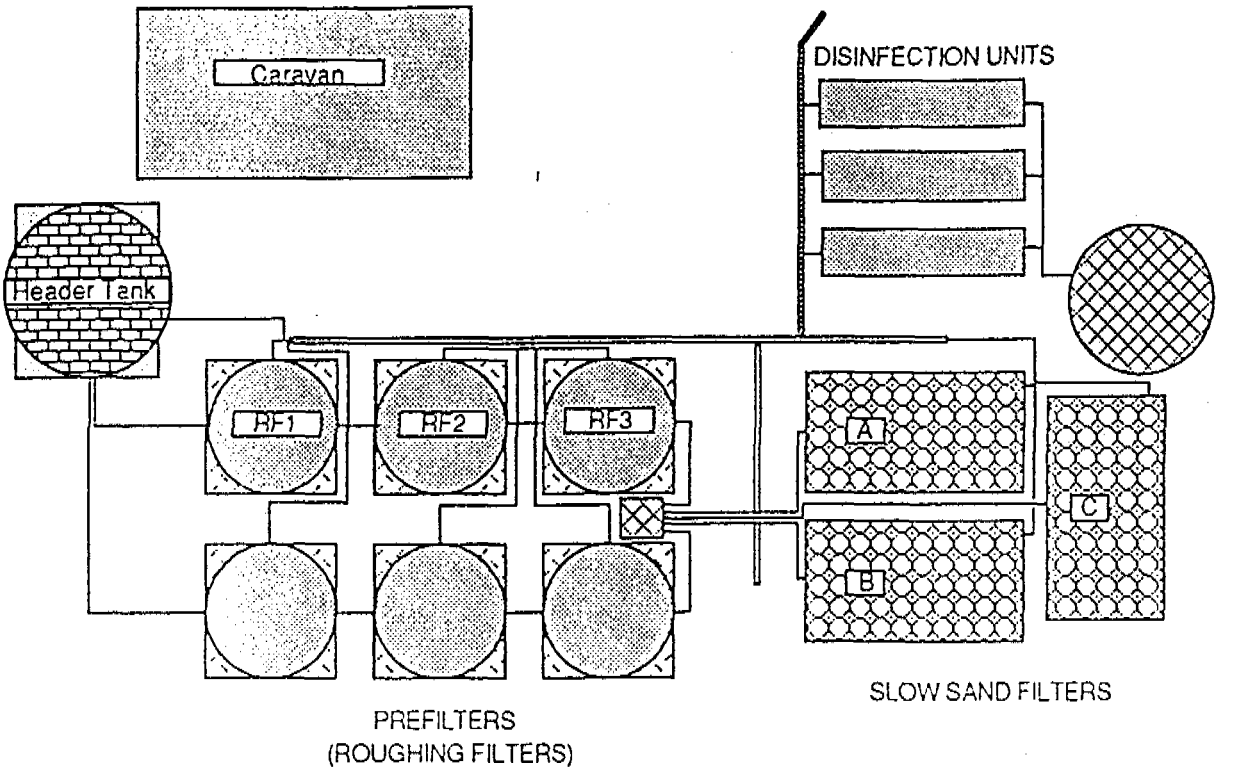
Work Carried out in the Reporting Period

The fabric selected for the tests was delivered to site and multiple layers (x6) fitted to the three slow sand filters (SSF's) to allow Run 1 to commence on 30th May 1991. Particular attention was paid to the plastic welding of the support brackets to minimise the risk of tracking around the fabrics, this was tested on all SSF's before the run commenced. Distortion of the old rectangular tanks made this a relatively difficult process.

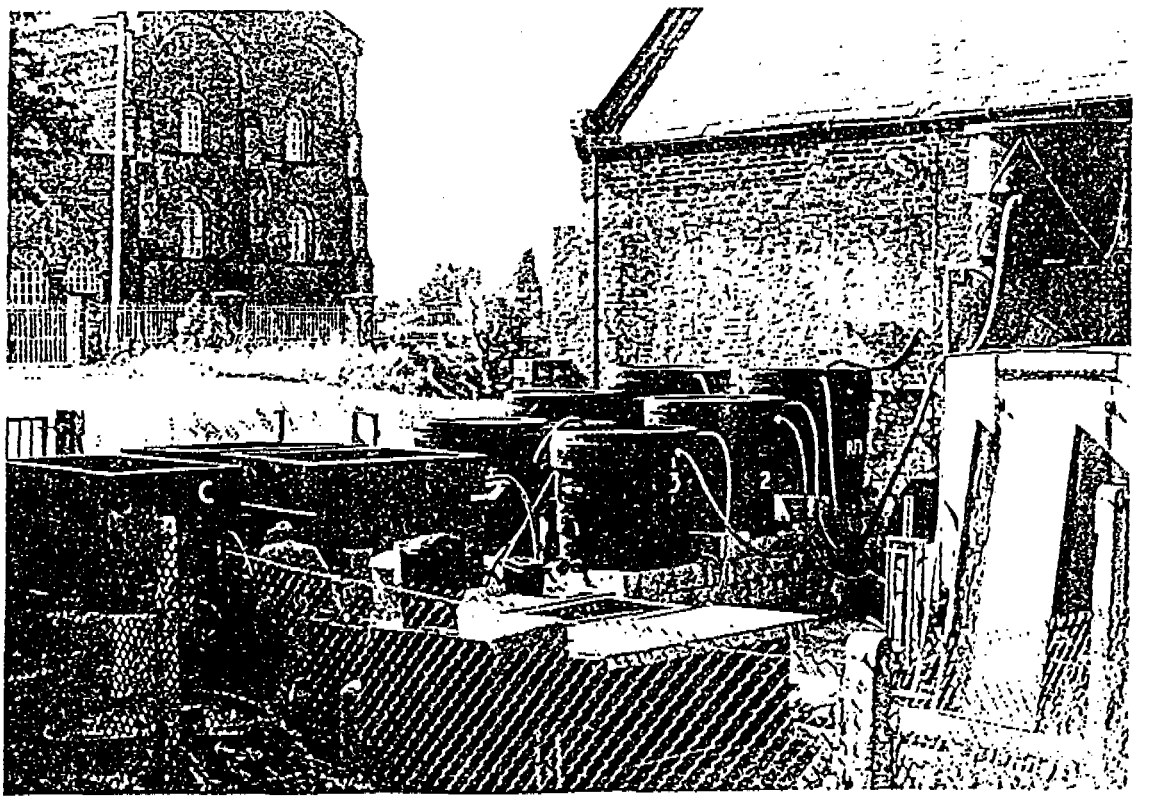
Three gravel prefilters RF1, RF2 and RF3 (40mm, 20mm and 10mm nominal size shingle respectively) were operated in series to provide pretreatment. The prefilters were in a "mature" condition, having commenced operation on the 1st March 1991.

Three slow sand filters (SSF's A, B and C) were operated in parallel, all were fabric enhanced with six layers of synthetic fabric. SSF C was effectively the "control" with a 500mm depth of sand, SSF A was operated with a "reduced" sand depth of 200mm and SSF B with a sand depth of 300mm. A loading of 0.15m/h was maintained on the slow sand filters and 1.0m/h on the prefilters.

Pilot Plant Installation



Schematic diagram of the Surbiton Pilot Plant.



Overview of the Surbiton Pilot Plant.

Run 1 on the SSF's was terminated on the 10th June due to the build up of excessive filter resistance. The fabric fixing arrangements were revised to provide a system which was quicker to install and avoided problems of bolts rusting.

The fabrics were carefully cleaned and refitted to allow Run 2 to commence on 12th July. Apart from problems of limited duration, associated with the operation of valves and pumps, the pilot plant has operated extremely reliably. Unfortunately on the 21st September an old Thames Water main fractured beneath the research compound and flooded the area. SSF B suffered slight settlement and, subsequently, SSF C had to be drained down and temporarily moved to allow the repair to proceed. Accordingly it was decided to terminate Run 2 in early December and refurbish the pilot plant to commence Run 3 in early January.

Experimental Work Details:

Run 1: Total run time - 12 days

Run 1 commenced on 30th May 1991 and was terminated after a run-time of 12 days. The SSF's had been filled by backflow to minimise air entrainment in the sand and fabric layers. Initially there were problems with erratic manometer readings in the sand filters and changes in throughput.

The microbiological performance of the system was evaluated by monitoring Escherichia Coli levels (Fig 1), although with such a short run time the SSF's were mature for only approximately 6 days before blockage occured. Nevertheless, it appeared that the reduced depth filters SSF A and SSF B were similarly effective as SSFC in removing E.Coli from the supernatant for concentrations of between 12 to 58/100ml. In addition an indication was given of the systems ability to deal with variations in raw water E.Coli levels.

Turbidity monitoring commenced late in the run after extensive checks of the sampling arrangements had been completed (Fig 2). In essence the system needs to run for a few days before reproducible turbidity values can be obtained, probably for reasons of fine particles being wasted out of the filters. On the final day of Run 1 raw water turbidity was relatively low, at

6NTU and the product water from SSF's A, B and C had turbidites of 0.45, 0.40 and 0.4 NTU respectively.

Filter resistance in the SSF's was monitored by manometers located in the supernatant and fabric / sand layer. The disposition of the manometers was as shown in the following table.

Manometer	Depth below top of Sand	Comment
R	-	In supernatant above fabric Reference manometer
1	0	Below fabric layers Top of sand
2	25mm	-
3	50mm	
4	100mm	-
5	300mm	In filter support shingle SSF A
6	500m	In filter support shingle SSF A and B

Initially extensive (but expected) problems were experienced, with air blockages of the manometers making it impossible to take stable readings. The manometers required bleeding to remove air bubble on a daily basis. Although in broad terms an increase in filter resistance could be detected the manometers finally stabilised on day 6. Filter resistance subsequently developed at an unexpectedly fast rate and virtual blockage occured on day 12.

Figures 3, 4 and 5 show the development of filter resistance as being almost entirely between the supernatant and the bottom of the fabric; indicating an unusual blockage of the voids within the fabric layers. Particularly as the porosity of the fabric is approximately 0.9 compared with 0.5 for the filter

sand; the total dry thickness (at 2kPa) of a 6 layer depth is 19.2mm. It is speculated that the reason for the rapid blockage of the fabric layers was either "microbubbles" of air on the fibres or abnormally high particulate levels due to Thames Water activity in the vicinity of the pump inlets, or possibly a combination of both. When the fabrics were removed and cleaned by a combination of hosing and brushing considerable amounts of silt issued from the top fabric. It should be remembered that to minimise air entrainment the bed had been initially filled by backfilling.

Water temperature was recorded as a further physical feature and remained at the 15-17°C level throughout the duration of the run. (Fig 6).

Run 2: Run time reported - Initial 80 days

Run 2 commenced on 12th July and was terminated in a staged manner to accommodate major repair works to a defective iron water main beneath the compound and associated refurbishment. SSF C was shut down on 31st October and SSF's A and B taken out of service four weeks later. The reporting period is 12th July - 30th September.

The SSF's were backfilled to minimise air entrainment in the sand and fabric layers. Fabrics were returned in the same order and to the same units as for Run 1. Only very minor problems were experienced with the air blockage of manometers. Experiments with upstream flow control caused slight disruption of the plant between days 25 - 30, problems with the pumps electricity supply caused a major disruption to the plant between days 52 - 56 and the raw water supply line fractured a day later. However, flow was quickly restored and after a short maturation period the run continued in a satisfactory manner.

The microbiological performance of the system during Run 2 was principally evaluated by monitoring E.Coli levels although, in addition, the system was tested on two occasions by dosing with the bacteriophage Serratia Marcescens. On day 19 a bacteriophage suspension was dosed into the inlet of RF1 at a steady rate, on day 60 a single dose of bacteriophage suspension was added to the supernatant of SSFC. In the first phage test sampling was carried out at all stages of the system to determine the relative performance of the prefilters and slow sand filters.

A feature of Run 2 was the effectiveness of the prefilters in removing E.Coli, consistently reducing levels by over 90% despite sudden variations in raw water quality with a peak of 2200 E.Coli/100ml (Fig 7 and 8). The reduced depth slow sand filters, SSF A and B, both effectively removed the remaining E.Coli with filtrate levels of 0-1 E.Coli/100ml generally being recorded. The "control" filter SSF C performed in a similar manner (Fig 9).

Bacteriophage removal on day 19 was similarly effective, with an 86% reduction of levels in prefiltration and removal of the remaining phage in the SSF's; except in the case of SSF A where 20.8 pfu/ml were recorded in the filtrate (Fig 10). The average bacteriophage concentration in the raw water was 9×10^4 pfu/ml.

The bacteriophage test on day 60 in SSF C recorded 3.57 log pfu/ml phage removal for a supernatant concentration of 7.748 log pfu/ml.

Raw water turbidity followed a falling trend from a relatively low level of approximately 4NTU down to 1 NTU through the 80 days of run time, with a sharp increase recorded on day 80. The prefilters were quite effective, removing 60-70% of the raw water turbidity and the SSF's maintained a filtrate with a turbidity generally in the order of 0.3 - 0.4 NTU. Although a matter of fine distinction, SSF A produced the more turbid filtrate and SSF C the less turbid filtrate of the three SSF's; a matter clearly related to the depths of the sand filters (Fig 12 and 13).

Filter resistance slowly increased through the 80 days period in all units. A major part of the relatively small total increase in filter resistance occured across the fabric layers. There were also increases in filter resistance apparent between 100-200mm depth in SSF A, 50-100mm depth in SSF B and 50mm - 300mm depth in SSF C (Fig 14,15 and 16). Settlement of the filter sand beneath the fabric layers in all units gave rise to the situation where manometers 1 and 2 recorded similar readings, as the lower manometer was uncovered.

Water temperature followed a downward trend for most of the 80 days run time, from a high of 21.5°C down to 16°C.

Discussion of Results

1. Sampling of testing procedures were reliable for a range of turbidity, E.Coli and Serratia M levels.

2. Run 1 had an exceptionally short run time. If blocking of the filter was associated with microbubbles on the fabric fibres closing down void spaces, it could point to operating problems when fabrics are deployed in field studies.

3. In Run 1 the gravel prefilters provided a brief indication of their effectiveness as a mean of microbiological treatment, reducing raw water E.Coli levels by over 90%.

4. In Run 2 extensive data was obtained in relation to E.Coli removal in both the prefilters and slow sand filters. The effectiveness of the prefilters as a means of microbiological treatment was confirmed, with E.Coli levels consistently reduced by over 90%, despite variations in raw water quality and with a recorded peak level of 2200 E.Coli/100ml.

5. The use of the bacteriophage Serratia Marcescens provided further interesting data relating to the microbiological treatment efficiency. Bacteriophages are viruses which use bacteria as hosts in which to replicate (not animal cells as in the case of enterovirus). It is relatively easier to detect bacteriophage in a small laboratory and they can act as models of viral pathogens because they are similar in size and composition to enteric viruses.

   The prefilters removed 86% of the Serratia M. in the test on day 19 from a raw water peak of 9×10^4 pfu/ml (pfu = plaque forming units).

6. **The reduced depth slow sand filters SSF A and B achieved similar levels of E.Coli removal as the "Control" filter SSF C, generally reducing levels to 0 - 1/100ml with a peak supernatant E.Coli concentration of 390 $/_{100ml}$.**

In the bacteriophage test on day 19 Serratia Marcescens was effectively removed by the slow sand filters, although with a phage concentration of 20.8 pfu/ml recorded in the filtrate of SSF A.

The bacteriophage test on day 60 in SSF C established the order of removal for a given supernatant concentration; this was done to assist further work with Serratia M in that a filter needs to be penetrated to a measurable extent in order to establish the maximum removal capability.

7. Further E.Coli and Serratia M test will be carried out routinely in subsequent runs and additional virus and protozoan cyst work is proposed by Thames Water. On the initial evidence provided by Run 1 and 2 the reduced depth filters SSF A and B appear to offer adequate microbiological treatment capabilities - however, this needs further investigation.

8. Raw water turbidity was relatively low with the dry autumn weather and the filtrate from all of the SSF's was of good physical quality. As expected the filtrate turbidity tended to be lower the deeper the filter, but this was a fine distinction.

9. In terms of filter resistance Run 1 and 2 were totally different, the former recording a run time of 12 days and the latter being terminated at 8 times this run time for reasons other than filter resistance. In general there does not appear to be any appreciable difference in performance, in terms of filler resistance, for the reduced depth filters; other than that related to overall filter depth.

Priority tasks during the next reporting period.
Import new filter sand, Reinstall the washed fabrics and commence Run 3.

Staff time on project:- April 1991 - October 1991

B A Clarke	8 person weeks
N J D Graham	5 person weeks
Technicians	12 person weeks

Fig 1

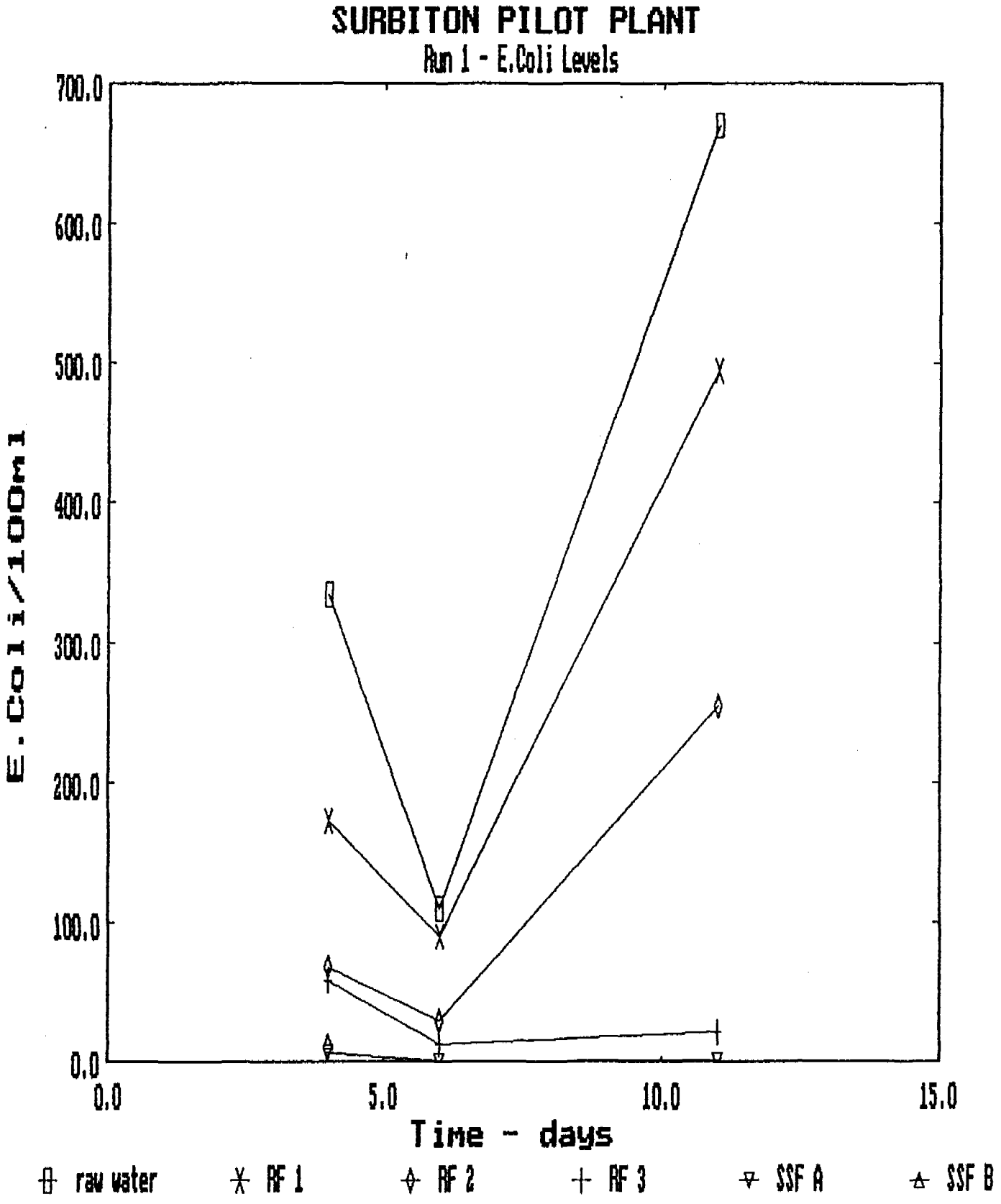

SURBITON PILOT PLANT
Run 1 - E.Coli Levels
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
E.Coli/100ml
0.0
5.0
10.0
15.0
Time - days
raw water
RF 1
RF 2
RF 3
SSF A
SSF B

Fig 2

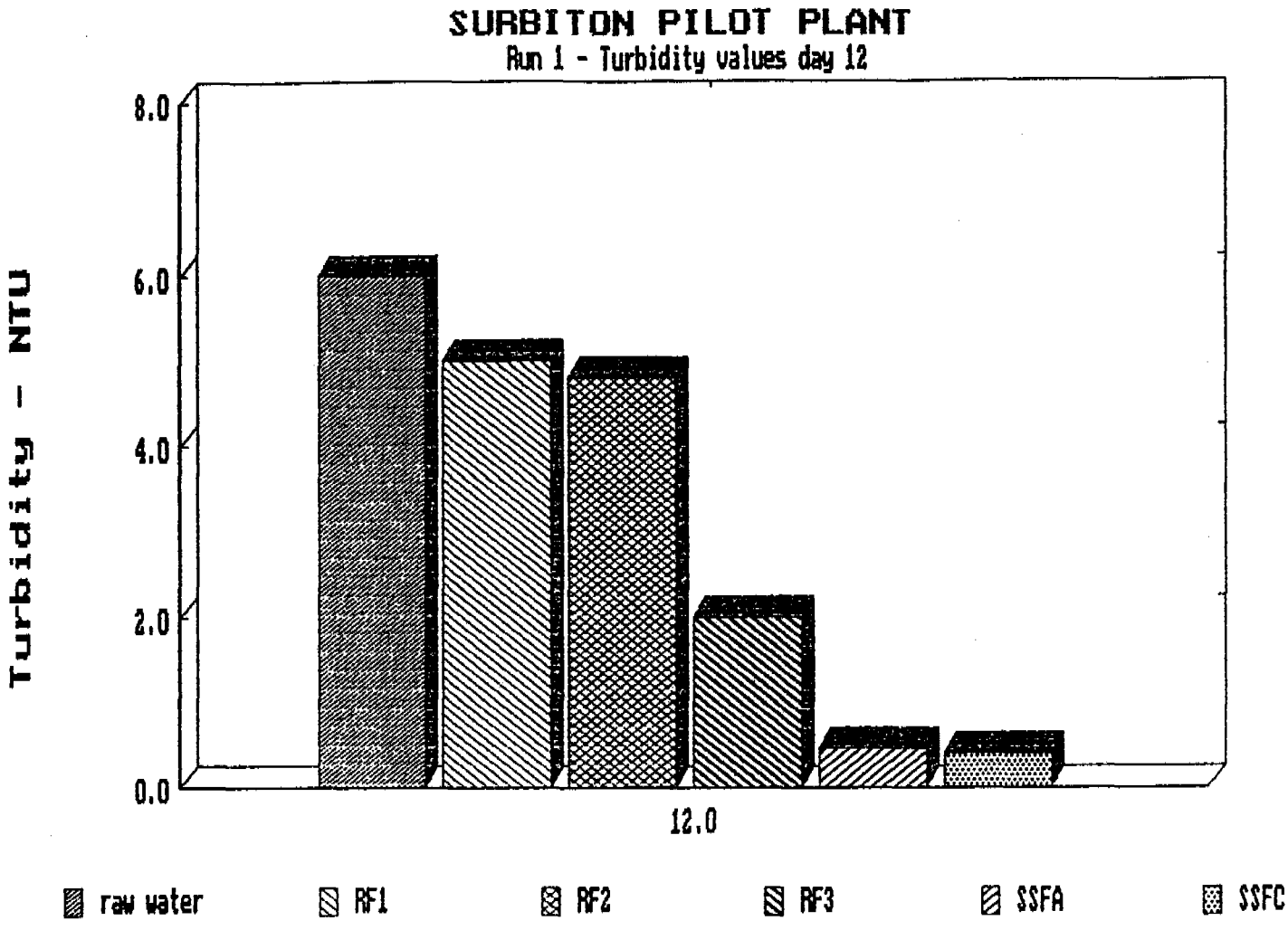

SURBITON PILOT PLANT
Run 1 - Turbidity values day 12
Turbidity - NTU
8.0
6.0
4.0
2.0
0.0
12.0
raw water
RF1
RF2
RF3
SSFA
SSFC

Fig 3

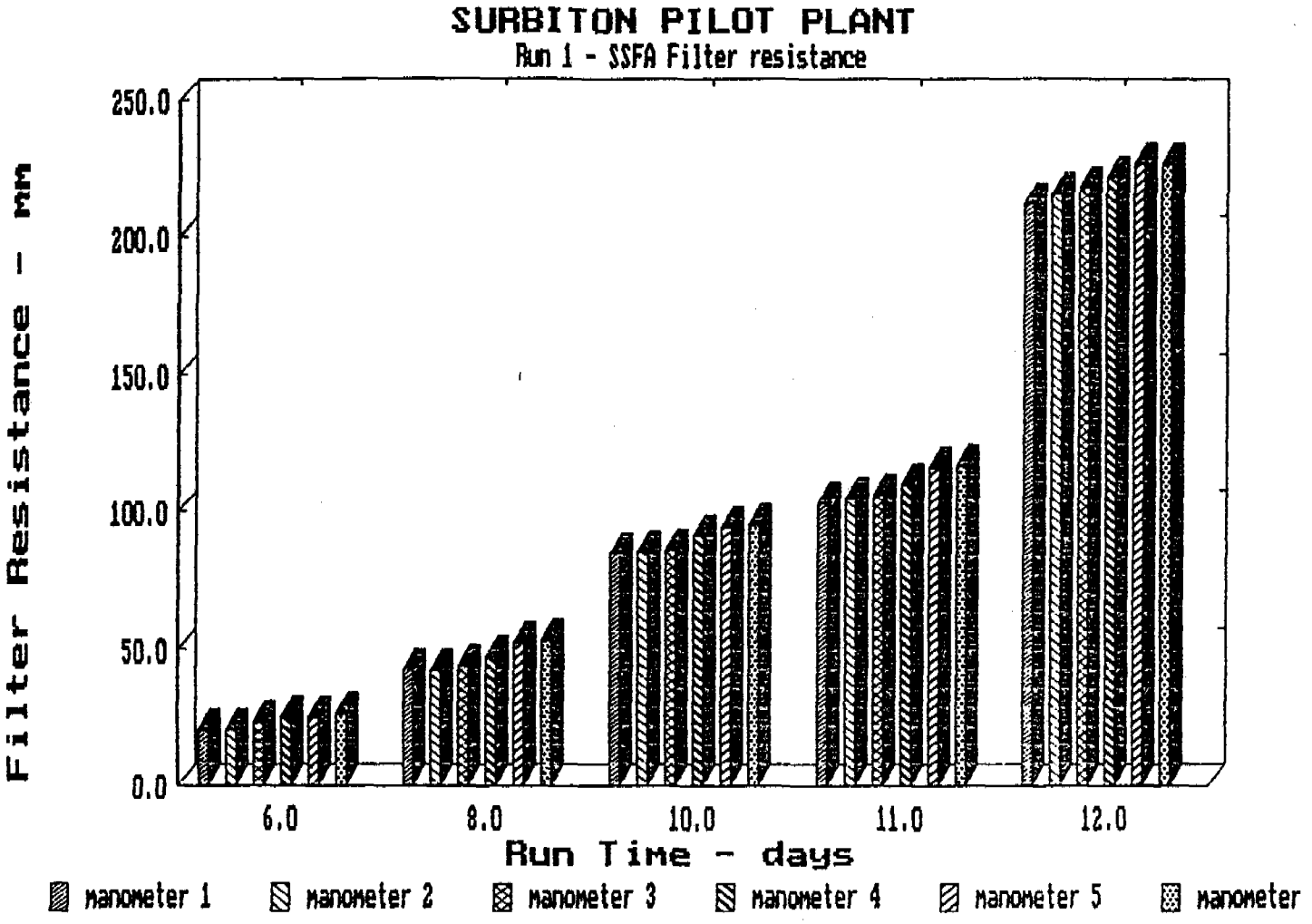
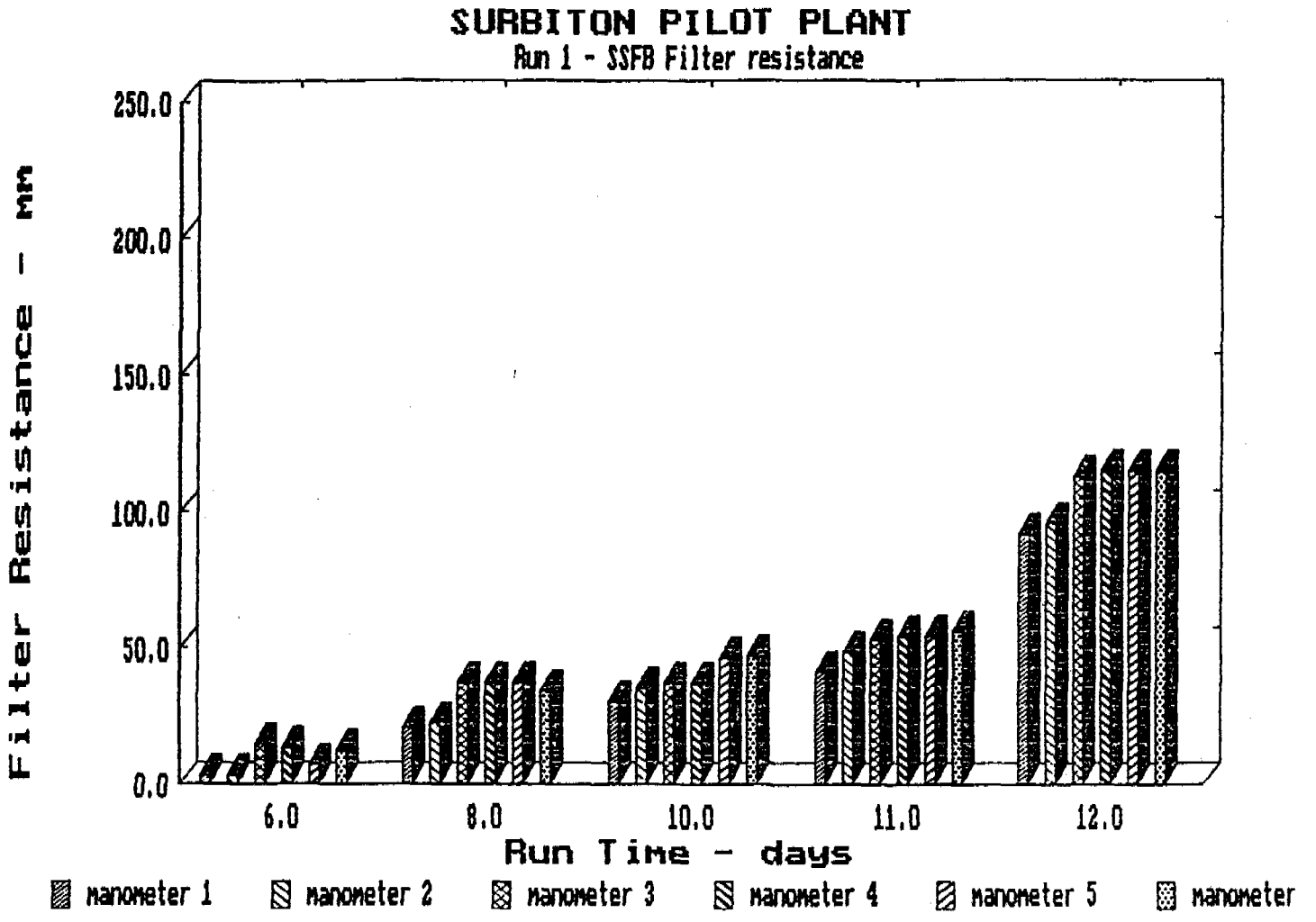

SURBITON PILOT PLANT
Run 1 - SSFA Filter resistance
Filter Resistance - mm
250.0
200.0
150.0
100.0
50.0
0.0
6.0
8.0
10.0
11.0
12.0
Run Time - days
manometer 1
manometer 2
manometer 3
manometer 4
manometer 5
manometer

Fig 4


SURBITON PILOT PLANT
Run 1 - SSFB Filter resistance
Filter Resistance - mm
250.0
200.0
150.0
100.0
50.0
0.0
6.0
8.0
10.0
11.0
12.0
Run Time - days
manometer 1
manometer 2
manometer 3
manometer 4
manometer 5
manometer

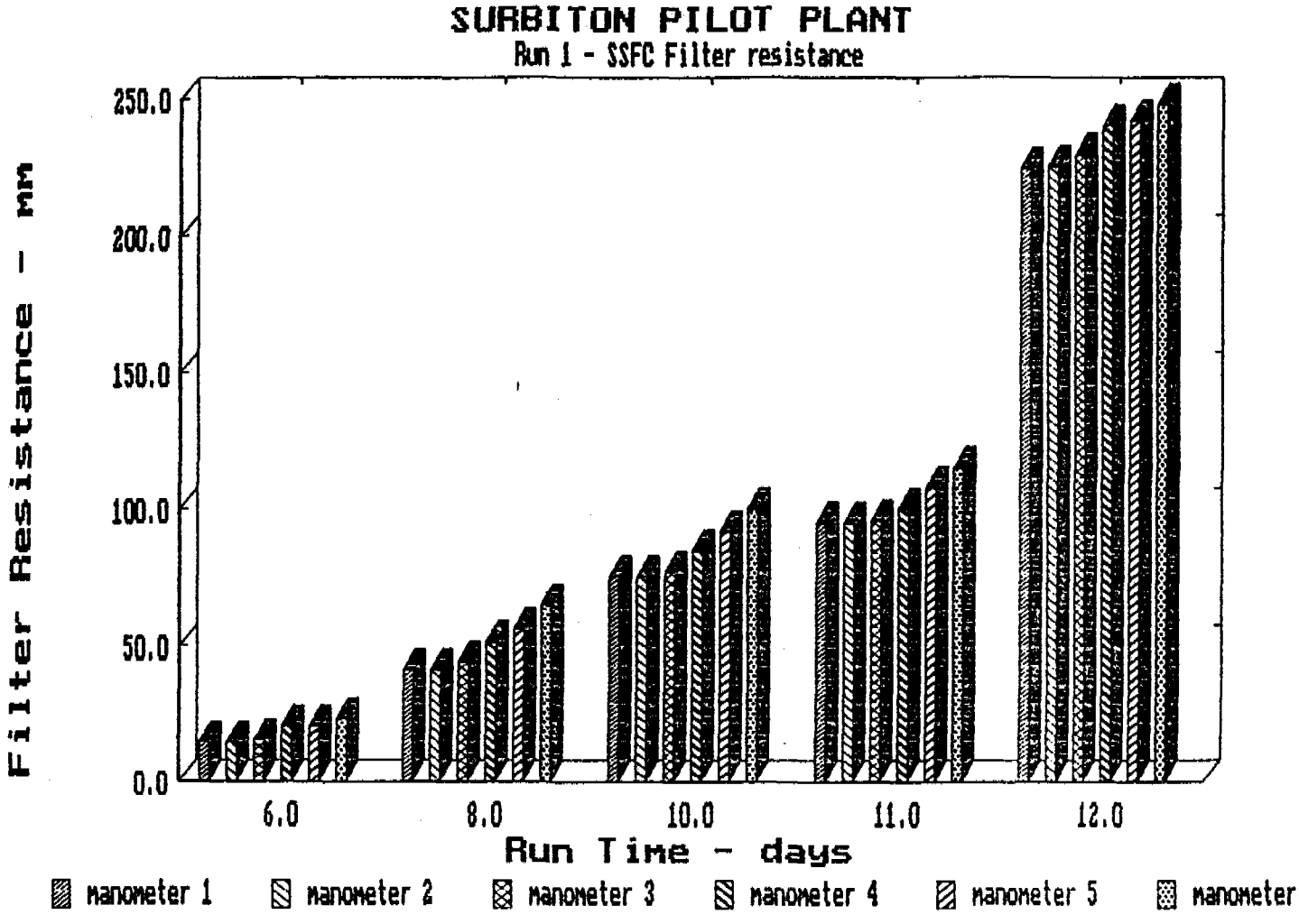

SURBITON PILOT PLANT
Run 1 - SSFC Filter resistance
Filter Resistance - mm
250.0
200.0
150.0
100.0
50.0
0.0
6.0
8.0
10.0
11.0
12.0
Run Time - days
manometer 1
manometer 2
manometer 3
manometer 4
manometer 5
manometer

Fig 6

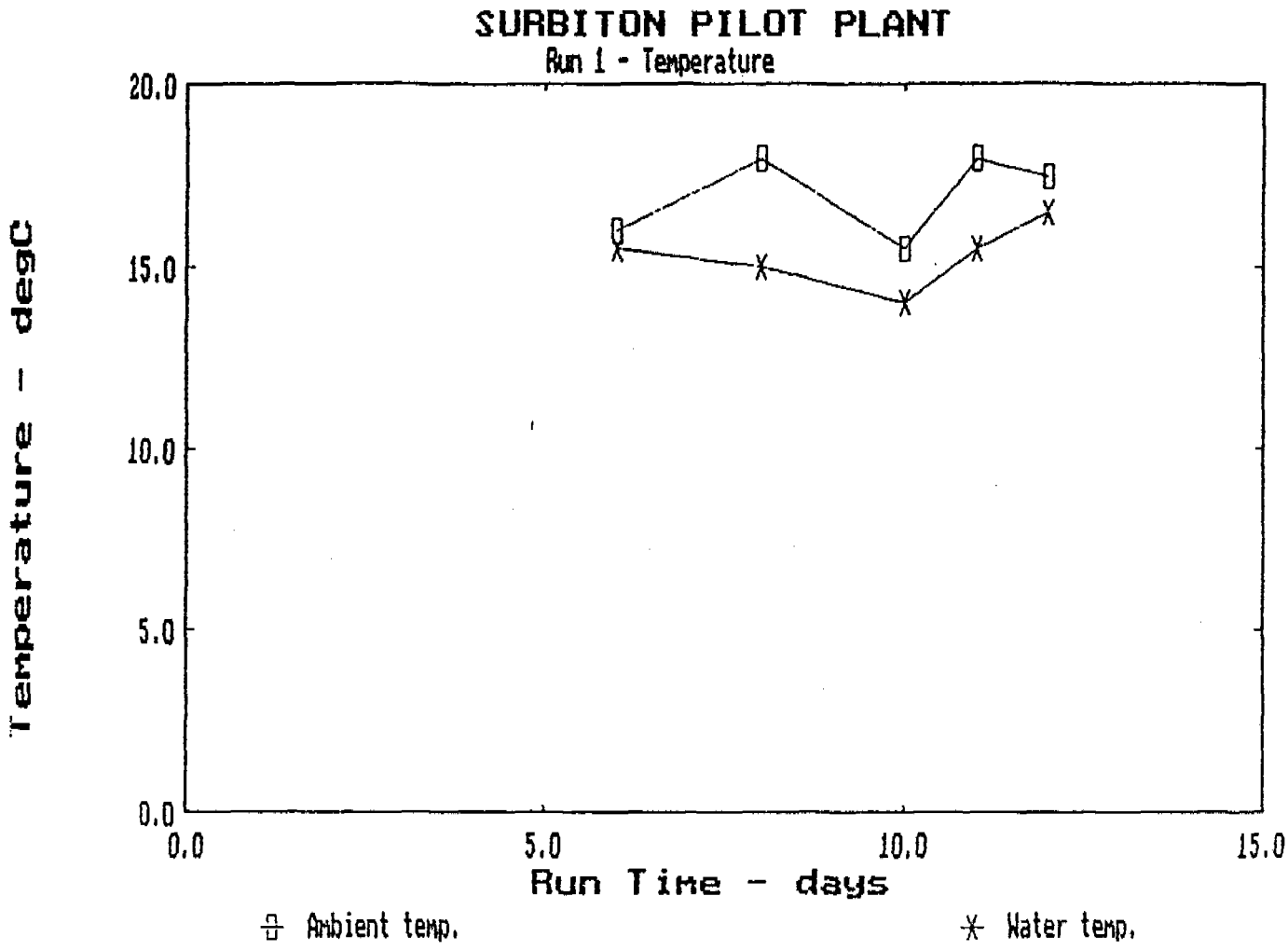

SURBITON PILOT PLANT
Run 1 - Temperature
Temperature - degC
20.0
15.0
10.0
5.0
0.0
0.0
5.0
10.0
15.0
Run Time - days
Ambient temp.
Water temp.

Fig 7

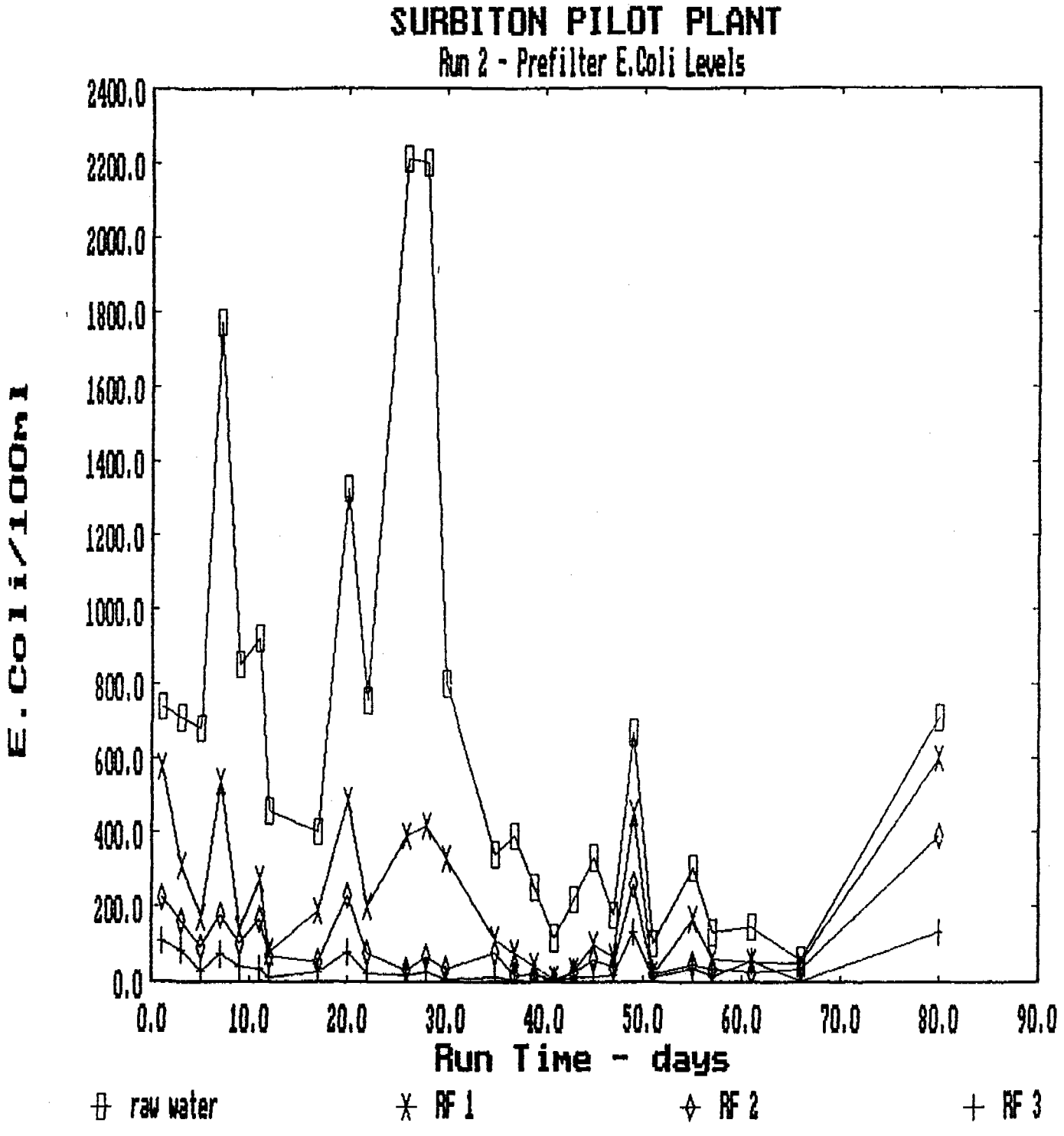

SURBITON PILOT PLANT
Run 2 - Prefilter E.Coli Levels
E.Coli/100ml
2400.0
2200.0
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
raw water
RF 1
RF 2
RF 3

Fig 8

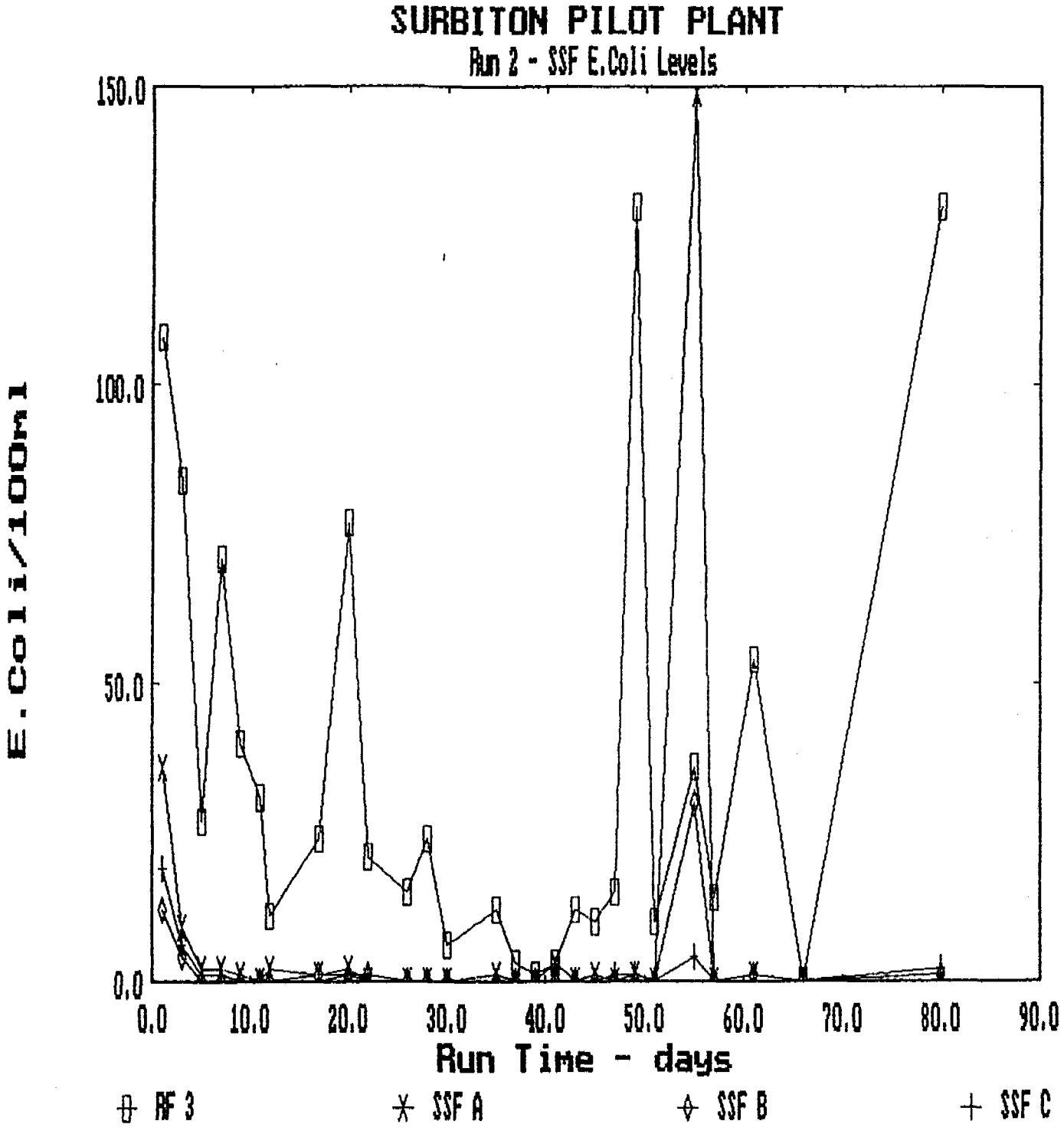
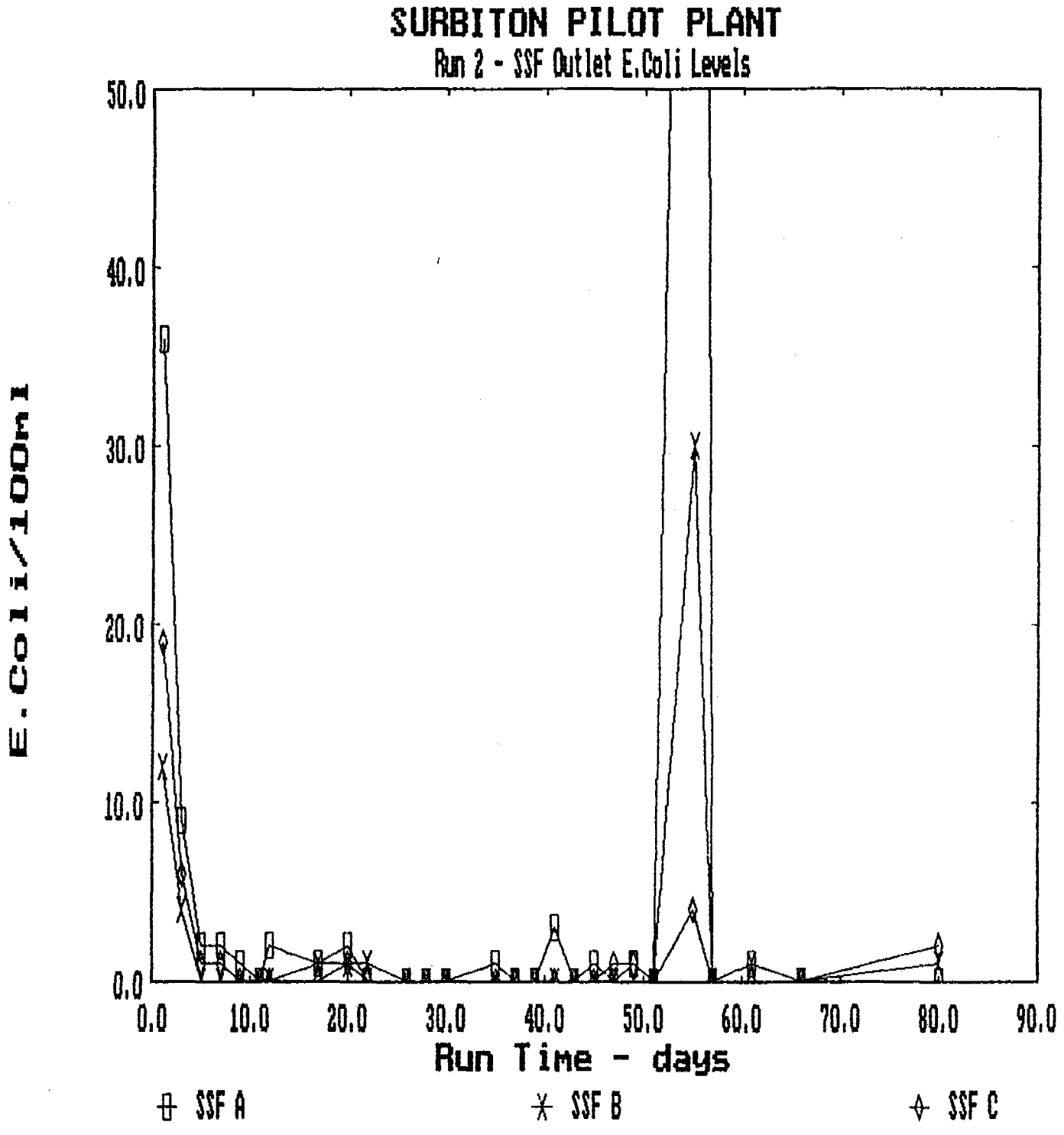

SURBITON PILOT PLANT
Run 2 - SSF E.Coli Levels
E.Coli/100ml
150.0
100.0
50.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
RF 3
SSF A
SSF B
SSF C

Fig 9


SURBITON PILOT PLANT
Run 2 - SSF Outlet E.Coli Levels
E.Coli/100ml
50.0
40.0
30.0
20.0
10.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
SSF A
SSF B
SSF C

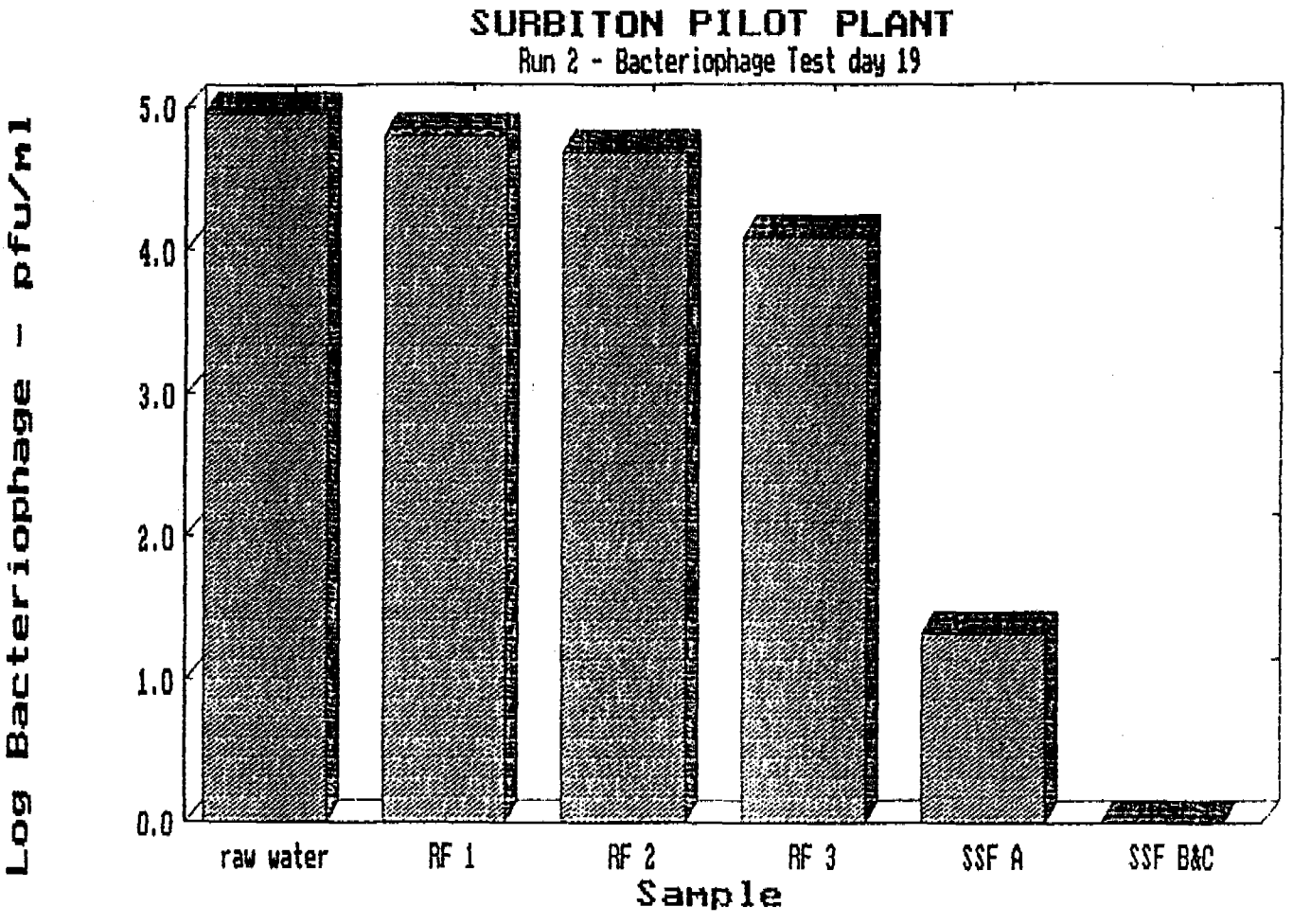

SURBITON PILOT PLANT
Run 2 - Bacteriophage Test day 19
Log Bacteriophage - pfu/ml
5.0
4.0
3.0
2.0
1.0
0.0
raw water
RF 1
RF 2
RF 3
SSF A
SSF B&C
Sample

Fig 11

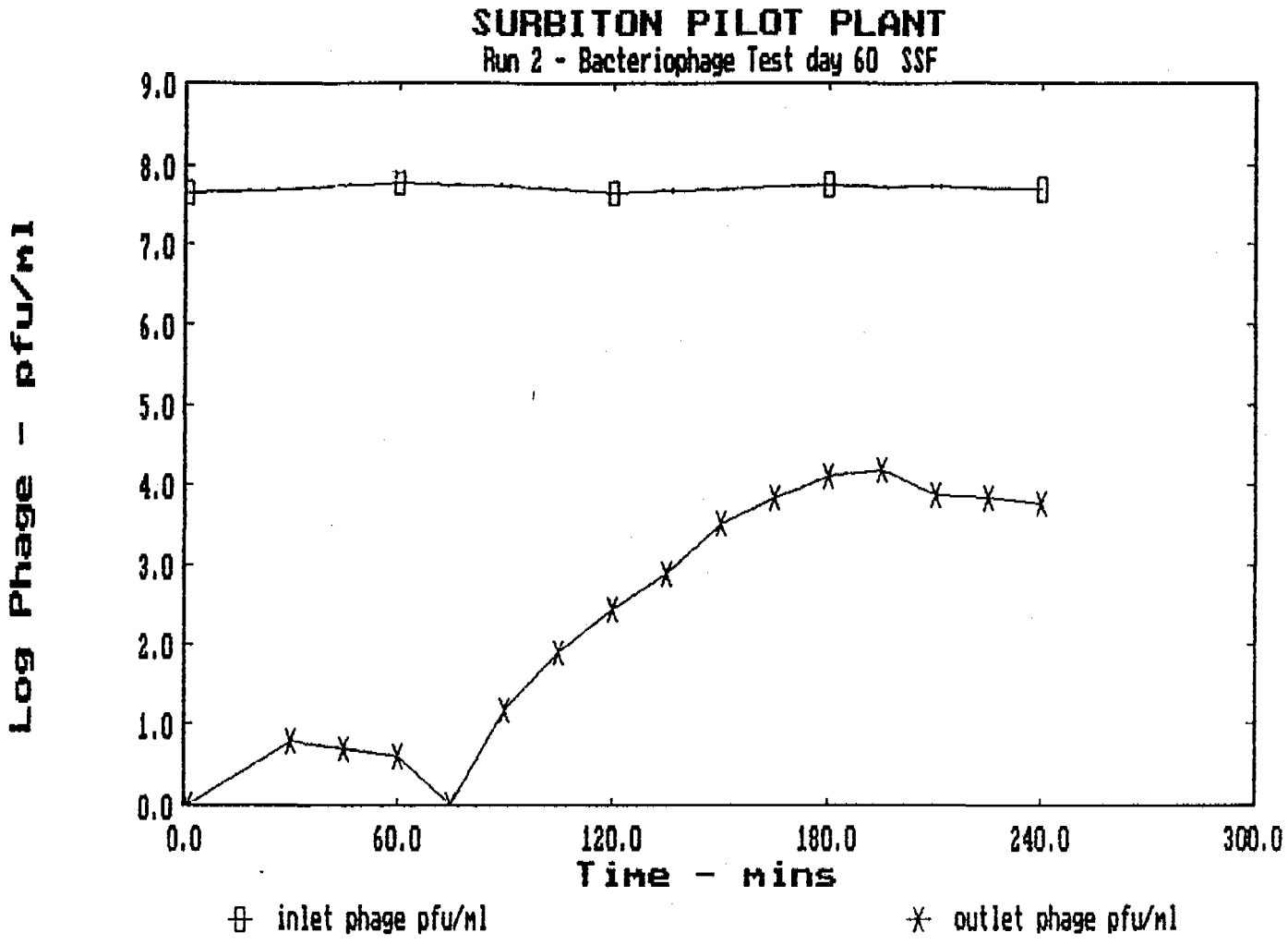

SURBITON PILOT PLANT
Run 2 - Bacteriophage Test day 60 SSF
Log Phage - pfu/ml
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0.0
60.0
120.0
180.0
240.0
300.0
Time - mins
inlet phage pfu/ml
outlet phage pfu/ml

Fig 12

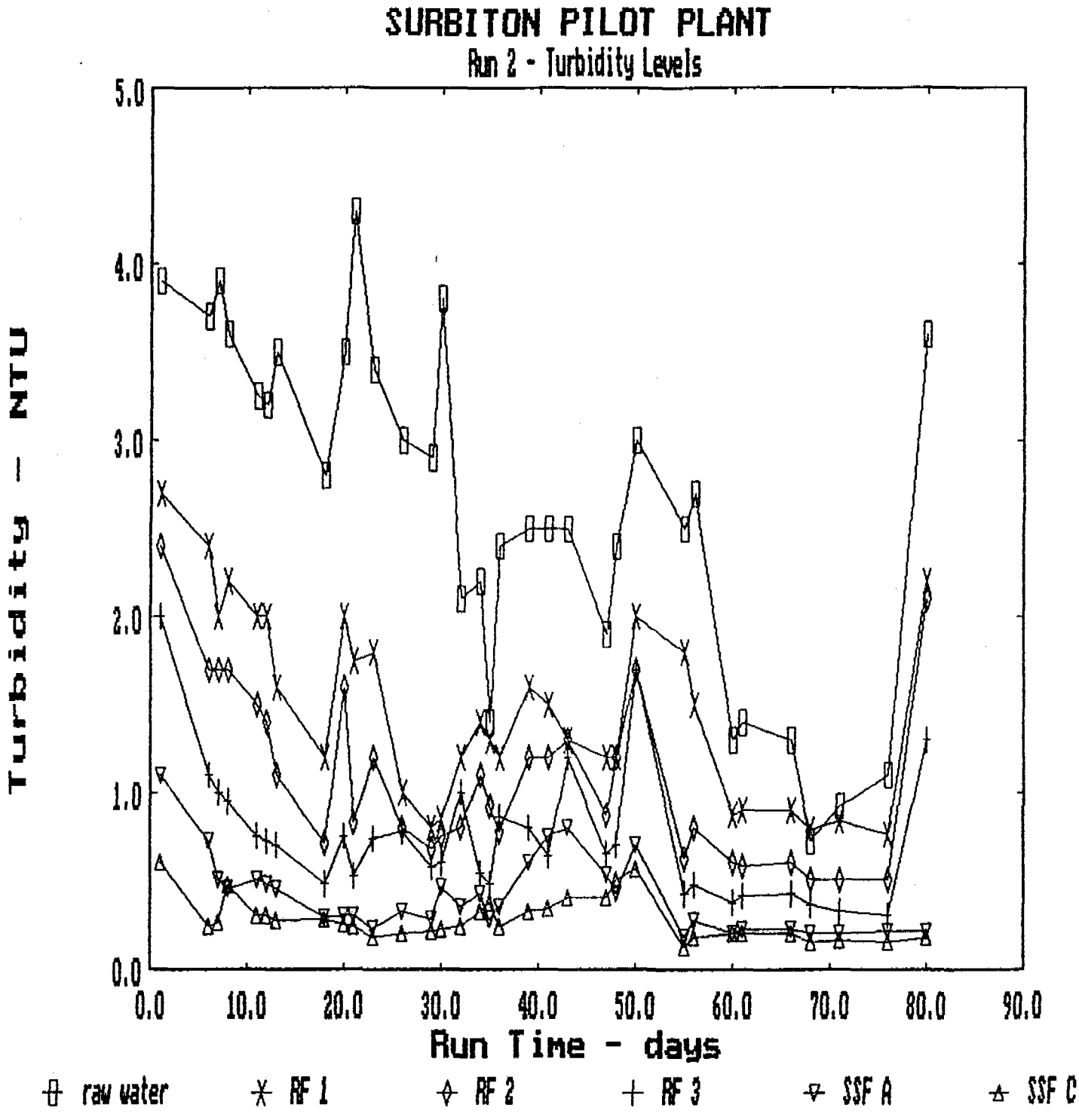
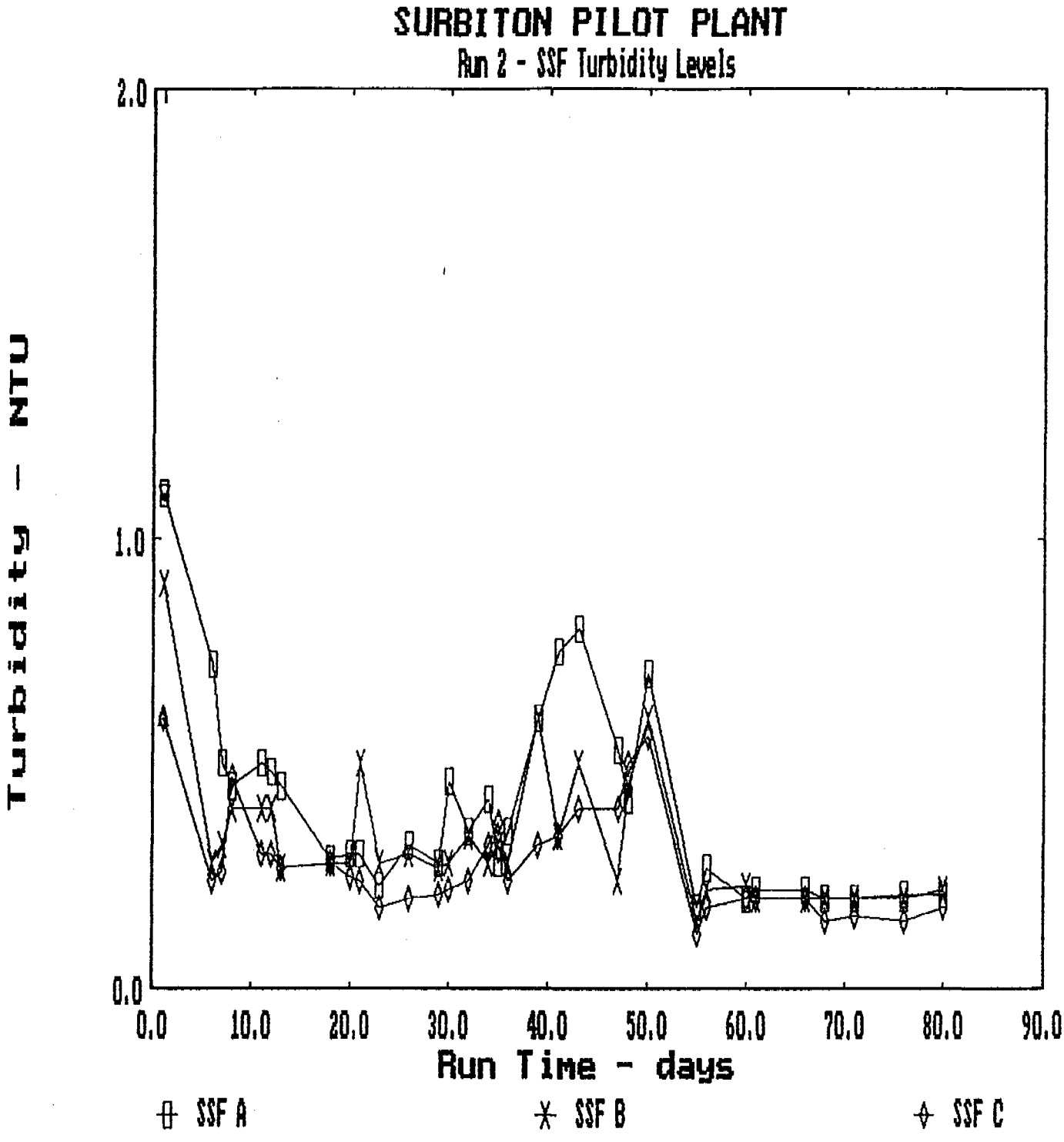

SURBITON PILOT PLANT
Run 2 - Turbidity Levels
Turbidity - NTU
5.0
4.0
3.0
2.0
1.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
raw water
RF 1
RF 2
RF 3
SSF A
SSF C

Fig 13


SURBITON PILOT PLANT
Run 2 - SSF Turbidity Levels
Turbidity - NTU
2.0
1.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
SSF A
SSF B
SSF C

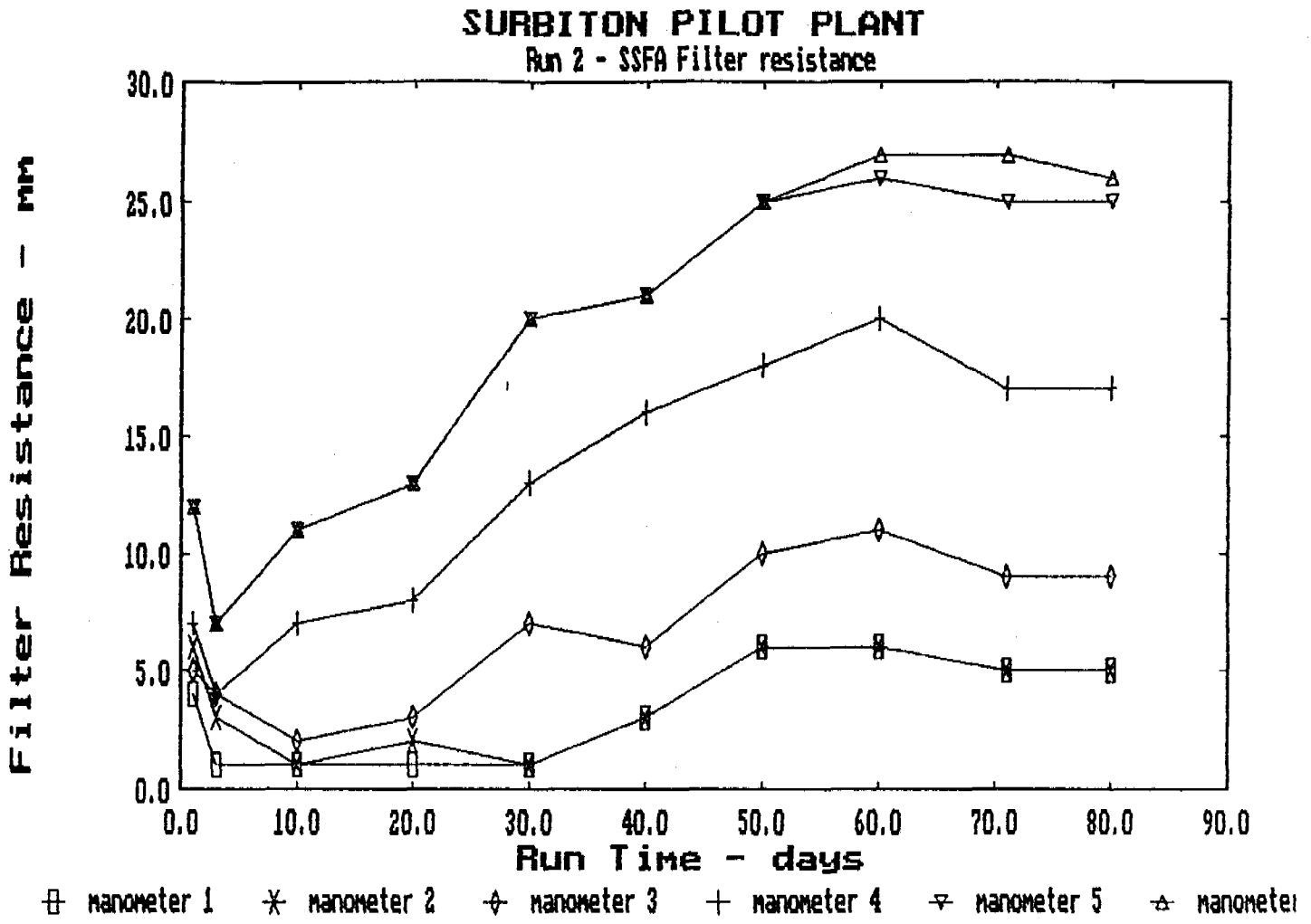
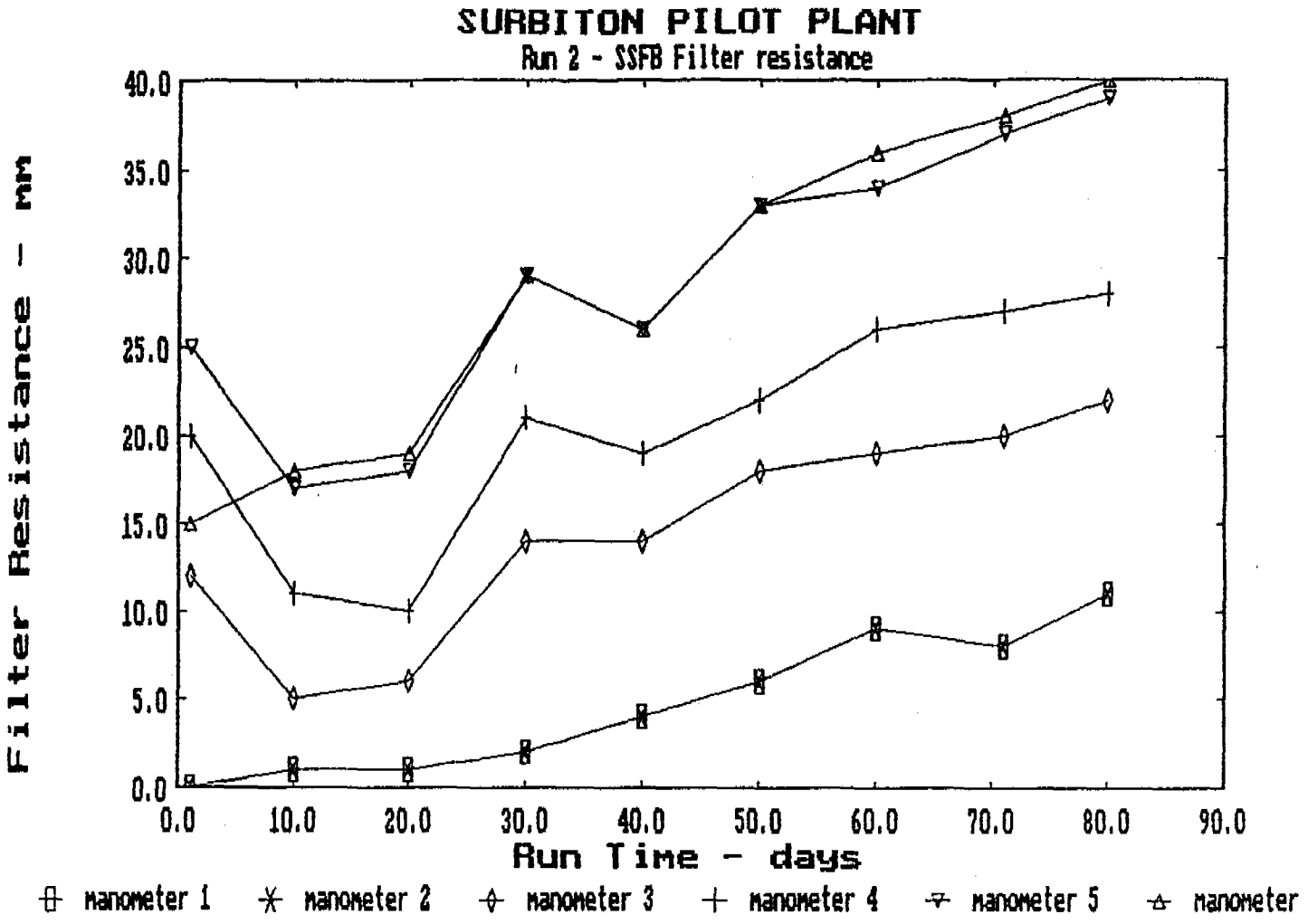

SURBITON PILOT PLANT
Run 2 - SSFA Filter resistance
Filter Resistance - mm
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
manometer 1
manometer 2
manometer 3
manometer 4
manometer 5
manometer

Fig 15


SURBITON PILOT PLANT
Run 2 - SSFB Filter resistance
Filter Resistance - mm
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
manometer 1
manometer 2
manometer 3
manometer 4
manometer 5
manometer

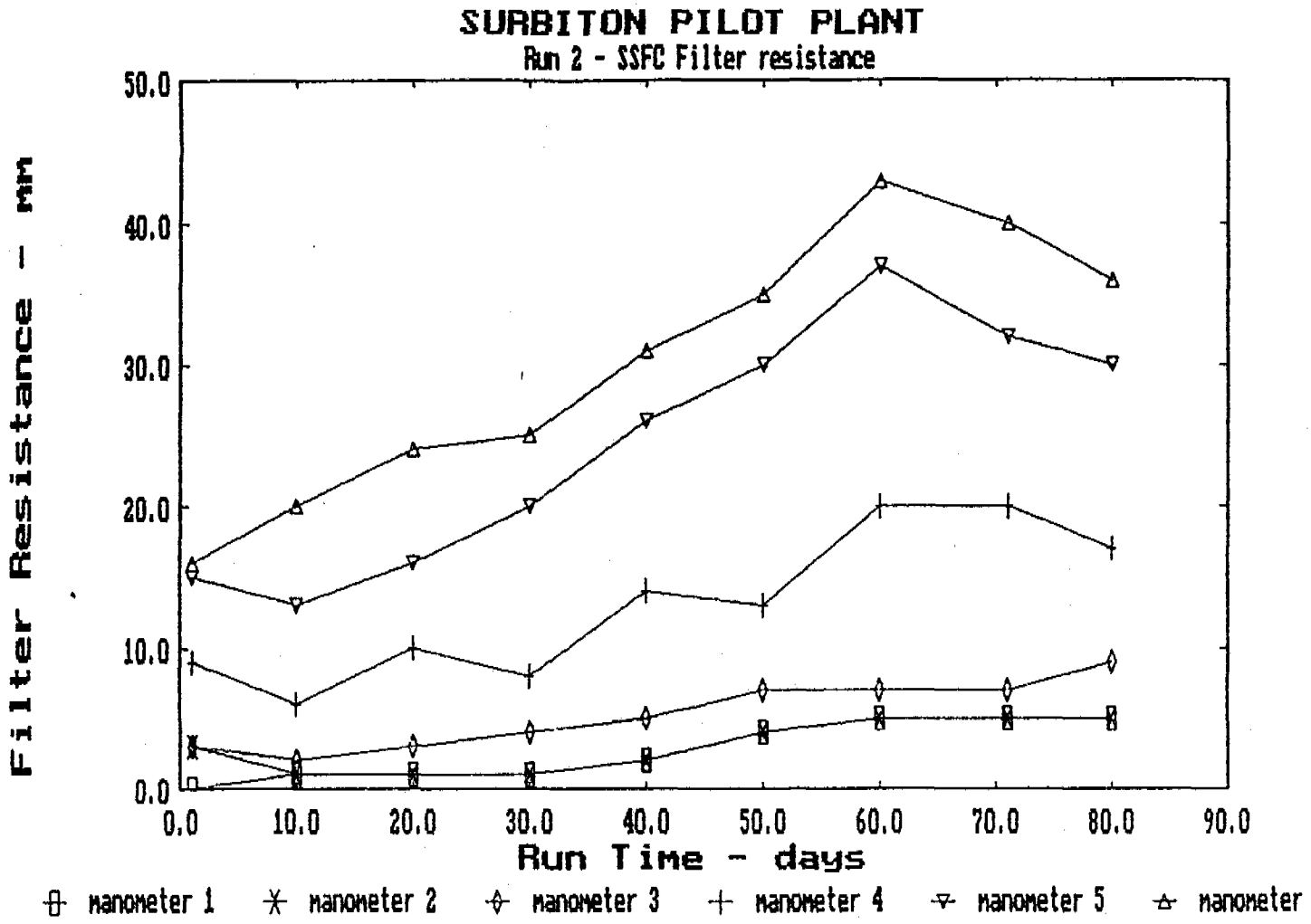
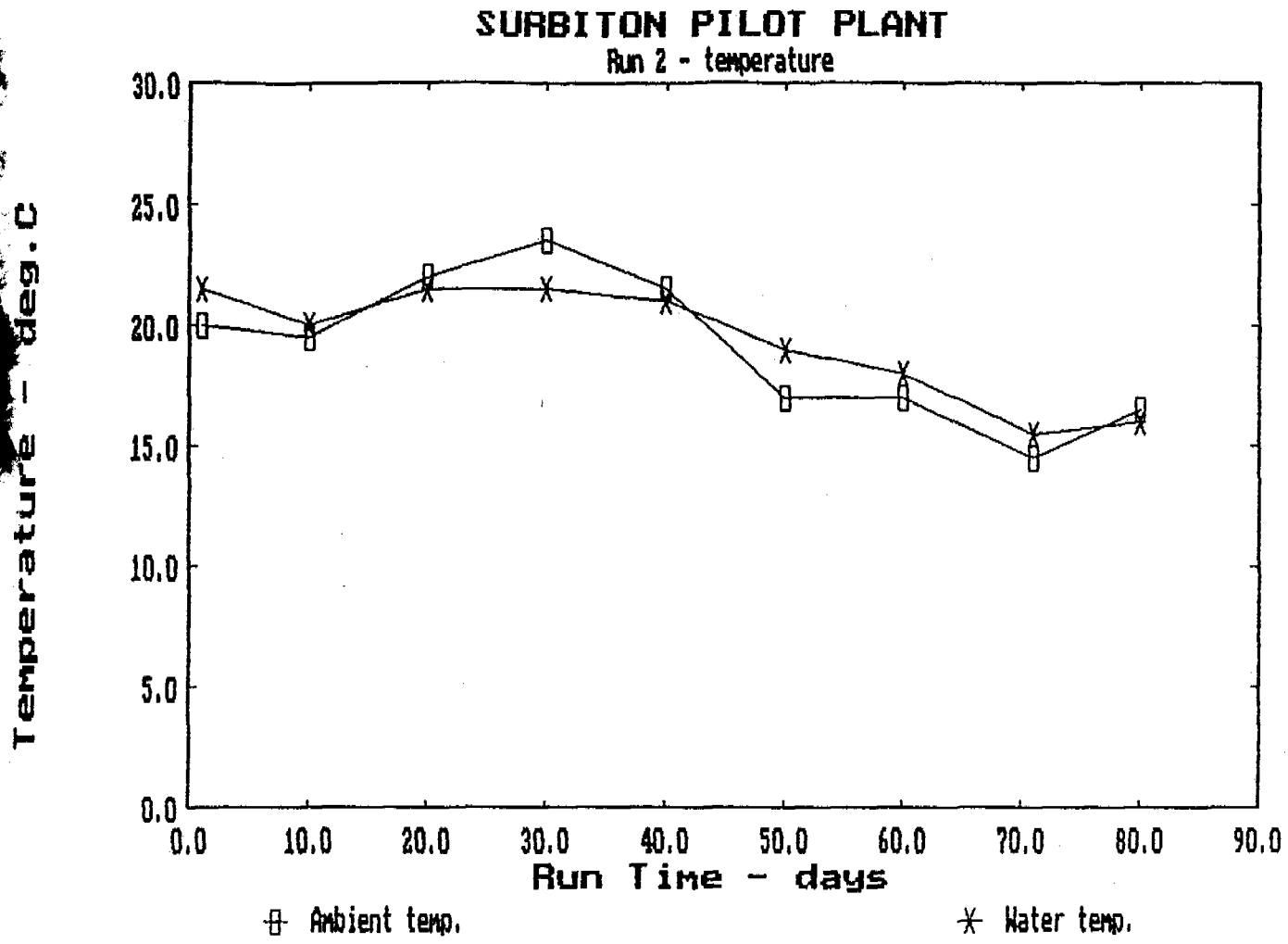

SURBITON PILOT PLANT
Run 2 - SSFC Filter resistance
Filter Resistance - mm
50.0
40.0
30.0
20.0
10.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
manometer 1
manometer 2
manometer 3
manometer 4
manometer 5
manometer

Fig 17


SURBITON PILOT PLANT
Run 2 - temperature
Temperature - deg.C
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
Run Time - days
Ambient temp.
Water temp.