SLOW SAND FILTRATION

PHASE IV

FINAL REPORT

NATIONAL ENVIRONMENTAL ENGINEERING RESEARCH INSTITUTE
(CSIR), NEHRU MARG, NAGPUR-440 020, INDIA

INTERNATIONAL REFERENCE CENTRE FOR COMMUNITY WATER SUPPLY
AND SANITATION, THE HAGUE, THE NETHERLANDS

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PROJECT PERSONNEL

Dr. R. PARAMASIVAM

Project Leader

Mr. Andey, S.P.
Mr. Ansari, M.H.
Ms. Deshpande, V.A.
Ms. Dhage, S.S.
Ms. Joshi, N.S.
Dr.(Ms).Kamatchiammal
Mr. Kelkar, P.S.
Mr. Kothandaraman, V.
Mr. Manivel, U.
Dr. Mhaisalkar, V.A.
Dr. Patil, M.D.
Dr. Parhad, N.M.
Mr. Raguraman, D.
Mr. Raman, A.
Mr. Ravindar Rao, R.
Mr. Saraf, R.K.
Mr. Sharma, L.N.
Mr. Singh, L.P.
Mr. Subbarao, K.
Mr. Subbaiah, V.
Mr. Tajne, D.S.
Mr. Verma, S.R.

Secretarial Assistance

Mr. Krishna Kumar, C.
Ms. Sabjiwale, J.N.
Mr. Swaminathan, G.

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Contd...

ANNEXURES

1. INTRODUCTION

The need for a simple and reliable water treatment method was the stimulus for the International Reference Centre for Community Water Supply and Sanitation (IRC) in the Netherlands to initiate, in close collaboration with institutes in six developing countries, the Integrated Research and Demonstration Project on Slow Sand Filtration (SSF).

This project implemented with financial support from the Netherlands Ministry of Foreign Affairs, Directorate for Development Cooperation, Section for Research and Technology, covered applied research,demonstration programmes and dissemination and exchange of information on SSF. In India, these activities have been carried out by the National Environmental Engineering Research Institute (NEERI), Nagpur.

After the reliability of the process was established for tropical conditions, the second phase focussed on the demonstration of the effectiveness of SSF as an appropriate, simple purification technique at village level and development of guidelines for rational design. Recognizing the important role of the users in such a programme, the village communities were involved in the planning, construction, operation and maintenance of the schemes. A health education programme was also run at the same time in the villages.

In the third phase of the project, national and international seminars were organized for dissemination and transfer of information generated and to encourage the wider application of this technology.

In its final extension the project addressed to issues related to simplification and cost reduction in SSF design, critical appraisal of existing plant designs, development of a training package for caretakers, pilot investigations on pretreatment of turbid water before slow sand filtration and completion of the manual on design, construction, operation and maintenance of SSF plants. This report presents the salient findings and output from Phase IV of the project.

2. SIMPLIFICATION OF SLOW SAND FILTER CONTROL

2.1 Filter Rate Control

2.1.1 Inlet Control

2.1.1.1 Introduction

Despite its overall simplicity, a traditionally designed slow sand filter has features that require operational efforts often beyond the technical capacity of small, rural communities in developing countries. One such feature is its flow control system installed at the outlet end of the filter. To maintain a constant filtration rate, which is crucial to obtaining the best efficiency, the outlet flow control valve must be adjusted on a daily basis as indicated by a measuring system (a weir in conjunction with a float operated level indicator). In rural plants the daily monitoring of the filtration rate and manipulation of flow control valve are not practical due to several constraints. The complexity of this operation can be minimized by controlling the filter rate at the inlet through a regulating valve and a weir. The advantages of the inlet rate control are its ease and simplicity and minimum need for monitoring and supervision. It renders the operation of the slow sand filter virtually automatic without introducing any complicated mechanical parts.

2.1.1.2 Experimental Studies

With a view to assessing the relative performance of filters with the two modes of filter rate control, studies were carried out at NEERI. Three pilot filters with an initial depth of 75 cm of sand having an E.S of 0.22 mm and U.C 2.43 were used for the studies. One of the filters (F1) was operated with conventional outlet rate control mode while the other two (F2 & F3) had influent rate control. Filtration rates of 0.1 m/hr and 0.2 m/hr were studied and the experiments lasted for about 6 months including the initial ripening period. The feed water quality was the same for all the filters. Samples of raw and filtered waters were collected regularly and tested for important physico-chemical parameters (Table 2.1) and bacteriological quality. Biological observations on the schmutzdecke were also made to study the difference in its characteristics when operated with the two modes. The summary of filter runs is given in Table 2.2. The turbidity and headloss observations for a typical run are presented graphically in Figs 2.1 and 2 2 respectively.

2.1.1.3 Initial Ripening

During the initial ripening period which lasted for about 3 weeks, samples of schmutzdecke were collected from all the filters at the beginning, middle and end of the run as indicated by the total headloss. These were analysed for qualitative and quantitative estimation of phytoplankton to assess any variation in the formation and development of schmutzdecke between the two modes of operation. The tests were repeated for the second run and typical results presented in Tables 2.3 and 2.4. No significant difference in the total number and type of algae could be found on the schmutzdecke of the three filters. The

TABLE 2.1

PHYSICO-CHEMICAL CHARACTERISTICS OF RAW AND FILTERED WATERS

Parameters	Raw Water	Filtrate		
		F_1	F_2	F_3
Turbidity (NTU)	1.3-8.6	0.37-0.81	0.4-0.83	0.23-0.75
pH	8.2-8.7	8.0-8.2	8.0-8.5	8.0-8.5
Total Alkalinity ($CaCO_3$)	83-115	87-113	83-113	85-115
Total Hardness ($CaCO_3$)	83-98	86-96	86-98	86-98
Calcium Hardness ($CaCO_3$)	53-66	53-62	54-66	54-65
Total Iron (Fe)	0.1-0.25	N.D.	N.D-0.1	N.D.-0.1
Sulphates (SO_4)	5.0-10.8	5.0-11.7	5.0-11.7	4.5-11.3
Chlorides (Cl)	4.0-10.5	3.5-10.5	4.0-10.5	3.5-10.5
Chemical Oxygen Demand	1.7-7.4	N.D.-4.5	N.D.-4.9	N.D.-3.9
Chlorine Demand	0.18-0.65	0.10-0.45	0.10-0.45	0.10-0.45

All values are expressed as mg/l except pH

TABLE

PERFORMANCE OF FILTERS WITH INLET AND OUTLET RATE CONTROL MODES

Summary of Filter Runs

Sl. No.	Description	Filter 1 (outlet control)				Filter 2 (inlet control)				Filter 3 (inlet control)			
		1	2	3	4	1	2	3	4	1	2	3	4
1.	Filtration rate (m / hr)	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.1
2.	Depth of sand (cm)	72	70	68	68	74	72	70	68	74	72	70	68
3.	Headloss (cm)												
	(i) Initial	7.7	6.2	9.0	2.7	7.7	5.7	8.6	4.3	12.2	8.2	8.7	4.2
	(ii) Final	8.6	90.2	99.7	102.3	100.3	102.2	100.5	102.0	99.3	115.7	96.7	102.0
4.	Length of run (days)	18	12	33	86	15	13	88	66	16	10	24	122

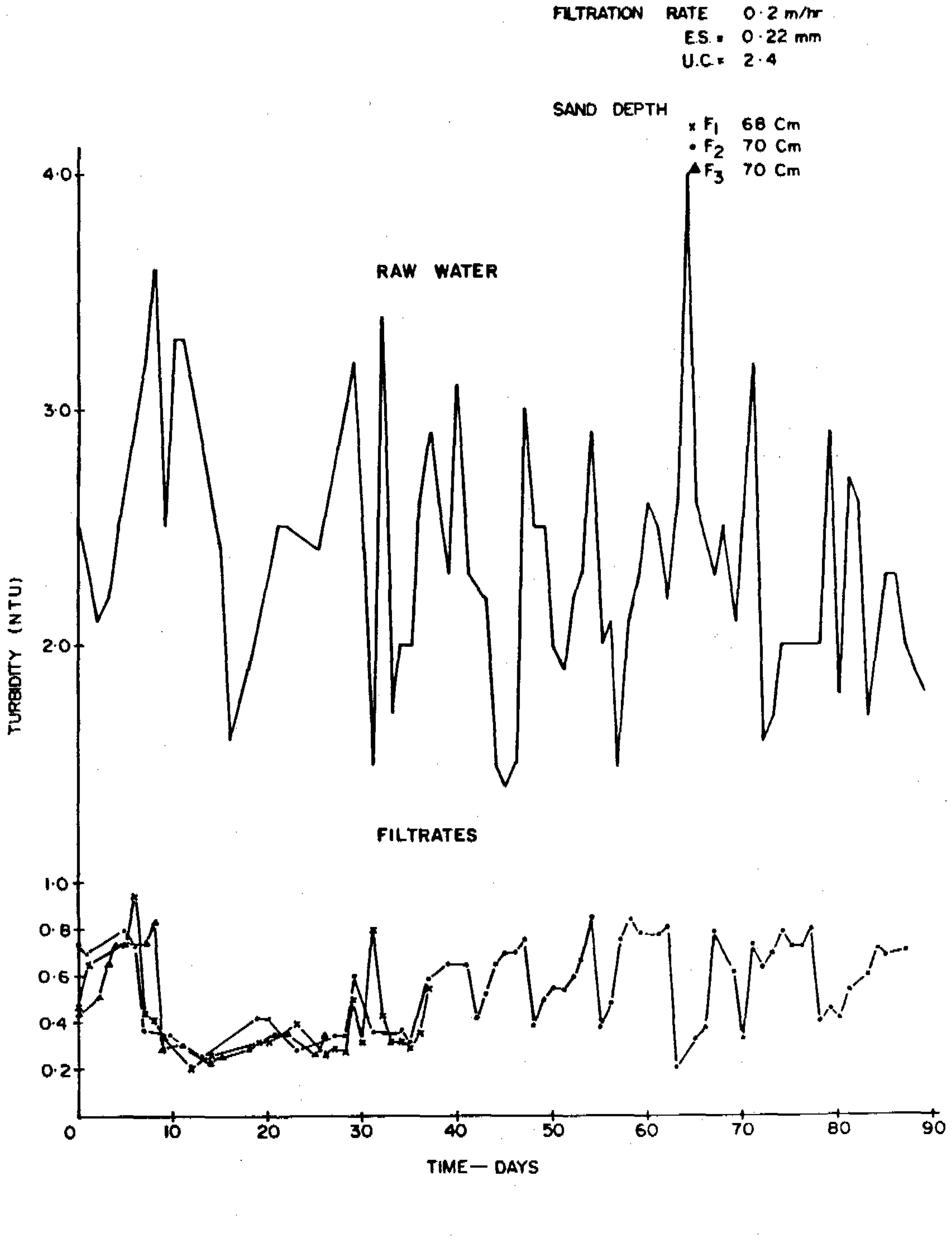


FIG. 2.1 PERFORMANCE OF FILTERS WITH INLET AND OUTLET CONTROL– TIME Vs TURBIDITY

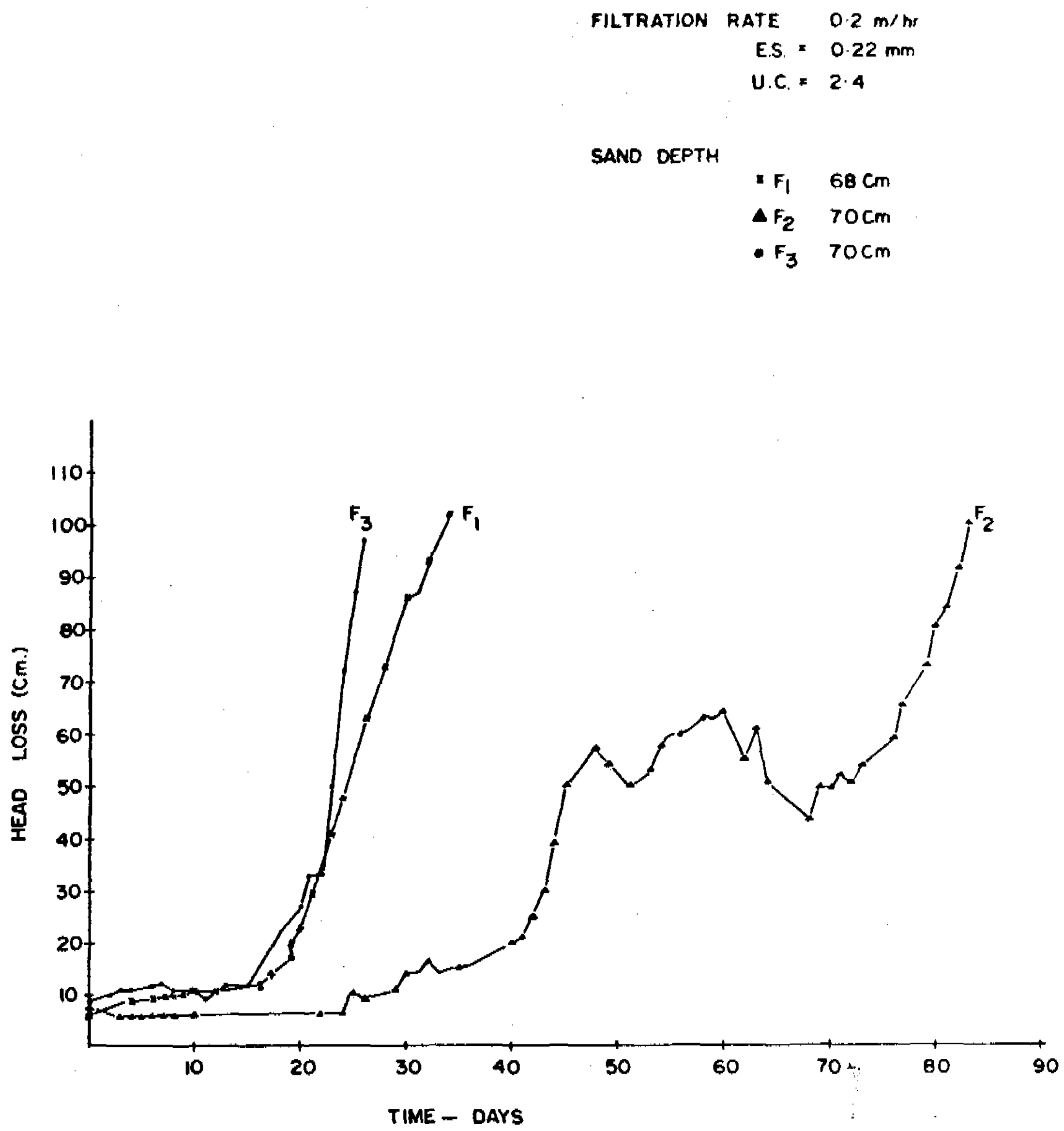


FIG. 2.2 PERFORMANCE OF FILTERS WITH INLET AND OUTLET CONTROL-
TIME Vs HEAD LOSS

TABLE 2.3

QUALITATIVE PLANKTON ANALYSIS OF SCHMUTZDECKE FROM FILTERS WITH INLET AND OUTLET RATE CONTROL MODES

A -Initial stage of run B -Middle stage of run C -End of run

Filters		F1			F2			F3		Raw
Plankton Form	A	B	C	A	B	C	A	B	C	water
Blue Green Algae										
CYLINDROSPERMUM	XD	X	X	XD	X		XD	X		X
AGMENELLUM	X	X	X	X	X		X	X	X	X
ANABAENA		X								
ANACYSTIS					X	X				
TOLYPOTHIRIX			X							
Green Algae										
ZYGNEMA	X									
ULOTHERIX	X	X	X	X	X	X		X	X	X
STAURASTRUM	X	X	X					X		
CHLORELLA	X	X	X	X			X			
MOUGEOTIA	X	X		X			XS			X
*EUASTRUM	X	X	X			X	X	X	X	X
PEDIASTRUM	X	X	X		X	X		X	X	X
CHLOROCOCCUM					X					
PALMELLA					X					
SCENEDESMUS		X	X		X	X				
ANKISTRODESMUS							X			
MICROSPORA								X		
CLOSTERIUM		X				X			X	
TETRAEDRON		X	X			X		X	X	
OEDOGONIUM			X			X			X	
COELASTRUM			X							X
ARTHROSPIRA			X							X
SPIROGIRA										X
*CHLOROGONIUM	X						X			
Diatoms										
NAVICULA	X	X	X	X	X	X	X	X	X	X
SYNEDRA	XD	XD	XD	XD	XD	XD	XD	XD	XD	XD
NITSCHIA	X	X	X	X	X	X	X	X	X	X
CYMBELLA	X		X			X	X	X	X	
DIATOMA	X	X	X	X	X	X	X	X	X	X
CYCLOTELLA	X	X	X	X						
PENULARIA						X				
PERIDINIUM				X						
Higher Forms										
Cyclops		X	X		X	X		X	X	
Chironomus Larvae										

X - Present D - Dominant S - Sub-Dominant

TABLE 2.4

QUANTITATIVE DATA ON ALGAE FROM SCHMUTZDECKE OF FILTERS WITH INLET & OUTLET RATE CONTROL

(count 10^6 /cm^2)

Sample	Algae Group	Headloss (cm)	7.7	57.0	98.6
FILTER 1 (Outlet Control)	Blue Green		0.72	0.02	N.D.
Sample A	Green		0.24	0.68	0.24
	Diatoms		0.46	3.72	5.42
	Total		1.42	4.42	5.66
Sample B	Blue Green		0.35	0.03	N.D.
	Green		0.11	0.82	0.43
	Diatoms		0.96	4.19	8.18
	Total		1.42	5.04	8.61
		Headloss (cm)	13.0	59.6	122.4
FILTER 2 (Inlet Control)	Blue Green		0.20	0.05	0.04
	Green		0.10	1.19	0.34
	Diatoms		0.35	3.20	5.28
	Total		0.65	4.44	5.66
		Headloss (cm)	18.8	65.5	99.3
FILTER 3 (Inlet Control)	Blue Green		0.37	0.13	0.05
	Green		0.21	0.87	0.36
	Diatoms		0.48	3 04	4.50
	Total		1.06	4.04	4.91

Quantitative Information on Algae in Raw Water

ALGAE Group	Numbers x 10^4 / L
Blue Green	2.69
Green	4.15
Diatoms	7.51
Total	14.35

N.D. - Not determined

formation of the schmutzdecke was uniform and equally good in all the filters. The filtrate DO (Table 2.5) which could be considered a measure of the intensity of biological activity, indicated no perceptible difference between the ecology of the three filters with the two modes of rate control.

2.1.1.4 Turbidity Removal

During the initial ripening period, the turbidity of raw water varied from 6 to 12 NTU and remained below 5 NTU subsequently. The turbidity of filtrate from all the filters was well below 1 NTU except during the ripening period. There was no significant difference between the turbidity values of filtrates obtained from filters operated with the two different modes at both the rates of filtration studied (Table 2.6).

2.1.1.5 COD Removal Efficiency

The organic pollution in raw water measured as COD varied from 1.7 mg/l to 7.4 mg/l. When operated at 0.1 m/hr, the filter with outlet rate control gave a COD removal efficiency of 44.1 per cent, whereas the two filters with influent rate control gave a removal efficiency of 51.6 and 46.3 per cent respectively. At a filtration rate of 0.2 m/hr, the corresponding removal efficiency was 67.3, 50.6 and 60.3 per cent respectively. No significant difference was observed in the performance of filters with reference to COD removal (Table 2.7).

TABLE 2.5

DISSOLVED OXYGEN CONCENTRATION IN FILTRATES WITH INLET AND OUTLET RATE CONTROL

Sl. No.	Raw water DO (mg/l)	Filtrate DO mg/l		
		Outlet Control	Inlet Control	
		F1	F2	F3
1	8.6	6.4	6.7	6.7
2	8.4	6.4	6.7	6.6
3	7.9	5.9	6.2	6.0
4	10.0	7.1	7.6	7.0
5	9.1	7.2	8.7	7.2
6	8.8	6.0	6.8	6.2
7	8.6	5.7	6.5	5.9
8	8.5	5.6	6.2	5.6
9	9.9	5.8	7.1	6.7

ote : Samples for DO collected between 10.00 and 10.30 hrs.

TABLE 2.6

COMPARATIVE PERFORMANCE OF FILTERS WITH INLET AND OUTLET RATE CONTROL WITH REFERENCE TO TURBIDITY

Description	Outlet Control (F1)		Influent Control (F2 & F3)			
	Turbidity (NTU)		Turbidity (NTU)			
	Raw	Filtered	Raw	Filtered	Raw	Filtered
Filtration Rate - 0.1 m/hr						
Mean	1.99	0.64	1.76	0.56	2.01	0.57
Standard Deviation ±	0.50	0.18	0.36	0.19	0.51	0.19
Percentage Reduction	-	67.8	-	68.8	-	76.6
Filtration Rate - 0.2 m/hr						
Mean	3.22	0 51	2.69	0.61	3.55	0.50
Standard Deviation ±	1.67	0.27	1.27	0.26	1.85	0.23
Percentage Reduction	-	84.2	-	77.3	-	85.9

TABLE 2.7

COMPARATIVE COD REMOVAL EFFICIENCY OF FILTERS WITH INFLUENT & OUTLET RATE CONTROL

Description	Outlet Control (F1)		Influent Control (F2 & F3)			
	COD (mg/l)		COD (mg/l)			
	Raw	Filtered	Raw	Filtered	Raw	Filtered
			Filtration Rate - 0.1 m/hr			
Mean	4.69	2.62	5.16	2.5	4.69	2.52
Standard Deviation ±	0.78	0.88	0.83	1.05	1.17	1.23
Percentage Reduction	-	44.1	-	51.6	-	46.3
			Filtration Rate - 0.2 m/hr			
Mean	4.99	1.63	4.82	2.38	5.47	2.17
Standard Deviation ±	2.18	1.46	1.83	1.77	2.05	1.92
Percentage Reduction	-	67.3	-	50.6	-	60.3

2.1.1.6 Bacteriological Performance

The bacteriological quality of raw water and that of the filtrates with the two modes of operation is presented in Tables 2.8 and 2.9. respectively. When operated at 0.1 m/hr, the filters (F2 & F3) with inlet rate control gave 74 and 59 per cent of the samples respectively free from E.coli while in the case of filter with outlet rate control,38 per cent of samples were negative for E.coli. The efficiency values at 0.2 m/hr were 30, 62 and 41 per cent respectively. The performance of filters with inlet rate control appears to be better (at 0.1 m/hr) than or equal to that of filters with outlet rate control (Table 2.10).

2.1.1.7 Biological Aspects

The qualitative and quantitative data on planktonic algae (Tables 2.3 and 2.4) from the schmutzdecke showed that the occurrence and distribution of different forms of algae in filters operated in either mode was quite comparable. It was also observed that with the progress of the run, as reflected by the increase in headloss, there was a gradual buildup of the number of algae in the schmutzdecke. The total count of algae was also quite comparable irrespective of the rate control mode.

2.1.1.8 Length of run

The filter with inlet rate control gave an average run of 94 days at 0.1 m/hr as against 86 days for filter with outlet rate control. At 0.2 m/hr the average length of run for the filters with the two modes of operation was 16 and 21 days

TABLE 2.8

SUMMARY DATA ON BACTERIOLOGICAL QUALITY OF RAW WATER

E.Coli (MPN/100 ml)	Filtration Rate	
	0.1 m/hr	0.2 m/hr
Less than 100	37	20
101 - 200	11	7
201 - 500	25	18
501 - 1000	8	6
1001- 5000	25	17
5001-10000	9	6
Greater than 10000	5	6
Total No. of Samples	120	80

TABLE 2.9

BACTERIOLOGICAL PERFORMANCE OF FILTERS WITH INLET & OUTLET RATE CONTROL

E.coli (MPN/100 ml)	No. of samples			No.of samples		
	Outlet Control	Inlet Control		Outlet Control	Inlet Control	
	F1	F2	F3	F1	F2	F3
	Filtration Rate - 0.1 m/hr			**Filtration Rate - 0.2 m/hr**		
0	31	49	74	13	22	13
1 - 2	8	5	19	6	11	2
3 - 5	13	9	10	2	3	3
6 - 10	6	1	3	1	2	-
11 - 50	23	2	20	9	34	3
51 - 100	-	-	-	1	1	-
Total No. of Samples	81	66	126	32	73	21

TABLE 2.10

PERFORMANCE OF FILTERS WITH CONVENTIONAL OUTLET RATE VIS A VIS INLET RATE CONTROL

Summary Findings of Statistical Analysis of Data

Sl. No.	Parameter	Method of Analysis	Inference
1.	Turbidity	Completely randomized technique	Pairwise comparison between the two modes of rate control at 0.1 and 0.2 m/hr shows no difference in performance at 5 % level of confidence.
2.	COD	Pairwise comparison using students ´T´ test	Insignificant - No significant difference in COD removal efficiency between the two modes of rate control at both the filtration rates at 5 % level of confidence.
3.	Bacteriological quality (absence of E.coli)	Pairwise comparison using the method of Test for proportions	At 0.1 m/hr filtration rate, inlet rate control mode is more efficient. At 0.2 m/hr, no difference in performance between the two modes of rate control.

respectively. No significant difference in filter runs was observed with the two modes of operation (Table 2.2). The overall performance of filters with inlet rate control appeared to be equal to or better than that of filters with outlet rate control (Table 2.10).

2.1.1.9 Conclusion

Inlet rate control is simple in operation which could be effected with a valve and a weir at the inlet chamber. The need for daily operator attention for rate control could be minimized and the manipulation of rate more readily achieved. The rate indicator and loss of head gauge can be dispensed with. The headloss progression can be visually observed by noting the water level in the filter box. Any variation in filter rate due to changes in plant inflow will be gradual with no adverse effect on filtrate quality. Thus, the advantages of inlet rate control would outweigh those of outlet control when simplicity of operation and maintenance, consistent with reliability of filtrate quality, is crucial, especially for rural installations in developing countries.

2.1.2 Outlet Control

In a slow sand filter of classical design, the rate control is effected at the outlet by means of a regulating valve and a measuring weir. The rate control is facilitated by a float operated rate indicating device installed at the outlet chamber. The commercially available rate indicators are not only expensive but also require regular maintenance which can not be ensured in rural areas. Often, these devices do not function due to corrosion and other associated problems of maintenance. The need therefore, was recognized for a simple system which will be within the means and capability of small rural communities.

Two versions of rate indicator devices were developed. These could be fabricated locally using readily available materials. One such system depicted in Fig.2.3 consists of the following.

> A G.I. pipe of 7.5-10 cm dia. and about 2 m long open at both ends and fixed to the cover slab of the outlet chamber. At one end, the pipe is perforated to a length of about 30 cm and this portion is submerged in water in the outlet chamber. At the other end, a frictionless pulley is welded to the pipe. A float made of a plastic ball is connected through a non-elastic chord to a pointer (indicator) at the other end. The pointer moves over a vertical scale calibrated against the outlet weir.

This system of float with the pointer (counter-weight) has been tested for its effectiveness and suitability in the demonstration plant at Borujwada near Nagpur and found to be very satisfactory.

Another equally simple version of rate indicator system is depicted in Fig.2.4. In this system, the non-elastic chord is

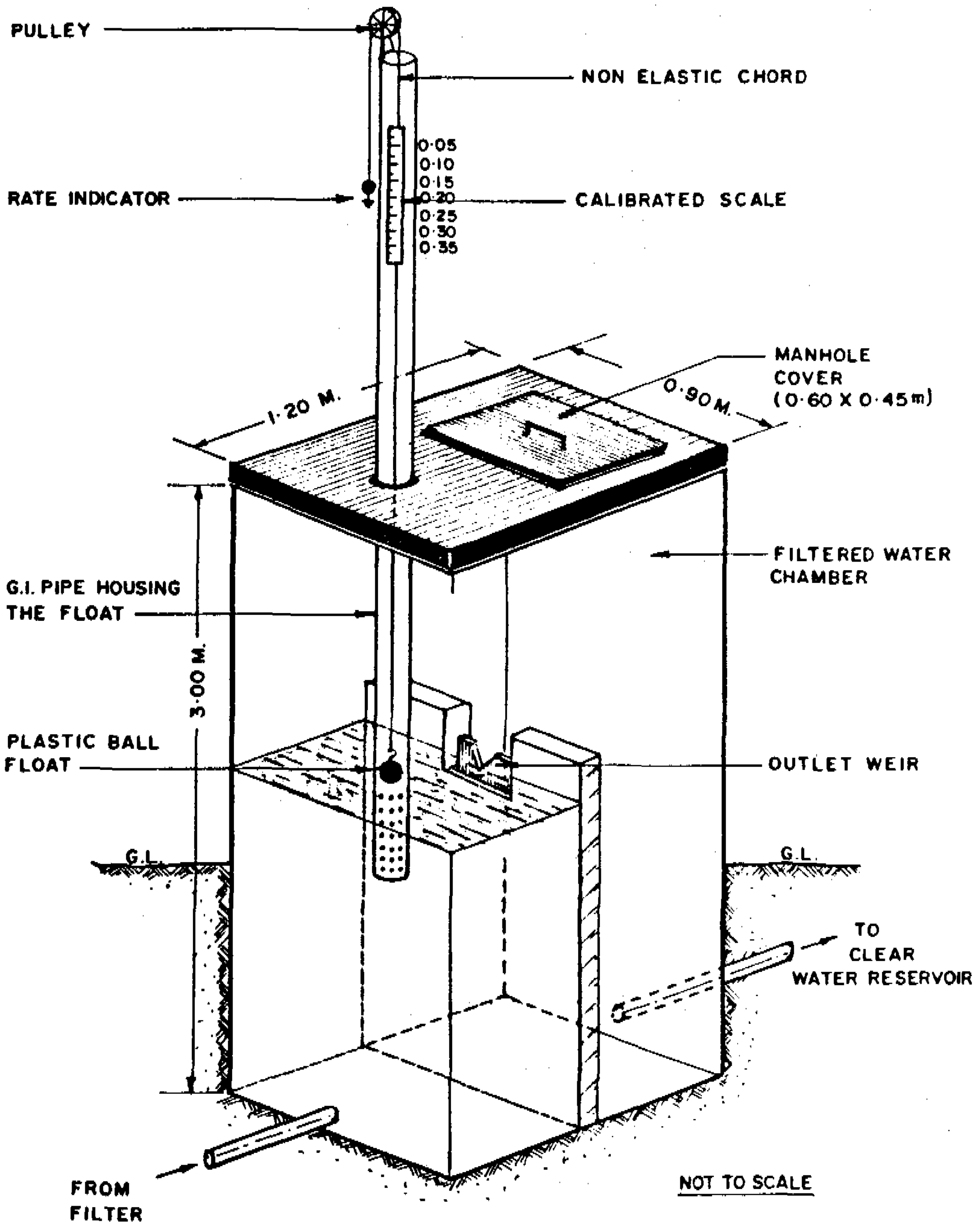


FIG. 2.4 FILTER RATE INDICATOR

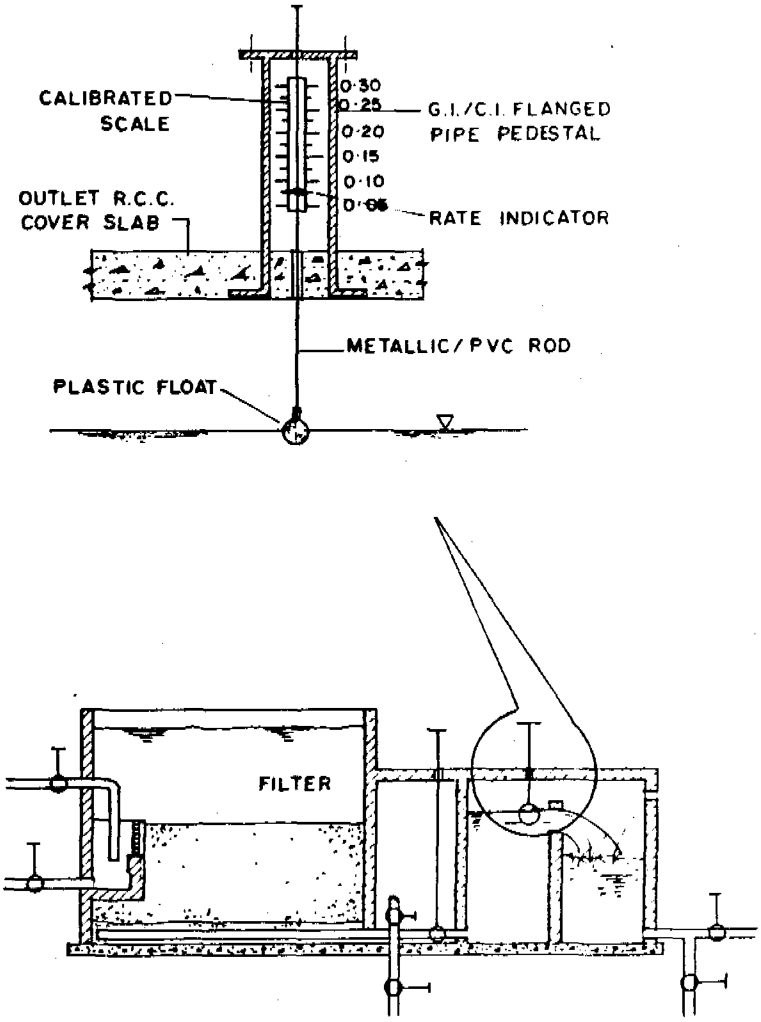


FIG. 2.4 FILTER RATE INDICATOR

replaced by a metallic/ PVC rod with a pointer passing through a vertical slit in the pedestal to which a measuring scale calibrated against the weir is fixed. In order to ensure verticality of the float rod and its free movement with changes in water level, suitable guides are provided in the pedestal at appropriate intervals. The pedestal could be made of cast iron/ galvanised pipe while the rod with the attached float could be of PVC or brass.

Both the systems described above have been found to be quite satisfactory for filter rate control.

2.2 Turbidity Measurement

One of the common, routine tests for the functional efficiency of a filter is to measure the turbidity of the filtered water. While sophisticated instruments are available to measure turbidity accurately, these are often beyond the capacity of small, rural systems. With this in view, attempts were made to develop simple methods for determination of turbidity by visual comparison with standards of known turbidity.

As a parameter for routine monitoring of the performance of a slow sand filter, the filtrate turbidity is more crucial than the influent turbidity. The operator should be able to discern fairly well the changes in the filtrate turbidity so as to take appropriate preventive/corrective measures. Therefore, the system of measurement should be sensitive enough to differentiate between filtered water turbidity of say 1 NTU and 2 NTU.

Turbidity standards using Formazine were prepared as per Standard Methods (15th Edition) using double distilled water and appropriate dilution to obtain desired turbidity values. Three standards, viz. 40 NTU,5 NTU and 2 NTU were calibrated using Hach Model 2100-A Direct Reading Turbidimeter. The standards kept in air-tight containers were checked at the end of 10, 13, 17, 23, 29 and 38 days to assess their keeping quality. The observations are summarized in Table 2.11.

It could be seen from the results that the turbidity standard of 40 NTU on storage for varying periods of time loses its keeping quality. Interestingly, when a stabilizing agent (Alcohol + Glycerol) is added to the standard, the change in the turbidity value with storage appears to be minimal. A similar trend was observed with turbidity standards of 5 NTU and 2 NTU also.

The studies have shown that this approach of developing stable turbidity standards of low values for use as visual standards for comparison has not served the intended objective. Therefore, there is a need to explore other methods of turbidity determination for small installations in developing countries.

TABLE 2.11

KEEPING QUALITY OF FORMAZINE TURBIDITY STANDARDS

Description of standards	Turbidity (NTU) after time interval in days						
	0	10	15	17	23	29	38
	Formazine Standard - 40 NTU						
a) Standard in Distilled Water	40	38	37	36.5	36	36	35
b) "	40	37	36	36	36	36	34
c) "	40	37.5	35.5	34.5	32	31	28
d) c sealed in Hach Standard Cell	40	38	39	39	39	38	38
e) Standard + Conditioning reagent *	38	37	36	36	36	36	36
	Formazine Standard - 5 NTU						
a) Standard in Distilled Water	5.0	4.7	2.6	2.7	1.0	1.0	1.2
b) "	5.0	4.5	2.4	1.8	0.9	1.0	1.0
c) "	5.0	4.5	2.5	2.6	1.8	1.7	1.6
d) c sealed Hach Standard Cell	5.0	4.7	2.4	2.3	1.0	1.3	1.1
e) Standard + Conditioning reagent *	5.8	5.6	4.0	4.5	3.4	3.5	3.6
	Formazine Standard - 2 NTU						
a) Standard in Distilled water	2.0	1.8	0.6	0.5	0.43	0.48	0.7
b) "	2.0	1.7	0.5	0.57	0.6	0.51	0.7
c) "	2.0	1.8	0.5	0.31	0.78	0.6	0.8
d) c sealed in Hach Standard Cell	2.0	2.2	1.5	1.0	0.22	0.3	0.27
e) Standard + Conditioning reagent *	2.0	2.2	1.4	1.0	2.1	1.6	1.7

* Glycerol + Ethyl alcohol (1:2) 5 ml of the mixture to 100 ml of standard

3. EVALUATION OF EXISTING PLANTS

Experience during the course of the project in India revealed that there have been deficiencies in the traditional practices followed for the design and construction of slow sand filters. These result not only in sub-optimal designs but also give rise to difficulties in effective operation and maintenance of filters to produce continuously a satisfactory filtrate. Recognising the need for rationalising and standardizing slow sand filter designs, a national workshop on "Design and construction of slow sand filters" was organised in New Delhi during January 19-21, 1987. The general objectives of the workshop were to :

i) critically study and review the design and construction practices for slow sand filtration schemes traditionally followed by different states in India;

ii) suggest possible improvements; and

iii) develop new design approaches suited to Indian conditions.

The workshop was attended by senior water supply design engineers from several states of India and representatives of NEERI, IRC, UNICEF and DANIDA. The highlight of the workshop was a critical study and review by the participants themselves of the designs and drawings for five typical SSF plants obtained from various states in the country and visits to a few full scale plants resulting in practical suggestions for improvements. Based on the discussions and recommendations of the expert group, annotated design criteria have been formulated. The proceedings of the workshop have been published in the form of a report. The positive impact of this report is very evident from the large number of requests received for the copies.

4. STANDARD DESIGNS

As a part of the project further research was addressed to the development of a methodology for evaluation of alternate SSF system designs and selection of the minimal cost design. The methodology involves identification of feasible alternatives meeting the design criteria, formulation of cost functions and regression models for the individual components of the alternative systems and thereby the total annual costs functions. Appropriate assumptions need to be made wherever necessary. A comparison of the total annual costs of alternate designs leads to the identification and selection of the least cost design. The methodology has been presented with an example in Annexure 1 and a computer program developed for the purpose alongwith typical outputs is given in Annexure 2

5. RAPID APPRAISAL OF SOME RIVER BED INFILTRATION WORKS IN TAMIL NADU

5.1. Introduction

Experience has shown that, slow sand filtration, as a single step treatment, is not suited for waters of high turbidity unless preceded by appropriate pre-treatment. River bed filtration (infiltration galleries and wells) can provide a simple, effective pre-treatment to prepare water that can be readily treated by slow sand filters. However, not much published information is available regarding the performance of such pre-treatment systems. As part of the IRC-NEERI research and demonstration project on slow sand filtration, a rapid appraisal of a few river bed infiltration works in Tamil Nadu has been undertaken. The following is a brief report on the findings.

5.2. Description of Infiltration Works

Six river bed filtration works were selected for the study (Table 5.1). Of these, two are located in river Vaigai in Madurai district, three in river Cauvery in Trichy district and one in river Kollidam (Coleroon) in Tanjore district. The installations consist of two types, viz. (1) infiltration galleries and (2) infiltration wells with or without radial collectors. The salient engineering details of the works are summarised in Table 5.2.

TABLE 5.1

GENERAL DATA ON INFILTRATION WORKS EVALUATED

Description	Location (River)	Year of Construction	Design Capacity (mld)	Terminal Treatment	Cost (Rs.) in Lakhs
Infiltration Gallery	Kochadai (Vaigai)	-	20	Chlorination	-
-do-	Melakkal	-	19.4	-	-
Infiltration well	Kambarasan Pettai (Cauvery)	-	18	Chlorination	7.5
-do-	BHEL, Puthapuram (Cauvery)	1980	13.6	-	36
-do-	Vengoor II (Cauvery)	1969	6.4	Chlorination	10
-do-	Thirumanoor (Kollidam)	1978	10.45	-	12.71

TABLE 5.2

ENGINEERING DETAILS OF INFILTRATION WORKS EVALUATED IN TAMIL NADU

Description	Kochadai (Madurai)	Melakkal (Madurai)	BHEL, Vengur (II) (Trichy)	BHEL, Puthapuram (Trichy)	Kambrara sampettai (Trichy)	Thirumannor (Tanjore)
1. Source	Vaigai (infiltration gallery)	Vaigai (infiltration gallery)	Cauvery	Cauvery	Cauvery	Coleroon
2. Inner dia. of collector	3 m	3 m	4.5 m	6 m	5 m	5 m
3. Dia of radial arm	450 mm	450 mm	300 mm	375 mm	300 mm	300 mm
4. No. of radial arms	-	-	-	3	13	8
5. Total length of radial arm of gallary	-	660 m	420 m	240 m	441 m	400 m
6. Depth of collection well/suction well below bed level	10 m	10 m	5.5 m	-	22 m	36 m
7. Pumping rate	19.4 mld	19.4 mld	-	13.6 mld	22 mld	10.47 mld

The Kochadai installation is an infiltration gallery constructed across the river Vaigai 2.5 km from Madurai city and is designed to supply 20 MLD. The gallery installed in the river bed comprises open jointed pipes surrounded by graded gravel and sand as shown in Fig.5.1 Infiltered water is pumped and supplied after chlorination. Surface flow is always ensured in the river through regulation of sluice gates at the Vaigai dam upstream.

The infiltration gallery at Melakkal is located in Vaigai river 20 km from Madurai city. The gallery is constructed along the river bank.

The two pre-filtration works evaluated in Trichy district are located in the Cauvery river bed and the one at Thirumanoor in Tanjore district is constructed in river Kollidam. These are all infiltration wells with radial collector arms. River water after infiltration is chlorinated before supply. The infiltration well at Puthapuram in Cauvery river is shallow (5.5 m below river bed level) as clay is encountered at deeper level. Depending upon the meandering of the river, the surface flow is diverted towards the infiltration works.

5.3. Performance Observations

The performance of the river bed filtration works is summarized in Table 5.3. It could be seen from the results that there has been a significant reduction in turbidity, as also the indicator organisms of fecal contamination due to infiltration. A considerable reduction in the chemical oxygen demand (COD) of

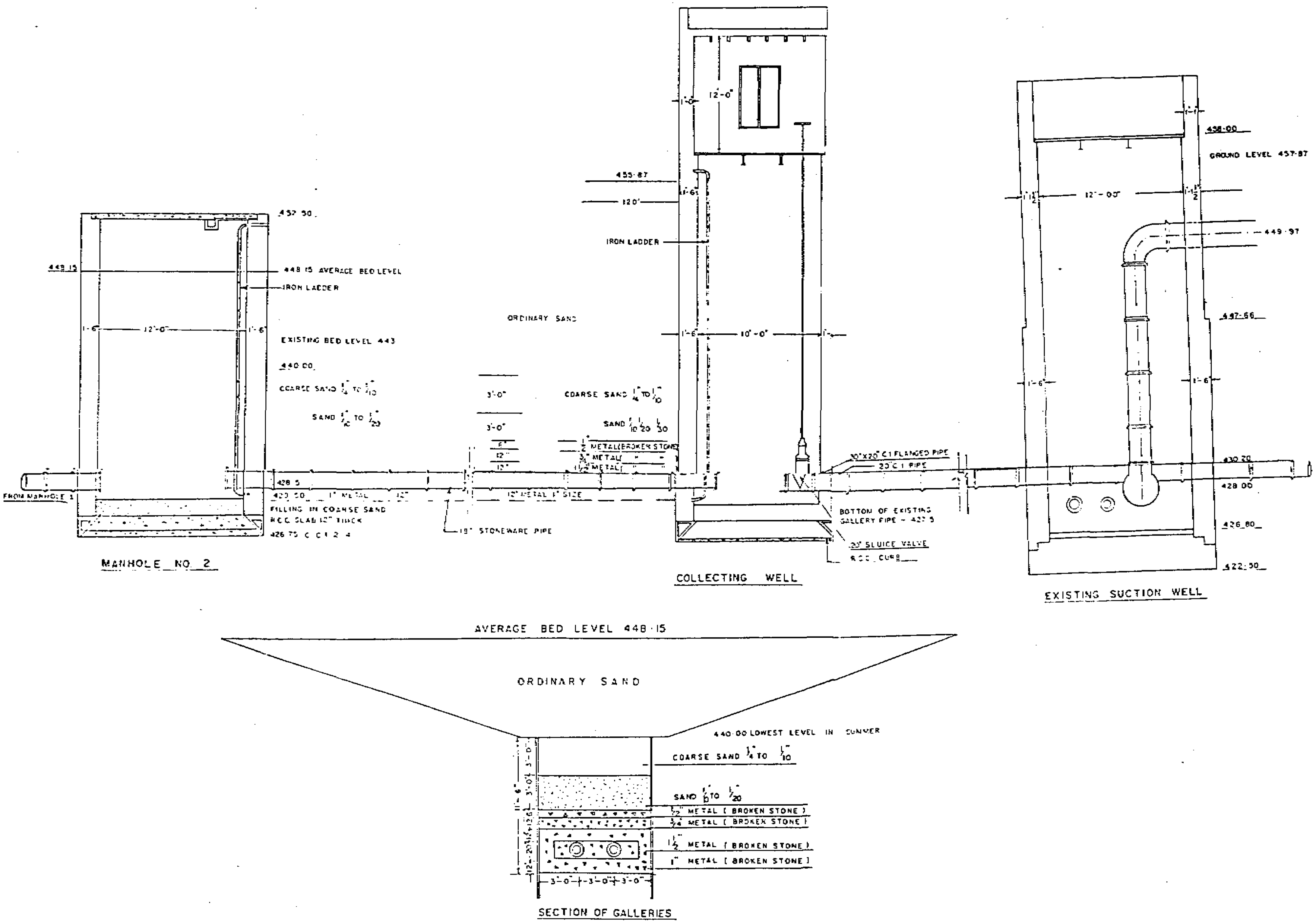


FIG. 5.1 DETAILS OF INFILTRATION GALLERY AT KOCHADAI

TABLE 5.3

PERFORMANCE OF RIVER BED FILTRATION WORKS IN TAMIL NADU

Installation	Kochadai		Melakkal		Kambarasanpetti		BHEL Puthapuram		Vengoor II		Thirumannor	
Parameter	Raw	Infiltered	Raw	Infiltered	Raw	Infiltered	Raw	Infiltered	Raw	Infiltered	Raw	Infiltered
Physico-chemical												
Turbidity(NTU)	4.7	0.4	2.5	0.2	2.6	0.6	3.4	0.4	3.4	0.4	2.4	0.3
pH	7.5	7.8	7.8	7.7	7.8	7.5	8.0	7.8	8.4	7.8	8.5	7.9
Total Alkalinity (as $CaCO_3$)	164	160	182	174	170	144	212	198	162	152	185	177
Total Solids	-	-	-	-	-	338	372	348	-	332	346	330
Dissolved Solids	245	240	256	252	-	320	352	338	-	300	321	322
Chlorides as Cl	31	30	32	31	50	41	74	69	52	51	58	53
Sulphates as SO_4	12	9	11	9	24	15	28	24	28	21	24	21
Iron as Fe	0.2	Traces	0.2	Traces	Nil	0.2	Nil	Nil	Nil	Nil	0.1	Traces
Manganese as Mn	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
COD	6.2	3.6	10.4	3.7	9.2	3.0	16.0	4.9	13.5	4.2	9.7	1.4
Bacteriological (MPN/100 ml)												
Total Coliform	240	5	540	80	480	240	35000	540	3500	0	7900	700
E. Coli	17	0	8	0	70	0	50	0	240	0	0	0
F. Coliforms	33	2	46	0	70	8	1700	27	350	0	490	110
F. streptococci	49	0	23	0	2	0	23	4	8	0	23	0
Plate Count(per ml)	600	590	590	330	8400	6900	360	82	49000	400	360	350

All values except pH and Turbidity are expressed as mg/L water has also been observed. However, as expected, there is no appreciable reduction in the dissolved mineral constituents. The general experience with river bed filtration works in Tamil Nadu is a gradual decrease in yield over the years due to silting.

5.4. Conclusion

Due to recurrent droughts and low flows in the river, high turbidity in raw water has not been encountered during the period of appraisal. The raw water turbidity remained fairly very low ($\leqslant$ 5 NTU). Nevertheless, there has been a significant improvement in the physical and bacteriological quality following river bed filtration. Enquiries with the water supply agency officials have indicated that the performance of the infiltration works has been satisfactory even during periods of high turbidity. However, this needs confirmation by further studies.

6. PILOT PLANT STUDIES ON PRE-FILTRATION OF TURBID WATERS

6.1. Introduction

Slow sand filtration has many attractive features which favour its adoption for treatment of surface waters in developing countries and especially for rural and small urban communities. However, one problem in applying slow sand filtration for direct treatment of surface waters is that even moderately high turbidities will cause rapid clogging of the filters necessitating their frequent cleaning. Pretreatment of raw water will be necessary before slow sand filtration if it contains an average turbidity in excess of about 25 NTU. It should as well be considered for lower turbidity levels(1). In tropical countries, the rivers carry very high turbidities during monsoon periods. In India, many rivers are found to carry peak monsoon turbidities as high as 2000 NTU or even more and hence it will be possible to apply the SSF process only if some effective pretreatment is provided to reduce the initial turbidity substantially.

Some of the pretreatment methods used for the reduction of turbidity are plain settling, extended sedimentation, river bed filtration and pre-filtration (also termed roughing filtration). Plain settling is generally applied for periods of 4-12 hrs and will be useful only when the turbidity is of a quick-settling type. Extended sedimentation may be for a duration of a month or more and may be effective in the removal of even colloidal turbidities. However, sedimentation tanks require considerable land area and are costly to construct. The method may therefore be applicable only when raw water supply is intermittent making storage inevitable. Storage-cum-sedimentation tanks have found much use in the Punjab and Haryana states of India where often irrigation canals having intermittent closures serve as water supply sources. There are over 400 SSF installations in the two states having sedimentation-cum-storage tanks successfully handling monsoon turbidities as high as 1000 NTU or more. River bed filtration as pretreatment prior to SSF has been adopted atleast in one case in India(2).

Pre-filtration has attracted attention recently as an effective method of treating turbid surface waters before SSF without the use of chemicals or requiring much O & M attention. This chapter presents the results of pilot-plant studies carried out on prefiltration at the Delhi Zonal Laboratory of NEERI.

6.2 Prefiltration Methods - A Brief Review

6.2.1 General

Several methods of pre-filtration have been suggested for the pretreatment of turbid waters before SSF. Of these, three methods viz, horizontal flow roughing filtration (HRF), upflow coarse media filtration (UCF) and upflow fine media filtration (UFF) were taken up for pilot plant studies. Details of the three types of pre-filters are described below :

6.2.2 Horizontal Flow Roughing Filter

A horizontal flow roughing filter consists of a rectangular box, usually 1.0-1.5 m deep and 2-5 m wide with the raw water inlet on one side and the outlet on the other. The box is usually divided into three compartments each of 2-3 m lengths and packed with crushed stone or gravel graded from coarse to fine. The raw water is applied at a rate of 0.5-1.5 $m^3/m^2/hr$. Research has been carried out on HRF by the Asian Institute of Technology, Bangkok, the University of Dar es salaam, Tanzania (both on behalf of the IRC, The Netherlands) and the IRCWD, Dubendorf, Switzerland. The predominant process in HRF is sedimentation although with time, biological activity may also play a role. The IRCWD has explained that the horizontal movement of turbid water through the pore system in the filter is accompanied by a gravitational downward drift of suspended particles. The solids settle on top of the media and form loose agglomerates of several mm height. The shape of these small heaps is controlled by their slope stability. Once the deposits exceed this stability, small lumps of settled matter will move downwards restoring partially the retention capacity of the upper part of the filter. This mechanism endows to HRF with great silt storage capacity enabling long filter runs(3).

6.2.3 Upflow Coarse Media Filtration

The upflow coarse media filter (UCF) consists of watertight structures of 1-1.5 m depth usually placed in series and packed to 0.7-1.2 m depth with crushed stone or gravel graded from coarse to fine. The raw water is distributed at the bottom of the first bed at a rate of 0.5-1.0 $m^3/m^2/hr$ and the upflow is collected at the top over the media. The process is repeated in the subsequent units. The mechanism of turbidity removal in the UCF is mainly sedimentation as in HRF. As the UCF ripens, there may also be biological action in the unit. This method has been used in Colombia (South America) but has not been reported upon.

6.2.4 Upflow Fine Media filter (UFF)

The upflow fine media filter consists of a filter box with a depth of about 1.0-1.5 m filled with filter sand having E.S of about 0.5 mm and U.C of about 1.5 and supported by graded gravel. The raw water is applied at the filter bottom at a rate of 0.15 to 0.30 $m^3/m^2/hr$ and collected over the filter bed. The mechanism of turbidity removal in the process is the same as in HRF and UCF except that because of higher surface area presented by the smaller sized media, biological forces may play a greater role in purification. The UFF like the upflow coarse media filter has been tried in Colombia, but in this case again, no performance reports appear to have been published.

6.3. Objectives of Study

Pilot plant studies were taken up at Delhi on the different methods of pre-filtration mentioned above with the following objectives :

i) To demonstrate the methods and gain first-hand experience with them as they have not been tried in India so far.

ii) To evaluate and compare the performance of the different methods for pretreatment of a natural river water.

iii) To provide an approach to the design of prefiltration systems for SSF.

6.4. Pilot Plant Set-up

6.4.1 Raw Water Source

The river Jamuna formed the source of raw water for the pilot plant studies. The Jamuna is one of the major rivers of north-western India and a tributary of the river Ganges. About 600 mld of water is being drawn for water supply to Delhi city from upstream of the Wazirabad Barrage constructed across the river at its entry into the city. The river water is pumped to three water treatment works namely Wazirabad Treatment works; Chandrawal Treatment works I and Chandrawal Treatment works II. The flow to the latter two is through gravity conduits into which the raw water pumps discharge. The conduit to Chandrawal Treatment works I passes through the premises of the Delhi Zonal Laboratory of NEERI and raw water for the pilot plant studies was pumped from this conduit.

The Jamuna River is not subject to any major pollution, industrial or domestic upto the point of tapping for Delhi water supply. However, the turbidity of the river water is reported to rise very high seasonally reaching values above 1000 NTU during high floods. During monsoon seasons, the water also carries high amount of quick-settling silt. During low flow seasons, the river water turbidity drops very low, even to 1-2 NTU. The dissolved mineral solids in the water is usually low (less than 250 mg/l).

6.4.2 Pilot-Plants

The schematic lay-out of the pilot plant arrangements is shown in Fig.6.1. The facilities consisted of the following :

i) Arrangements for pumping raw water to an elevated constant head chamber.

ii) Elevated constant head chamber for feeding the HRF and UCF units.

iii) Elevated constant head-cum-desilting chamber for feeding UFF units.

iv) Horizontal flow roughing filter unit with an initial desilting zone.

v) Upflow coarse media filter unit with an initial desilting zone.

vi) Two upflow fine media filter units in parallel.

The hydraulic profile of the pilot plant facilities is shown in Fig.6.2. Detailed description of the different units follows :

6.4.3 Raw Water Pumping

Two centrifugal pumps (one being a standby) were installed for pumping raw water. The pumping capacity was 30 lpm or about double the pilot plant requirements. Generally, pumping was maintained round-the-clock during the study period.

6.4.4 Elevated Constant Head Chamber

The raw water was pumped into an elevated chamber of size 0.6 m x 0.6 m x 0.6 m. The inlet pipe was taken to the bottom of

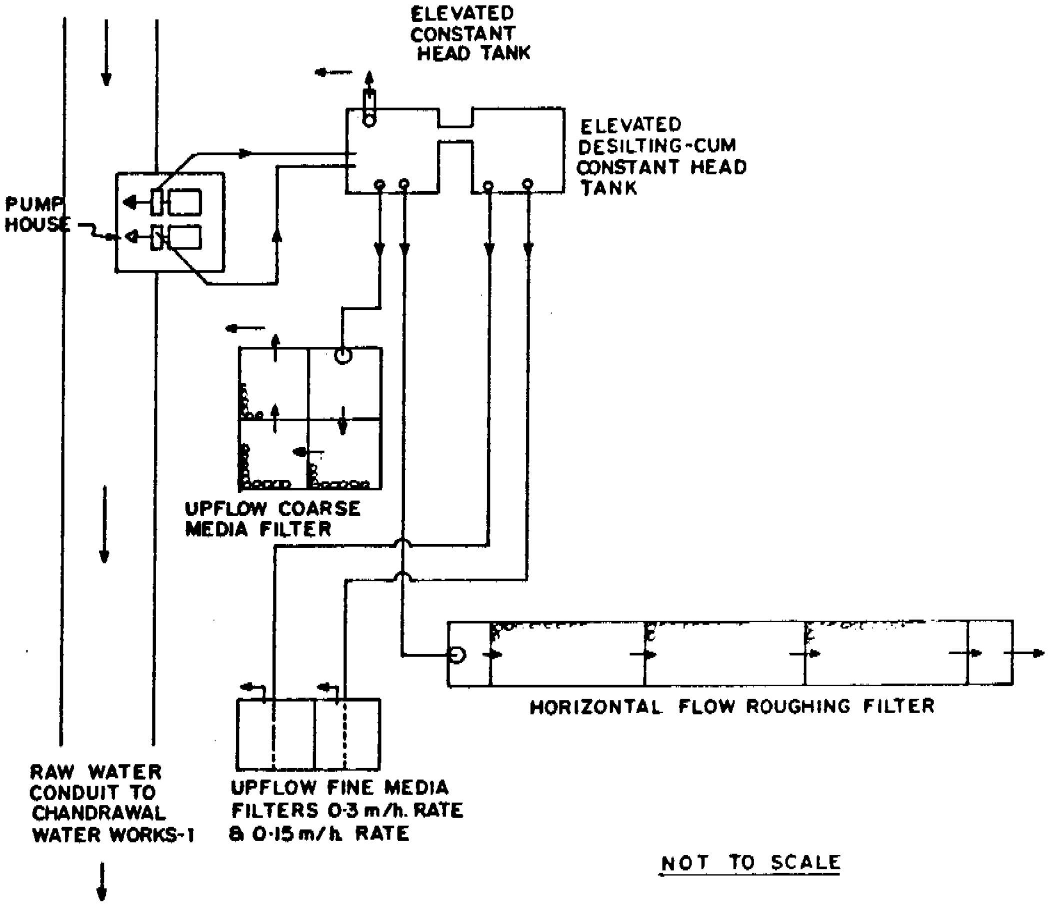


FIG. 6.1 SCHEMATIC LAY-OUT OF PILOT PLANTS FOR STUDIES ON ROUGHING FILTRATION

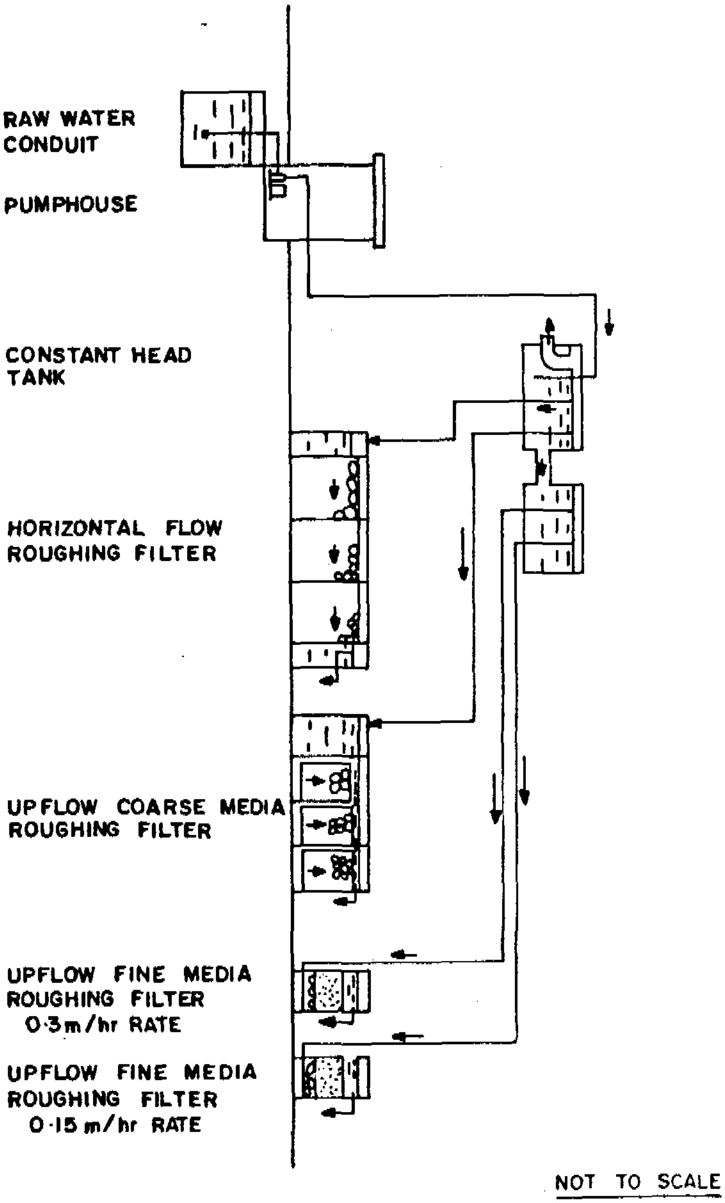


FIG. 6.2 HYDRAULIC FLOW DIAGRAM FOR PILOT PLANTS FOR STUDIES ON ROUGHING FILTRATION

the chamber so that the turbulance caused would prevent any silt in the water from settling. Constant level was maintained in the chamber by providing an overflow which surplussed excess pumpage back into the raw water conduit. Two drawoffs were taken from the chamber, one to the HRF and the other to the UCF. The drawoff arrangement consisted of 20 mm G.I. pipes with vertical drawoff arms provided with 6 mm dia drill-holes at different levels. The no. of drill-holes to be kept open to give the required discharges to the two pilot plants was determined by trial and error.

6.4.5 Elevated Constant Head-cum-Desilting Chamber

The unit of size 0.6 m x 0.6 m x 0.6 m was provided as an extension to the elevated constant head chamber with 50 mm dia G.I. pipe interconnection and had the same MWL as the latter. The chamber was intended for feeding the two UFF units at constant head and because of the detention provided (about 50 minutes) and the quiescent conditions maintained, it also served as a disilting chamber.

6.4.6 Horizontal Flow Roughing Filter

The details of the unit are shown in Fig.6.3. The unit was of brick masonary constructed and dosed at a rate of 0.7 m/hr (or 5 lpm) across effective filter media depth of 0.7 m. The inlet chamber provided a detention of 48 minutes for the above flow rate and served as a desilting chamber. Silt was removed from it manually at intervals using a long-handled scoop after

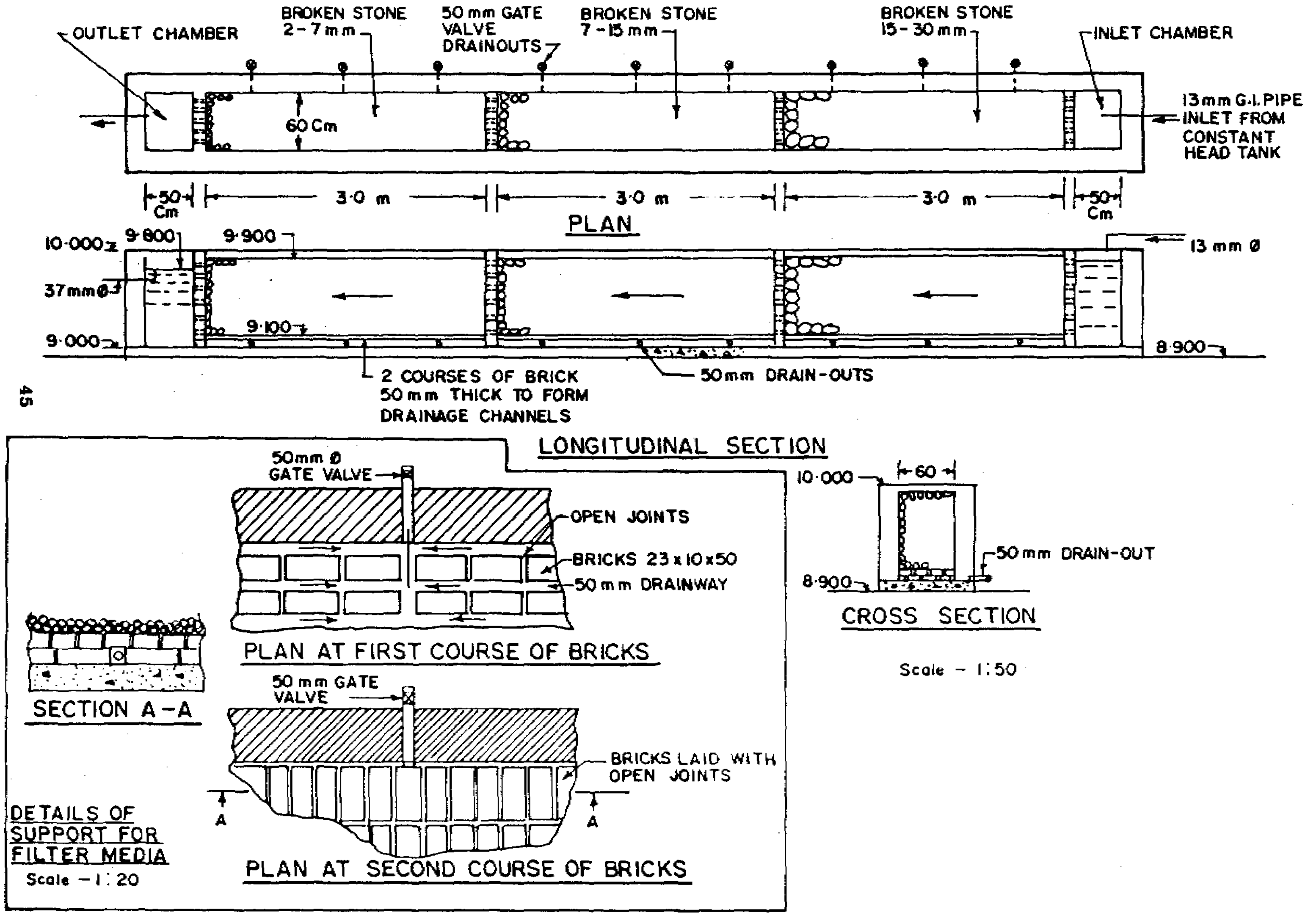


FIG. 6.3 DETAILS OF HORIZONTAL FLOW ROUGHING FILTER

stopping the flow temporarily. The detention period in the three filter sections combined was 4.2 hours (assuming 33 % voids in media).

6.4.7 Upflow Coarse Media Filter

The details of the unit are shown in Fig.6.4. The unit made of brick mansonry comprised three filter sections in series each of size 0.75 m x 0.75 m x 1.0 m (effective depth of media 0.7 m) was dosed at a rate of 5.6 lpm equal to an upflow rate of 0.6 m/hr. The detention period in the desilting compartment was one hour and 30 minutes while detention period provided in the three filter sections was 1.40 hours.

6.4.8 Upflow Fine Media Filters

The details of the units are shown in Fig.6.5. Two filters were provided for study at two different filtration rates. The filters were of brick masonary construction each of size 0.75 m x 0.75 m x 1.0 m with effective depth of 0.95 m.

One of the filters was worked at 0.3 m/hr i.e at 2.8 lpm. The detention period in this filter bed excluding the loose brick bottom was 1.5 hr. The second unit was dosed at 0.15 m/hr i.e at 1.4 lpm. The detention period in this unit was 3 hrs. The filtrates from the different roughing filter units were discharged into the raw water conduits leading to Chandrawal Treatment Works I.

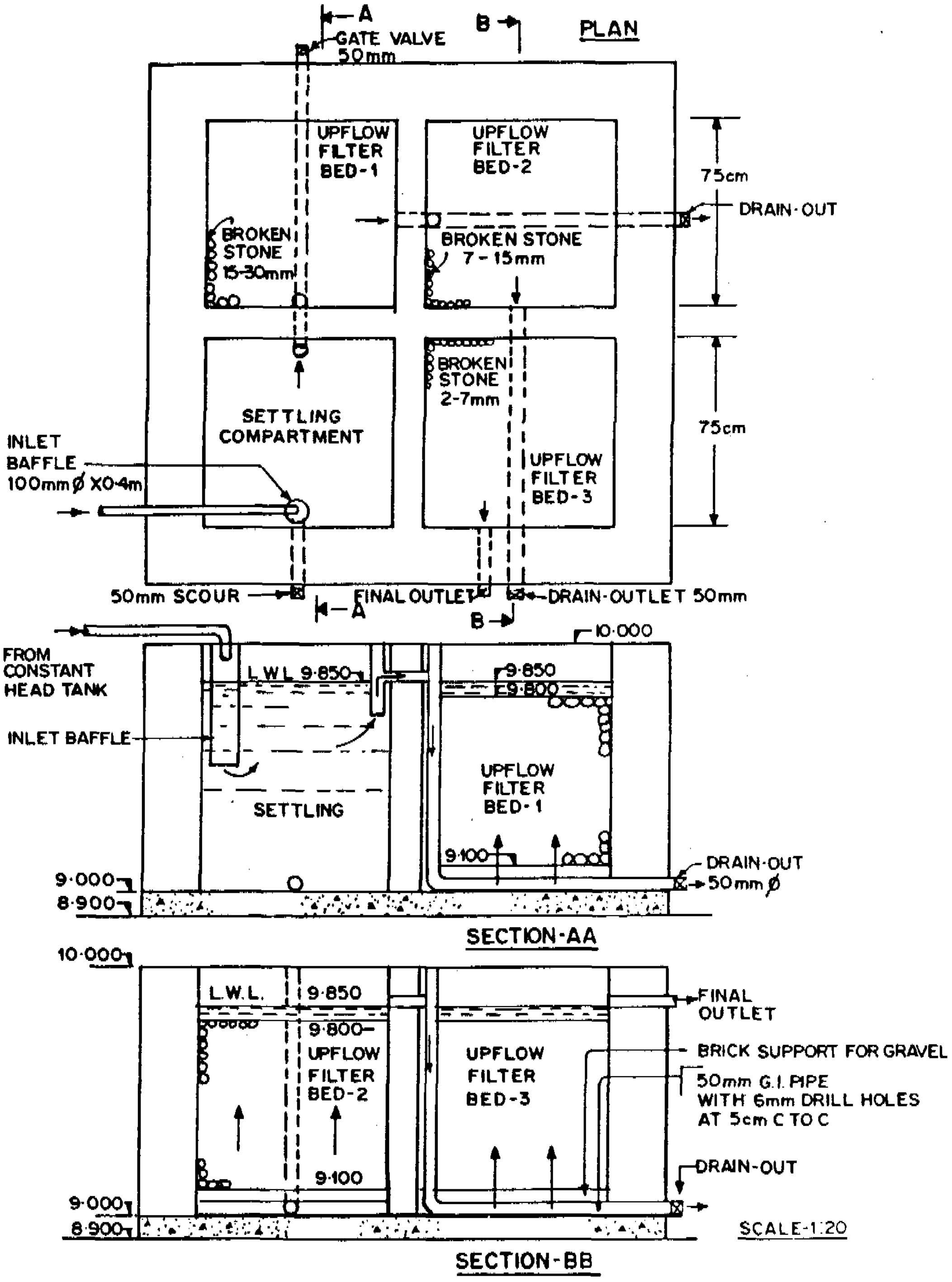


FIG. 6.4 DETAILS OF UPFLOW COARSE MEDIA FILTERS

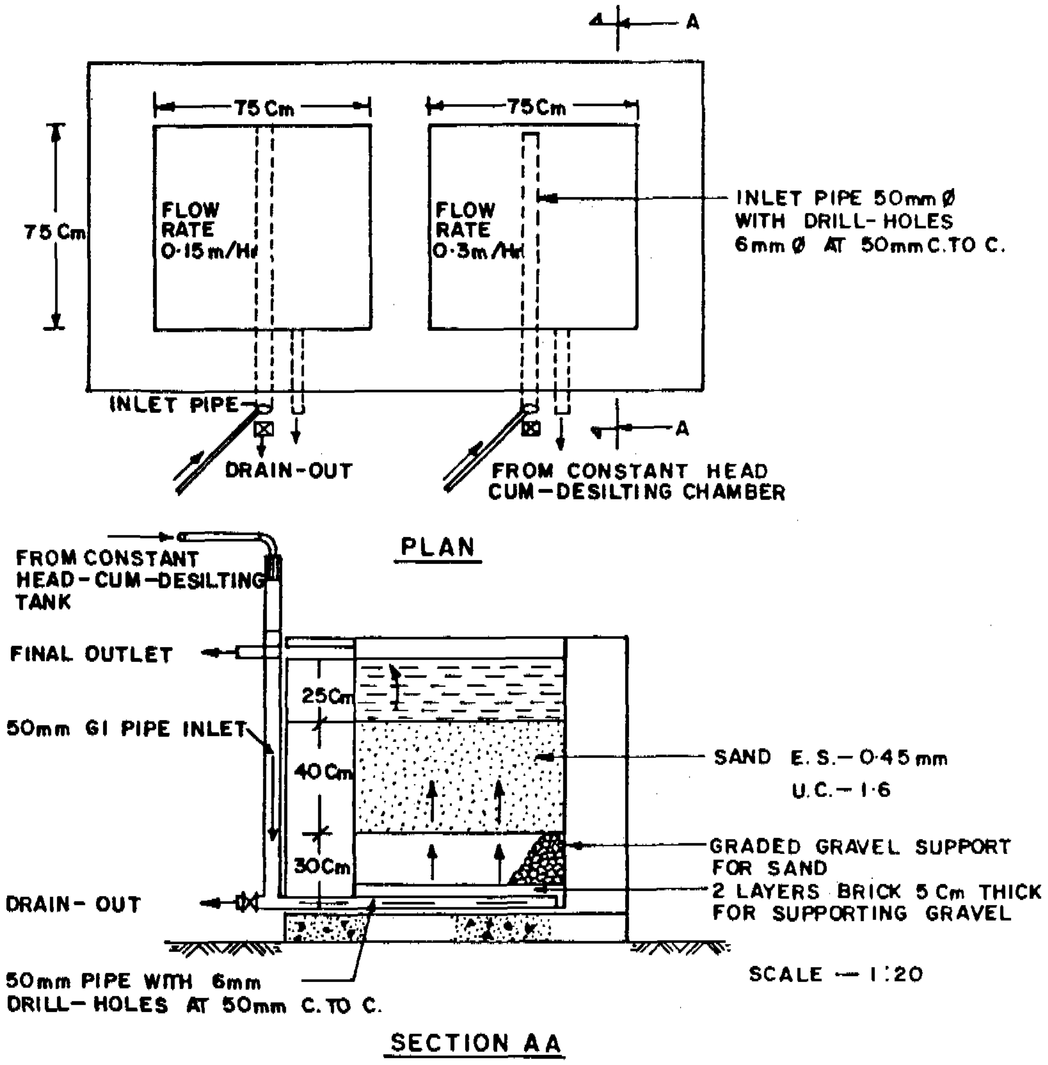


FIG. 6.5 DETAILS OF UPFLOW FINE MEDIA FILTERS

6.5 Operation and Maintenance

6.5.1 General

The upflow coarse media filter was started on 26.8.86, the horizontal roughing filter on 21.9.86 and the two upflow fine media filters on 6.10.86. All the filter units were stopped on 8.11.87. The filter media was washed well before placement in the filters in all cases. There were no interruptions in the operation of the filters on account of power cuts or power failures. Interruption for fast draining of the filters took only 2 hours maximum each time while in-situ cleaning occupied about 4 hrs maximum each time. Removal, washing and relaying of media was carried out once for the HRF involving an interruption of 4 days and once for the UCF which took 2 days. Overall, the interruptions were considered insignificant. The important occurences noticed during the operation and maintenance of the different pilot plant units are discussed below.

6.5.2 Horizontal Flow Roughing Filter

The HRF did not pose any problem of algae growth as it exposed the water only in the inlet and outlet zones. Soon after its start (i.e. within 15 days), the unit showed a sharp (but not complete) depletion of dissolved oxygen when it was decided to wash the unit. For this, the inflow was stopped and all the scour valves were opened quickly and simultaneously. This procedure which can be termed **fast draining**, removed an initial slug of turbidity probably formed of the solids settled near the drain-outs but did not wash out any significant amount of accumulated solids thereafter. Hence, the filter was flushed down by throwing bucketfuls of water on the media covering the wide area in steps. This procedure which can be termed **in-situ flushing** resulted in washing out considerable amount of solids accumulated in the filter. In the last section of the filter which had relatively finer media (7-2 mm) more flushings were required than in the first two sections. When the filter was put back into operation, it was found to exhibit much lesser DO depletion. Severe (almost complete) DO depletion occured in the HRF 9 months later also when the filter was again flushed in-situ.

The HRF unit had to be shut down midway during the study for 4 days for repair of some leaks when the opportunity was availed to completely overhaul the filter media. The overhauling was done by taking out the filter media, heaping it on a sloping floor and hosing it down with water while spading it over and over and finally recharging the filter with the cleaned media. The procedure was labour-intensive.

The maximum head loss observed in the HRF unit during the course of the study was only about 2 cm. No signs of any breakthrough of turbidity were observed in the HRF unit.

6.5.3 Upflow Coarse Media Filter :

A few months after its start, the UCF showed growth of filamentous algae on the walls of the desilting tank and on the top of the filter in all the three units. The algal filaments often got dislodged and got carried into the inlet pipes of the succeeding filter sections which was apparently responsible for some part of the comparatively frequent clogging noticed in the UCF. The algae also got carried down into the filter media during in-situ flushing posing the danger of lodging there and decomposing in course of time. The algae growth thus presented a major problem. To counter the algae problem, the filter was kept shaded from March'87 to July'87. The covers were then removed and as an alternative the media levels in the three filter sections were raised above the water level allowing the water to flow through the media to the outlets. This method was continued to the end of the study. Both the steps effectively controlled the growth of attached algae.

The UCF faced clogging problems on 8 occasions during 14 months of operation. The clogging resulted in flooding and overflow at the inlet chamber. To counter the colgging, the filter sections were fast-drained on some occasions which was not effective as also noticed with the HRF. In-situ flushing however, was more effective than fast-draining. The operation also helped reduce oxygen depletion significantly. The filter media was overhauled completely once.

The headloss in the filter at start was about 2 cm. Flooding and overflow occurred in the initial desilting section when headloss reached 10 cm. Filter cleaning reduced the head loss to 2-3 cm depending on the thoroughness of the operation.

Apparently, on one occasion there was a turbidity breakthrough in the final effluent.

6.5.4 Upflow Fine Media Filters

6.5.4.1 Performance at 0.3 m/hr rate

There was limited growth of attached filamentous algae on the filter surface. The algae growth did not create any of the operational problems faced in the UCF unit.

On three occasions, there was apparent clogging of the filter indicated by sudden overflow at the top of the inlet pipe. Fast-draining of the filter was then tried. There was initial slug discharge of turbidity but not any subsequent discharge of accumulated solids. In fact, there was no fast drainage of water in the filter, the water level over the sand surface falling only slowly. The fast draining procedure appeared to be effective only in scouring out the inflow distributor pipe. The procedure however, stopped the overflow problems at the inlet. Probably the overflow was caused only by clogging of the inflow distributor pipe. After the studies were over, in-situ flushing of the unit was tried but did not succeed.

The headloss in the filter was initially 1.0 cm. The head loss at the end of 12 months operation when the study was concluded was 30 cm, the maximum the unit could accommodate. At this stage, there was overflow at the inlet pipe which could not be controlled by fast-draining of the unit unlike during the earlier occasions of overflow. This observation indicated that the clogging observed towards the end was of the media itself and not of the inlet pipe as suspected in earlier cases.

6.5.4.2 Performance at 0.15 m/hr rate

Within a few months from the start, filamentous attached algae started developing on the sand surface in this unit, the algae soon forming a thick mat. The growth was much greater in this unit than in the one dosed at 0.3 m/hr already discussed. Presumably, the lower upflow velocity in the unit induced the greater growth. During hot summer months, at mid day, pacthes of the algal mat used to float up. The algae did not pose any particular problems in the UFF itselt, but the entry of uplifted patches of algae into subsequent SSF units may not be desirable and may have to be prevented in a regular plant.

Fast-draining was tried out in the unit on three occasions which helped only to scour out the inflow-distributor pipe as in the case of the 0.3 m/hr UFF unit. The head loss in the filter at start was less than 1 cm and it had increased to 8 cm by the time the study was concluded. There was no break through of turbidity from the sand bed till the end of the study.

6.6. Results of Performance Monitoring

6.6.1 General

In monitoring the performance of the pilot plant units the turbidity measured at the following stages of treatment was considered as the primary yardstick.

- Raw water as pumped to the pilot plants
- Raw water samples after centrifuging at 3000 rpm for 5 minutes. The values were determined less frequently than for raw water turbidities.
- Effluent from desilting chamber of the UCF. The values may be taken as applicable for effluents from the desilting chambers of the other units also.
- Final effluents from the different filter units.
- Effluents at different stages of filtration in the cases of the HRF and the UCF. Tests were made in these two cases only on limited occasions.

The general characterstics of river water are presented in Table 6.1. The turbidity values for raw water, centrifuged raw water, desilting chamber effluent and final effluents from different pre-filter units are shown in Table 6.2. The summary data on turbidity for the period of study is presented in Table 6.3. The performance of the pre-filter units with respect to turbidity removals at different stages of the HRF and UCF units are shown in Table 6.4 and Table 6.5 respectively.

COD, DO and Coliform counts were also determined in the raw water and different filter effluents, though only ocassionally. All these determinations were made according to the APHA Standard Methods (15th Edition). COD values were so low even in the raw water samples that the standard method modification for low COD samples had to be adopted in all cases, concentrating 100 ml samples to 20 ml volumes before refluxing. The D.O. values

TABLE 6.1

PHYSICO-CHEMICAL AND BACTERIOLOGICAL QUALITY OF JAMUNA RIVER WATER AT CHANDRAWAL WATER WORKS - DELHI

PARAMETERS	Water Quality (Range)
PHYSICO-CHEMICAL	
Turbidity(NTU)	1-530
pH	7.8-8.5
Total Alkalinity ($CaCO_3$)	72-144
Conductivity (uS/cm)	185-414
Hardness ($CaCO_3$)	
Total	86-248
Carbonate	86-144
Non Carbonate	0-104
Calcium (Ca)	22-42
Magnesium (Mg)	6-35
Chlorides (Cl)	7-58
Sulphates(SO_4)	10-45
Iron (Fe)	Traces
Fluoride (F)	0.2-0.4
BACTERIOLOGICAL (MPN/100 ML)	
Total coliform	170-5400
Fecal coliform	33-170

All values except pH ,Turbidity and Conductivity are expressed as mg/l.

TABLE 6.2

TURBIDITY OBSERVATIONS ON RAW WATER AND EFFLUENTS FROM PREFILTERS

Year and Month	Turbidity (NTU)						
	Raw Water		After Desilting	Prefilter Effluent			
	As pumped	Centrifuged		HRF	UCF	UFF	
						0.3 m/hr	0.15 m/hr
1986							
Aug.26	445	19	270	-	65	-	-
27	340	19	240	-	51	-	-
28	270	15	175	-	36	-	-
29	225	14	155	-	36	-	-
31	170	6	110	-	29	-	-
Sep. 1	135	4	95	-	21	-	-
2	96	4	40	-	4	-	-
15	25	7	21	-	9	-	-
17	17	6	12	-	6	-	-
18	12	5	10	-	5	-	-
19	11	5	10	-	5	-	-
21	14	5	11	3	3	-	-
22	19	5	15	8	6	-	-
23	21	5	19	3	5	-	-
25	13	7	13	3	5	-	-
Oct. 1	11	4	10	3	4	-	-
3	15	5	13	4	5	-	-
6	8	2	8	2	2	-	-
8	8	2	6	2	6	-	-
11	10	-	5	3	5	-	-
13	10	2	9	2	3	-	-
14	10	2	8	1	2	-	-
15	11	2	9	2	3	-	-
21	13	3	9	2	3	-	-
22	13	3	11	1	3	1	1
30	12	2	9	2	3	-	-
Nov. 6	12	4	11	3	3	2	2
12	11	4	10	3	3	3	3
28	11	1	7	2	1	1	1
Dec.15	9	-	7	2	1	1	1
27	7	-	7	1	1	1	1
1987							
Jan. 8	4	1	4	1	1	1	1
11	3	1	5	1	1	1	1
31	3	1	3	1	1	1	1
Feb.23	3	1	3	1	1	1	1
Mar.23	1	1	1	1	1	1	1
Apr.25	5	1	4	1	1	1	1
May. 2	24	-	-	1	1	1	1
6	64	15	-	1	2	1	1

TABLE 6.2 (Contd..)

Year and Month	Turbidity (NTU)						
	Raw Water		After Desilting	Prefilter Effluent			
	As pumped	Centri-fuged		HRF	UCF	UFF	
						0.3 m/hr	0.15 m/hr
May. 8	77	-	68	4	18	3	3
9	45	-	-	4	10	2	1
11	45	-	-	4	8	2	1
12	320	48	220	4	30	6	1
13	530	70	450	17	93	29	20
14	280	-	250	22	72	25	17
15	180	-	-	14	38	18	12
16	180	-	-	15	38	18	13
18	105	-	73	10	22	13	12
21	45	-	-	3	12	5	-
22	40	-	-	4	9	5	3
26	25	-	-	2	5	5	3
31	20	4	-	1	3	2	1
Jun.15	145	27	145	22	35	7	6
16	90	17	83	12	22	7	5
30	25	4	22	1	3	1	1
Jul. 7	32	-	-	1	3	1	1
8	46	4	11	1	3	1	1
17	43	7	14	1	5	1	1
30	71	12	32	2	8	4	2
31	165	-	-	11	31	16	4
Aug. 8	17	-	14	2	3	6	2
14	48	10	-	6	11	9	3
15	51	-	-	4	16	9	2
21	9	-	-	2	13	2	1
26	245	28	-	3	18	5	2
27	230	48	-	17	28	13	4
28	180	-	165	20	43	20	10
29	105	15	92	10	26	14	8
31	120	17	105	8	22	13	6
Sep. 3	151	23	150	9	27	18	7
7	60	-	55	7	17	17	7
14	83	-	80	7	23	18	5
29	9	2	7	2	3	4	2
Oct.15	12	-	9	2	3	2	2
30	18	-	12	3	4	3	2
Nov. 8	25	4	16	1	3	1	1

Turbidity values rounded off to the nearest integer. Values less than 1 NTU rounded off as 1 NTU.

TABLE 6.3

VARIATION IN TURBIDITY OF RAW WATER AND PREFILTER EFFLUENT

Year and Month	Turbidity (NTU)					Overall Percent Removal			
	Raw Water (Range)	Pre-filtered							
		HRF	UCF	UFF		HRF	UCF	UFF	
				0.3 m/hr	0.15 m/hr			0.3 m/hr	0.15 m/hr
1986									
Aug.	170-445	-	29-65	-	-	-	83-85	-	-
Sep.	11-135	3-8	3-21	-	-	73-94	73-84	-	-
Oct.	8-15	1-4	2-6	1	1	73-87	60-75	87-93	87-93
Nov.	11-12	2-3	1-3	1-3	1-3	75-82	75-91	75-91	75-91
Dec.	7-9	1-2	1	1	1	75-86	86-89	86-89	86-89
1987									
Jan.	3-4	1	1	1	1	67-75	67-75	67-75	67-75
Feb.	3	1	1	1	1	67	67	67	67
Mar.	1	1	1	1	1	0	0	0	0
Apr.	5	1	1	1	1	80	80	80	80
May	20-530	1-22	1-93	1-29	1-20	95-96	82-95	94-95	95-96
June	25-145	1-22	3-35	1-7	1-6	85-96	76-88	95-96	96
July	32-165	1-11	3-31	1-16	1-4	93-97	81-91	90-97	97-98
Aug.	9-245	2-20	3-43	2-20	1-10	78-92	67-82	78-92	89-96
Sep.	9-151	2-9	3-27	4-18	2-7	78-94	67-82	56-88	78-95
Oct.	12-18	2-3	3-4	2-3	2	83	75-78	83	83-89
Nov.	25	1	3	1	1	96	88	96	96

HRF- Horizontal Roughing filter; UCF- Upflow Coarse Media Filter; $UFF_{0.3}$ - Upflow fine Media Filter dosed at 0.30 $m^3/m^2/hr$; $UFF_{0.15}$ - Upflow Fine Media Filter dosed at 0.15 $m^3/m^2/hr$.

TABLE 6.4

TURBIDITY REMOVED AT DIFFERENT STAGES OF HORIZONTAL FLOW ROUGHING FILTER

Year and Month	Turbidity (NTU)				Percent Removal
	Raw Water	Prefiltered			
Stage		1	2	3	
1987					
Aug.27	235	130	63	17	93
28	180	74	48	20	89
29	105	43	29	15	86
30	120	41	21	8	93
Sep.14	83	35	29	7	92
Nov. 8	25	11	7	1	96

TABLE 6.5

TURBIDITY REMOVED AT DIFFERENT STAGES OF UPFLOW COARSE MEDIA FILTER

Year and Month	Turbidity (NTU)				Percent Removal (Total)
	Raw Water	Prefiltered			
Stage		1	2	3	
1986					
Aug.26	445	190	125	65	85
27	340	150	100	51	85
28	270	105	67	36	87
29	225	95	67	36	84
31	170	75	51	29	83
Sep. 1	135	65	39	21	84
1987					
May 12	320	140	75	30	90
13	530	200	145	93	82
18	105	47	35	22	79
Jun 15	145	82	61	35	76
Aug.28	180	101	72	43	76
29	105	64	46	26	75
31	120	61	43	22	82
Sep. 3	151	78	60	27	82

are furnished in Table 6.6; COD values in Table 6.7 and coliform counts in Table 6.8.

6.6.2 Raw Water Quality

The raw water temperature ranged from 12^{o}C in winter to 32^{o}C in summer. The highest turbidity recorded for the raw water was 530 NTU and the minimum was 1 NTU. High turbidities were experienced in short spells. During the study period of 1986-87, due to acute drought the river did not experience any high floods.

The turbidity of centrifuged samples may be considered as an approximate index of the colloidal turbidity in raw water. The centrifuged turbidities ranged from 70 to less than 1 NTU indicating that most of the raw water turbidity, especially at the higher values, was in suspended form. The COD of the raw water was quite low with a range of 6-2 mg/l and average of 5.0 mg/l. The coliform counts with a range of 1700-93/100 ml (MPN) also were not high.

6.6.3 Performance of Desilting Units

Desilting removed considerable silt from the raw water as found from the silt accumulated in the desilting units. Desilting also reduced the turbidities of the raw water upto about 15 %. It is to be pointed out here that the turbidity removed in the desilting chamber would have been of quick-settling solids. These solids would have been removed in the prefilters if not in the

TABLE 6.6

DO OBSERVATIONS IN PRE-FILTERS

Year and Month	Raw Water	Effluent		UFF	
		HRF	UCF	0.3 m/hr	0.15 m/hr
1986					
Oct. 2	6.2	1.0	1.0	-	-
8	6.4	1.5	6.2*	-	-
11	5.2	3.0*	4.8	4.8	5.2
Nov.13	8.0	6.2	6.6	6.8	7.6
Dec.23	10.8	7.2	8.8	7.6	7.6
1987					
Jan.27	11.5	7.0	8.9	7.5	7.4
Feb. 3	12.5	7.3	10.8	11.1	13.4
Mar.23	6.2	4.4	4.9	6.1	5.4
Apr.25	6.8	2.4	4.2	4.6	4.8
May 14	7.8	4.4	5.8	7.2	6.8
31	5.2	3.2	4.5	5.3	4.0
Jun 30	6.4	0.6	2.7	2.4	2.0
Jul 13	5.8	1.7*	3.3	2.4	1.9
Aug.13	6.2	1.2	1.8	3.9	4.2
31	6.4	3.4	4.8*	6.2	6.6
Sep.26	7.0	3.9	4.6	7.1	11.7

DO values are in mg/L ; * After in-situ cleaning

TABLE 6.7

COD OF RAW WATER AND PREFILTER EFFLUENTS ALONGWITH RAW WATER TURBIDITIES

Year and Month	Turbidity (NTU)	COD (Mg/l)				
		Raw Water	HRF	UCF	UFF	
					0.3 m/hr	0.15 m/hr
1986						
Oct.19	12	4.5	-	2.7	-	-
1987						
Jan.11	3	7.4	1.0	1.0	1.8	1.2
Jan 31	3	9.1	1.8	2.2	2.1	2.1
Feb.23	2	2.5	1.4	1.4	-	1.2
Mar.23	1	2.0	1.1	1.1	1.4	0.6
Apr.24	5	3.5	1.0	2.0	2.0	2.3
May 30	23	3.0	1.5	2.0	1.3	1.3
Jun 30	25	4.0	1.8	2.1	1.2	1.2
Jul.30	71	6.0	1.9	2.6	2.4	2.5
Aug.30	115	4.6	1.0	1.2	1.0	1.5

TABLE 6.8

COLIFORM COUNTS IN RAW WATER & PREFILTER EFFLUENTS ALONG WITH RAW WATER TURBIDITIES

Year and Month	Raw Water Turbidity (NTU)	Coliforms (MPN/100 ml)				
		Raw Water	HRF	UCF	UFF	
					0.3 m/hr	0.15 m/hr
1986						
Dec.31	5	150	43	43	15	23
1987						
Jan.27	3	460	240	23	23	75
Feb.23	3	93	43	15	23	9
Mar.23	1	93	43	23	15	23
Apr.29	5	93	43	43	7	43
Jun. 8	80	920	-	350	170	220
Jul. 4	30	540	350	23	17	-
30	71	540	540	-	110	70
Aug.31	120	1700	1400	330	330	1300

desilting chambers. On this reasoning, the percentage turbidity removals of the prefilters are worked out based on raw water turbidities only.

6.6.4 Performance of the Prefilters

The results of monitoring the performance of the different pre-filter units are summarised in Table 6.9.

There was considerable depletion of DO in the pre-filtration units. In the HRF, DO concentration in the effluent fell to 1.0 mg/l within a fortnight after commissioning the unit. On a second occasion, the DO concentration fell to 0.6 mg/l. By virtue of its design features, the HRF unit unlike other units did not allow any growth of algae which could have interfered with determination of DO.

In the UCF unit, the DO concentration fell to 1.0 mg/l soon after its start-up. On a second occasion, DO concentration fell to 1.8 mg/l. Though the UCF unit did allow growth of attached algae on the media the first occurrence of low DO was before algae had established itself on the filter surface and the second was when the filter surface had been shaded not allowing algae growth. Both the HRF and UCF units were cleaned in-situ when the low DO values were observed. The cleaning helped reduce DO depletion.

There was DO depletion in the two UFF units also but not to the same extent as in the HRF and UCF units. The two units supported algae growth on the surface which might have probably

TABLE 6.9

PERFORMANCE OF PRE-FILTERS WITH RESPECT TO TURBIDITY, COD AND COLIFORM REDUCTION

Description	Raw Water	HRF	UCF	UFF	
				(0.3 m/hr)	(0.15 m/hr)
Turbidity (NTU)	530-1	22-1	93-1	29-1	20-1
Percent Turbidity Removal	-	0-96	0-82	0-94	0-96
COD (mg/l)	6-2	1.9-1.0	2.6-1.0	2.4-1.0	2.5-0.6
Percent COD Removal (Average)	-	71	63	65	67
Coliform count (MPN/100 ml)	1700-93	1400-13	350-15	330-7	1300-9

interfered in the determination of the actual DO depletions in the units. The algae growth was more intense in the 0.15 m/h unit as already mentioned. On a few occassions, this unit presented effluent DO values higher than in the influent. The UFF units were not cleaned at any time during study period.

6.7. Discussion

6.7.1 General

In evaluating the results of the pilot plant studies presented so far, it is necessary to consider how far the different processes succeeded under the specific field conditions encountered and also what conclusions and recommendations can be drawn from the studies for general application. The ensuing discussions are made with these two aspects in mind.

6.7.2 Turbidity Limits for Direct Slow Sand Filtration

It has been mentioned earlier that pretreatment will be required before SSF if average raw water turbidity exceeds 25 NTU. Obviously, the limit should be applied to the average turbidity for any two months as two months constitute the desirable "minimum run" for slow sand filters. If a longer minimum run is desired, the turbidity limit should be lowered. If a shorter "minimum filter run" is permissible, the turbidity limit could be raised.

In tropical rivers, turbidities may fluctuate greatly within short intervals. Hence, extensive turbidity data may have to be collected at close intervals and the averages for different months worked out and examined before the feasibility of direct filtration for a particular source can be determined. In the case of the Jamuna River at Delhi, it may be noted from turbidity data for the 12 month period Nov.86 to Oct.87 that the values exceed the proposed limit for direct slow sand filtration during 5 months from May'87 to Sept.87 (Table 6.3). Probably, the limit might have exceeded during a longer period if the rains had not failed during the year.

6.7.3 Turbidity Removal Required by Prefiltration

In order to evaluate the results of the pilot-plant studies, reported here, it is necessary to set a yardstick for the turbidity reduction that should be achieved by pretreatment before SSF. Stipulations in terms of percent reduction cannot obviously be useful. The stipulation has to be in terms of the average turbidity to be achieved in the pretreated water, again during any two consecutive months so that filter runs may not fall below two months. This turbidity limit would have to be lower than the 25 NTU limit prescribed for raw water. As colloidal turbidity may predominate in the prefiltered water, it is desirable that the average turbidity in any two months after pretreatment is limited to say 10 NTU or less to ensure satisfactory runs for SSFs.

6.7.4 Adequacy of Turbidity Removals Effected

The performances of the different prefilter units in regard to removal of turbidity may be ranked as follows ; (1) UFF operated at 0.15 m/hr, (2) HRF (3) UFF Unit operated at 0.3 m/hr and (4) UCF unit. Judged by the desirable average turbidity of less than 10 NTU in any two months period, the performance of the 0.15 m/hr UFF unit and the HRF was adequate under the raw water quality conditions encountered in the study as may be seen from Table 6.2. The performance of the UFF unit worked at 0.3 m/hr and the UCF unit was however inadequate, the former during one two-months period and the latter during two two-months period during one year from Nov.86 to Oct.87 (Table 6.2).

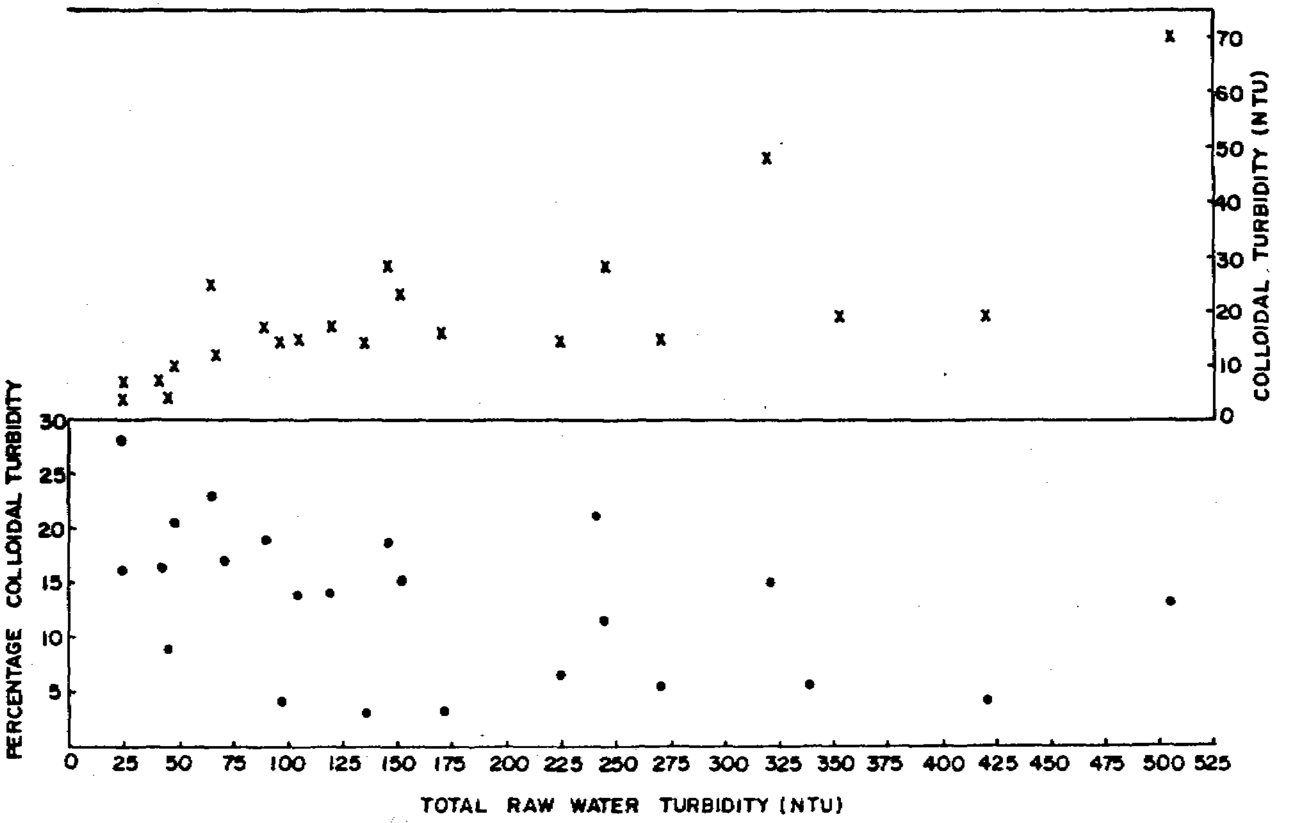
6.7.5 Correlation of Turbidity Removals

It is unfortunate that the present studies covered raw water turbidities only upto 530 NTU though the Jamuna River is subject to much higher turbidities (1000 NTU and above) during good monsoons. Still, an attempt is made here to project the results of the studies for general application.

Prefiltration may be considered essentially as plain sedimentation in many-storeyed sedimentation basin and turbidity removal in the process will be mainly by settling of suspended solids though there may be some adsorption of colloidal particles also. While the process can be expected to remove most of the suspended turbidity, the question of interest is how much of colloidal turbidity the process would remove.

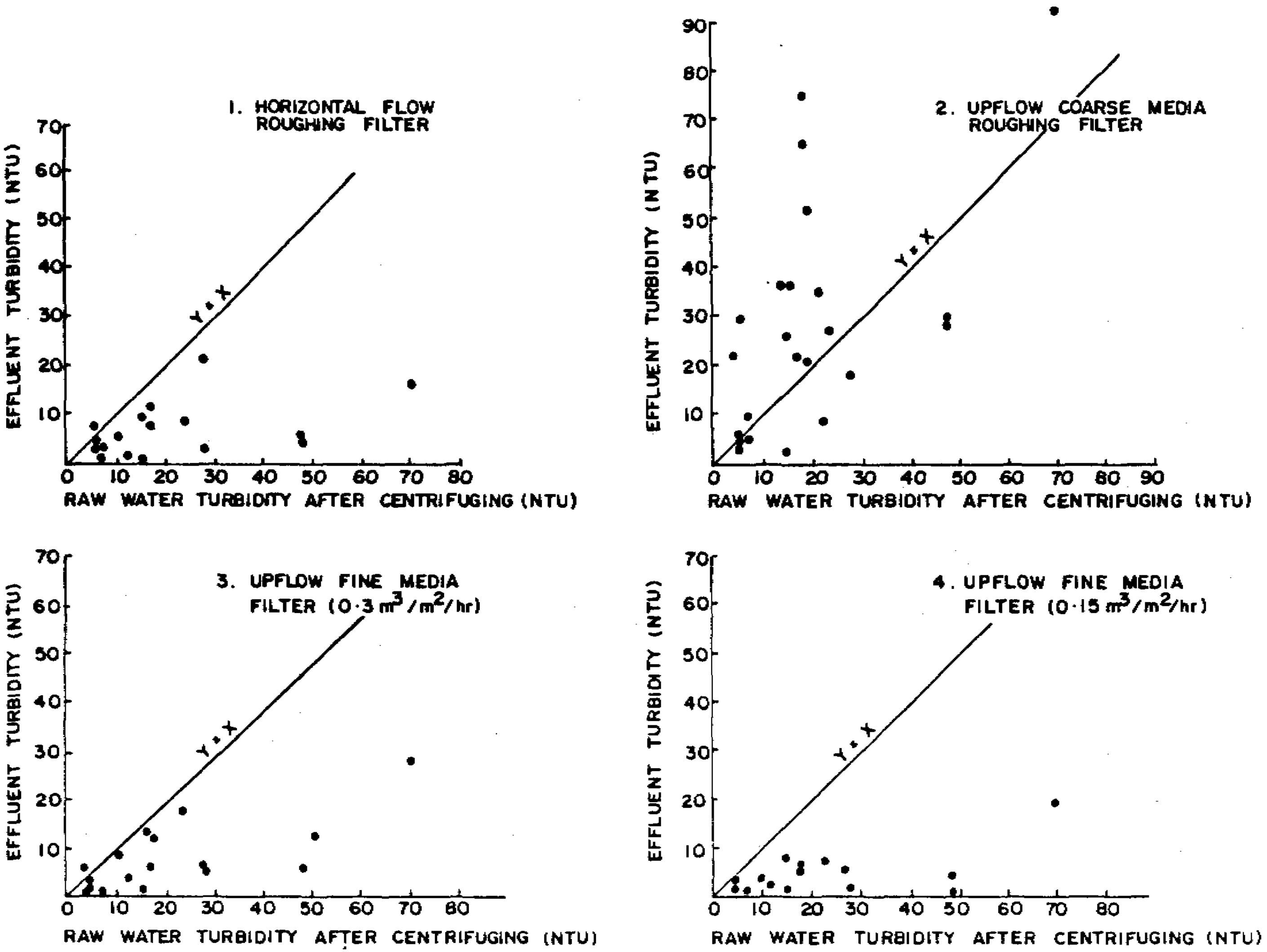
In the present studies an attempt has been made to correlate the turbidity remaining after prefiltration with the colloidal turbidity of the raw water. Colloidal turbidity was determined as the turbidity remaining after centrifuging under uniform conditions. This simple procedure was adopted as there appeared to be no standard method available for the purpose. The colloidal turbidity values obtained are plotted against total raw water turbidity values both in turbidity units and as percentage of total turbidity in Fig 6.6. The percentage values decreased with increasing raw water turbidity. Generally, the percentage value may be expected to vary greatly from season to season in the same source (as indicated by the wide scatter of data along y-axis in Fig.6.6) and from one source to another. Hence, colloidal turbidity values may not be estimatable from raw water turbidity values and may have to be actually determined as a seperate parameter of laboratory analysis.

For analysing the results, an assumption is made that when the effluent turbidity is higher than the influent colloidal turbidity, suspended turbidity is also passing through the prefilters and that when the effluent turbidity is less, than the influent colloidal turbidity suspended turbidity has all been removed in the unit. On this assumption, it would seem that the UCF was not able to remove suspended turbidity completely (Fig.6.7). The reason for this was not investigated but might have been partly short-circuiting and partly inherent design features such as inadequate detention which was only 1.40 hr compared to 4.2 hr in the HRF, the other coarse media filter studied.



NOTE : Y AXIS VALUES NOT PLOTTED FOR X AXIS VALUE LESS THAN 25 NTU

FIG. 6.6 COLLOIDAL TURBIDITY & % COLLOIDAL TURBIDITY Vs TOTAL RAW WATER TURBIDITY



NOTE : Y AXIS VALUES NOT PLOTTED FOR X AXIS VALUE LESS THAN 4 NTU

FIG. 6.7 PREFILTER EFFLUENT TURBIDITY Vs COLLOIDAL TURBIDITY OF RAW WATER

Removal of suspended turbidity was complete in the HRF and the two fine media prefilters except on a few occasions of very low raw water turbidities. The maximum suspended turbidity that the units were subject to was 460 (530-70) NTU. It may be reasonably expected that prefilters of the three types mentioned would remove any higher suspended turbidites also completely.

There was also considerable removal of colloidal turbidity in the HRF and the two UFF units. Colloidal turbidity removal can be attributed to adsorption by zoological and suspended solids coating of the media. The data available particularly at higher ranges of colloidal turbidity in raw water is inadequate to establish a mathematical relationship between colloidal turbidity of raw water and final water turbidity for the various prefilters studied. However, as a rough guide, the probable final turbidity has been worked out as percentage of the colloidal turbidity of raw water as follows based on the available data in Table 6.2.

Colloidal Turbidity of raw water	Turbidity of pre-filtered water		
	HRF	UFF	
		0.3 m/hr	0.15 m/hr
upto 2 NTU	100 %	100 %	100 %
3-10 NTU	60 %	60 %	40 %
11-25 NTU	45 %	60 %	35 %
more than 25 NTU	30 %	30 %	20 %

6.7.6 Dissolved Oxygen Depletion

The depletion of dissolved oxygen in the pilot plant is an important observation of the study. Complete depletion of DO has been reported in the pilot-scale studies on HRF carried out at

AIT, Bangkok(4). The raw water employed in the AIT studies had a BOD_5 of 7 mg/l average and COD of 22 mg/l average whereas in the present studies, the raw water had average COD of only about 5 mg/l. Even then, there was significant DO depletion in all the prefilter units.

It could be queried whether the initial high DO depletions in the HRF and UCF were not due to inadequate cleaning of this gravel media before being placed in the filtes. Such a question cannot however arise in regard to the late occurences of high DO depletions. It is felt that the DO depletion was largely caused by COD in the raw water. The phenomenon may be unavoidable with any raw water.

Complete DO depletion will cause anaerobic conditions in the roughing filters and may give rise to odour problems. Low DO in the effluents may also cause problems in the subsequent slow sand filters. To avoid such problems it is desirable that prefilters are not used with raw waters rich in organic content, i e. having high BOD, COD. It is also essential that prefilter effluents are monitored for DO at frequent intervals, say once every two weeks, and in case high DO depletions are noticed, the units should be cleaned. Further, the prefilter should provide for some aeration of its effluent before it is dosed into a next prefilter cell or slow sand filter.

6.7.7 COD Reduction

It could be noted that all the roughing filters brought about some COD reduction (Table 6.7). However, the COD values even in the raw water were too low for accurate determination and it may not be prudent to draw any conclusions about the comparative performance of different prefilters in regard to COD reduction. The reduction of COD in the prefilters will reduce organic load on subsequent SSF units and may therefore be considered a bonus benefit of pre-filtration.

6.7.8 Coliform Reduction

There was some reduction of coliform bacteria in all the prefilters which is an advantage for subsequent slow sand filtration. The number of coliforms tests conducted were too few to permit valid inferences about the comparative performance of the different units. However, there was an indication that the removal in upflow filters may be better than in horizontal flow filters.

6.7.9 Cleaning of Prefilters

The periodic cleaning of prefilters has been considered essential to prevent clogging of the filters and for maintaining their turbidity removal efficiency. The present studies indicate that periodic cleaning of prefilters may be required also for preventing excessive DO depletion.

The IRCWD has reported that as the gravel packs in horizontal flow roughing filters get gradually loaded with retained solids, the filter efficiency is exhausted and that the efficiency can be restored partially by fast draining which will move the retained solids downward and might even flush some of the solid matter out of the filter. However, after a period of six months or longer depending on raw water quality, filter cleaning has to be carried out by excavating the filter material, washing the media and refilling the filter box(3). Such a recommendation has also been made by the IRC(2). The WRC has stated that HRF requires complete overhaul only every few years (1). A report from Peru discusses a downflow prefilter, equipped with rapid opening drainage gates. The media is flooded to a height of 20 cm above the top of the gravel and then fast-drained which is said to effect automatic cleaning(5).

In the present studies, in the two fine media units, neither fast drainage nor in-situ flushing succeeded in cleaning the filter media. It is felt that in-situ cleaning may not be suitable for fine media prefilters. Complete overhaul may be required every time. In the two coarse media units studied fast drainage had limited effect and in-situ flushing had better effect though more flushings were necessary in the last sections of the units where 7-2 mm media was used.

Complete overhaul of media whether in coarse or fine media filters will be labour intensive as overhauling a HRF unit will require handling somewhat more media than the total media (sand + gravel) in a SSF. The need for complete overhaul of prefilter units should therefore be minimised, as suggested in Sec. 6.7.11.

6.7.10 Comparison of Different Prefilters

We have seen that only the 0.15 m/hr UFF unit and the HRF unit gave satisfactory turbidity removals (less than 10 NTU collidal) under the raw water quality conditions encountered in the present studies and that the performance of the former was better than of the latter (Sec.6.7.4). The media requirements of the different prefilters for treating 1 m^3/hr of water is as follows :

HRF	14.4 M^3
UCF	3.5 m^3
UFF 0.3 m/hr	2.0 m^3
UFF 0.15 m/hr	4.0 m^3

It will be noted that the media requirements of the 0.15 m/hr UFF unit is less than 25 % of the media requirements of the HRF units. Cost of a prefilter unit may be roughly equated with the media requirements and on this basis, the 0.15 m/hr UFF unit is adjudged to be much more economical than the HRF unit while giving a better performance also. However, it is to be noted that an UFF unit will be more difficult to clean than a HRF unit requiring overhauling every time.

6.7.11 Design Considerations

Here, some of the planning and design approaches to prefiltration are considered. The first is about decision making whether a raw water source requires pretreatment before slow sand filtration and whether prefiltration will provide sufficient pretreatment. To decide these issues, one should have adequate data about total turbidity of the raw water and about the colloidal fraction of it. The data should be collected at frequent intervals and preferably daily especially during monsoon months as the changes in turbidity of tropical rivers during such periods will be frequent and sudden. Also the data should be for a good rainfall year and not a drought year. Based on the total turbidity, it can be determined whether the average turbidity for any two months period exceeds 25 NTU in which case one should provide pretreatment. The likely turbidity in prefiltered water can be roughly estimated based on centrifuged sample turbidity and approximate conversion factors (percentages) mentioned in Sec.6.7.6. Prefiltration as tried out in the present study may be considered appropriate only if the average of the estimated effluent turbidities for no two months period exceeds the limit of 10 NTU significantly.

Tropical rivers are known to carry large amounts of silt during floods. Also, bed silt may be drawn into the river water diversions during low flow seasons when the turbidity itself may be low. Though no quantitative observations were made during the pilot plant studies on the silt carried by the Jamuna River water, visual observations of the silt that had accumulated in the desilting chamber before each cleaning indicated that the silt load in the river water was considerable. It is believed that if desilting chambers had not been introduced before the prefilters, they would have got clogged much more rapidly than experienced. To avoid the problem, it is necessary that prefilter units are always preceded by desilting chambers. The surface area requirements for the units will be only nominal as an area of 1 m^2 is sufficient for substantial grit removal from a flow of 400 m^3 per day even when the silt is of such small size as 0.15 mm and low specific gravity as 1.5(6). Of course the desilting unit should have adequate provision for preventing short-circuiting of flow.

For achieving the maximum possible removal of turbidity in a prefilter, short circuiting of flow through the unit has to be avoided. This requirement is easily met in a HRF requiring only the provision of adequate number of weepholes for the full depth of flow in the walls separating the media from the inlet and outlet chambers. But in the case of upflow prefilters, to prevent short circuiting it will be necessary to limit the head loss in the inflow distributor and the effluent collector to a small fraction of the headloss in the media itself. (The reasoning is the same as adopted for the design of the underdrainage system of SSF)(7). This will require a false bottom with a large area of openings, the raw water being let in below the false bottom. For effluent withdrawal an effluent launder will have to be provided at the top as in a settling tank extending all sides of the filter box.

As experienced in the present study the UCF units may be liable to algal problems which require control. In small units, a practical solution would be to provide removable covers which can be taken out readily when filters are to be flushed in-situ or overhauled. This suggestion holds good also for small UFF units.

In large UCF units, it may be cheaper to raise the media level to about 10 cm above the water level without affecting flow into the outlet launders. In large UFF units, where removable covers cannot be provided, a scum trap may be constructed on the effluent line so that algal scum in the effluent does not reach the slow sand filters.

It has been stated earlier that prefilter effluents should be subjected to some reaeration before being let into a second prefilter or a SSF. Provision of effluent launders with free fall can effect some reaeration. We have seen that effluent launders are required for upflow filters to prevent short-circuiting. Effluent launders should be provided for HRF units also for providing areation. The launders should have a free fall of atleast 10 cm.

The importance of effecting efficient in-situ cleaning of coarse media filters has already been stressed. In the present studies, flushing down of filter sections with media of size 7-2 mm took greater effort than filter sections having larger media. For making in-situ cleaning effective, the minimum size of coarse media should be kept as 4 mm as the downward movement of the settled matter is reported to get impeded when the media is smaller(3).

In UFF units, where in-situ cleaning is found not feasible, the need for overhauling of the media should be minimised. This can be achieved by interposing a singlecell of the upflow coarse media filter with upflow rate of 0.6 m/hr before the UFF. The coarse media should be neither too large which will reduce efficiency nor too small which will hinder in-situ cleaning. A size of 16-8 mm is suggested. The coarse media unit will remove bulk of the suspended turbidity and should be frequently cleaned in-situ as it may be liable to rapid clogging. Though it may not improve overall turbidity removal very much, the unit will slow down the clogging of the UFF unit considerably necessitating its overhaul only at long intervals. It should be noted that the addition of the coarse media cell will not upset the cost economy of the 0.15 m/hr UFF unit as the media requirements with the proposed modifications (5.2 m^3) for delivering 1 m^3/hr of water will still be lesser (37 %) than for the HRF unit. The 0.15 m/hr UFF units with the modification should therefore be preferred for prefiltration of turbid waters before slow sand filtration.

6.8 Summary and Conclusions

Pilot plant studies were taken up at the Delhi Zonal Laboratory of National Environmental Engineering Research Institute (NEERI), Nagpur on prefiltration as a method of pretreating turbid river waters before slow sand filtration. The type of prefilters studied were horizontal flow coarse media roughing filter (HRF) with a filtration rate of 0.7 m/hr, an upflow coarse media roughing filter (UCF) worked at 0.6 m/hr, one upflow fine media filter (UFF) with application rate of 0.3 m/hr and a second similar unit with a filtration rate of 0.15 m/hr. The raw water for the studies was drawn from the Jamuna river, the major source for Delhi city water supply. The studies were conducted from August,1986 to November, 1987, but some of the pilot plants were run only from Oct.1986 to Nov.1987. Though, the Jamuna river water has been known to carry maximum turbidities above 1000 NTU during good monsoon periods, the maximum turbidity experienced during the studies was only 530 NTU because of failure of monsoon in 1986 and 1987. The conclusions and recommendations arising from the studies are as follows :

1. It is suggested that the average turbidity limit for slow sand filtration be adopted as 25 NTU and preferably less than 10 NTU during any two months period.

2. For deciding whether a river water is suited for direct slow sand filtration, the water quality should be monitored frequently for a one year period with normal or above normal monsoon. As tropical rivers are subject to sudden fluctuations during monsoon seasons, the turbidity determinations should be made daily during such seasons.

3. Tropical rivers may not generally permit direct slow sand filtration and may often require pretreatment. In the Jamuna river at Delhi, during the study period of Oct. 1986- Nov.1987, the raw water turbidity exceeded the limit suggested for direct filtration during five months, though it was a drought year and the river had only low floods and peak turbidities were not very high.

4. Prefiltration is an appropriate technology for preparing river waters for slow sand filtration for community water supplies as like slow sand filters, prefilters require only limited operation and maintenance, skill and attention.

5. In the pilot plant studies, the HRF unit and the 0.15 m/hr UFF unit met the suggested limit for pretreated water turbidity, whereas the 0.3 m/hr UFF unit and the UCF did not give adequate turbidity removal.

6. In the pilot plant studies, the two UFF units and the HRF units removed all the suspended turbidity in the raw water (defined as turbidity removed by adequate centrifuging of the raw water samples in the laboratory) and also part of the colloidal turbidity in the raw water defined as residual turbidity after centrifuging. The percent colloidal turbidity in raw water tended to decrease with increase in total turbidity.

7. It may be expected that prefilters of the UFF type and HRF type at the filtration rates used and the river water turbidities experienced in the studies will in general effect complete removal of the suspended turbidity. An approach has been suggested for deciding whether prefiltration will be adequate for a particular river water and to determine roughly the turbidity likely to be present in the pre-filtered water (Sec. 6.7.5).

8. Besides reducing the turbidity of raw waters, prefilters will also reduce COD and Coliform counts to some extent which will be useful in subsequent slow sand filtration.

9. Prefilters may exhibit significant dissolved oxygen depletion at times, the severity depending on the organic content of the raw water. It is necessary that when investigating raw water to be treated by prefiltration, their BOD /COD values are determined at frequent intervals. Raw waters rich in BOD/COD may not be suited for prefiltration. Anyway, prefilter effluents should be monitored for DO at frequent intervals (say, once in two weeks) and the prefilters should be cleaned when high DO depletions are observed. Also, the prefilter effluents should be collected over free-fall effluent launders so that they are reaerated to some extent before being let into succeeding units.

10. Algae growth in pre-filters could be prevented by covering the filters with removable covers or by raising the filter media above the maximum water level by about 10 cm.

11. Pre-filters should be so structured as to facilitate effective in-situ cleaning using quick opening gates.

12. Tropical rivers will carry high amounts of silt which will clog the prefilters quickly unless removed from the raw water. Hence, prefilters should always be preceded by

desilting units. Nominal sizes will be adequate for the desilting chambers, in most cases but there should be no short circuiting through them.

13. Between the HRF and the 0.15 m/hr UFF both of which gave satisfactory pretreatment in the pilot plant studies, the latter is to be preferred as it effects marginally better treatment and is also more economical requiring only under 30 % of the media required for the HRF. The UFF will not permit in-situ cleaning unlike the HRF and requires overhauling of media every time which is labour-intensive and cumbursome. To reduce the need for frequent overhauling, a single-cell upflow coarse media prefilter (media size 15-7 mm) to be worked at 0.6 m/hr may be interposed before the UFF unit. The coarse media unit may be expected to remove most of the suspended matter in the water, clogging quickly in the process; but this clogging can be countered by frequent in-situ cleaning which will not be difficult. Even with the modification suggested, the media requirement for the 0.15 m/hr UFF unit will be only 37 % of that for HRF.

14. It is desirable to carry out full scale trials of prefiltration on the lines suggested already for slow sand filtration scheme based on river/ canal water to arrive at optimal design.

7. TRAINING

The caretaker of a slow sand filter plant has an important role to play in ensuring a finished water that meets the prescribed drinking water quality standards. He should possess a basic knowledge of the purification processes in a slow sand filter and be conversant with the elements of the filter, its initial commissioning and routine operation and maintenance. An important tool that can facilitate the caretakers job is the O & M manual.

On the basis of experience gained during the project, a draft manual for operation and maintenance of slow sand filters was prepared by IRC, with contribution from NEERI. This publication, however, was found to be less appropriate for training of caretakers. With a view to meeting this requirement, a more basic manual explaining the process of slow sand filtration and describing with illustrations the day to day operation and maintenance activities has been developed. Keeping in view the felt needs and the potential for wider application of the manual in many states of India, a Hindi version of the caretakers manual has been published. The manual successfully tested with the operator at the SSF demonstration plant at Borujwada, near Nagpur will go a long way in promoting the use of slow sand filters in general and their effective operation and maintenance in particular. Some excerpts from the reviewers of the caretaker manual are reproduced in Annexure 3.

The training course for training of trainers, as originally envisaged, could not be organised due to the urgent commitments to the National Mission on Drinking Water. However, three orientation cum training programmes on SSF have been organised for field engineers in charge of implementation of water mission activities in various states.

8. PROMOTIONAL ACTIVITIES.

An important component of SSF-Phase IV programme has been the continuing promotional activities. These include seminars/ conferences and orientation cum training programmes organised in the context of the National Mission on Drinking Water, expert advice to field engineers on design and construction of slow sand filters, lecturing to participants of training courses for waterworks operators and supervisors, contribution of revised chapter on SSF for the Government of India Manual on Water Supply and Treatment, preparation of national codes/ guidelines for slow sand filtration practice etc. These are briefly presented hereunder.

8.1. Technology Mission on Drinking Water in Villages and Related Water Management - Conference of Chief Engineers

A two day conference of Chief Engineers and senior engineers in charge of the implementation of Water Mission activities was organized in July 1987, at Nagpur. About 30 engineers from various states of India participated in the conference. One of the main objectives of the conference was creating an awareness of the various technologies developed by NEERI for rural water supplies. One session of the conference was devoted to the subject of slow sand filtration. As part of the programme, a field visit to the Borujwada SSF plant was also organised. A technology information package on SSF was released on this occasion. The feed back from the participants, has shown that the application of SSF for rural water supply is being actively pursued in the states of Meghalaya, Karnataka, Andhra Pradesh etc.

8.2. Orientation Programme on SSF

A one day awareness cum orientation programme was organized at Nagpur on 17th September 1987 in which about 20 participants (engineers) from the states of Andhra Pradesh, Uttar Pradesh, Meghalaya, Madhya Pradesh, Rajasthan, Maharashtra, Karnataka, and Assam participated.

The programme comprised of lectures on the basics of slow sand filtration process as also design, construction, operation and maintenance of slow sand filters. The relevance and potential application of SSF for rural water supplies in the context of the Water Mission were highlighted. The lectures were followed by discussions and a field visit to the slow sand filter plant at Borujwada. All the latest information on slow sand filtration was provided to the participants in the form of publications.

On a request from Government of Karnataka, this one-day awareness cum orientation programme on Slow Sand Filtration was organised at NEERI on 16th February 1989 and again on 23rd June 1989 in which about 30 engineers participated. (List of participants in Annexure 4).

During discussions, it was informed that there are sixteen villages in Gulbarga district alone where slow sand filters are being considered for installation. These villages have a population in the range of 1000-2000 with rivers as sources of water supply.

The awareness cum training programme highly appreciated by the participants is expected to be a valuable input to the implementation of slow sand filtration technology in Karnataka state.

8.3. Advice on SSF Design & Construction

With the launching of the Water Mission, activities related to source identification, water quality assessment and installation of appropriate treatment technologies for the problem villages have been stepped up quite substantially. The promotional activities undertaken by NEERI have had a significant impact as evidenced by the number of requests received from practising engineers seeking technical information and expert advice on SSF design and construction. This input showed that for several plants in the state of Rajasthan, SSF was the preferred option resulting in considerable savings in capital expenditure. Similar requests from the states of Orissa, Andhra Pradesh, Kerala, Tamil Nadu, Uttar Pradesh and Gujarat for supply of information and expert advice have been attended to by NEERI (Annexure 5).

8.4. Lecturing to participants of training courses

Special lectures are delivered by the project leader and his associates at various training courses organized by NEERI and other agencies from time to time. These are :

i) CPHEEO course for water works supervisors - a regular feature

ii) DANIDA course (international) for water supply engineers

iii) Orientation and awareness courses for engineers in-charge of Water Mission.

8.5. Revision of chapter on SSF for the Manual on Water Supply and Treatment of the Government of India

In the light of the research findings and recent developments on SSF, Dr. R. Paramasivam, in his capacity as a member of the Expert Committee constituted by the Government of India to revise the 2nd edition of the Manual on Water Supply and Treatment, has contributed the revised enlarged chapter on slow sand filtration for incorporation in the Manual which is under finalization.

8.6. Contribution to the Preparation of Indian Standards

At the instance of the Indian Standards Institution (now renamed Bureau of Indian Standards), the project leader Dr. R. Paramasivam has prepared Guidelines for Slow Sand Filtration. The guidelines, duly approved and adopted by the Civil Engineering Division Council of ISI, have since been brought out in two parts as detailed below :-

* 11401 (Part I) - 1985 Requirements for Slow Sand Filters - General Guidelines

* 11401 (Part II) - 1989 Requirements for Slow Sand Filters - Design, Construction, Operation and Maintenance

Following the Mission approach launched by the Government of India, there has been a significant increase in activities and investments in community water supply and sanitation programmes. In this context the role of slow sand filtration as an appropriate technology for purification of community water supplies has been increasingly recognised. This is evident from the increasing number of requestes received from field engineers for expert advice and supply of technical information on slow sand filtration. NEERI will continue to play this role in future as well.

9. REFERENCES

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Annexure 1

METHODOLOGY FOR EVALUATION OF ALTERNATE SSF SYSTEM DESIGNS

Presented hereunder is a methodology for evaluation of alternate SSF system designs and selection of minimal cost design. For purposes of illustration, the following criteria have been adopted based on the general practice followed in a number of Indian states.

- The system provides for a single step treatment using slow sand filters with no pre-treatment.
- The design filtration rate is 0.1 m/hr.
- The treatment works are so located with reference to the raw water source as to facilitate raw and clear water pumping operations to be controlled by one pump attendant.
- The shift timings are :

1st shift	...	6 am to 2 pm
2nd shift	...	2 pm to 10 pm
3rd shift	...	10 pm to 6 am

- Water supply is intermittent and the timings are 6 am to 8 am and 4 pm to 6 am.

In the light of the findings of the earlier studies and to ensure a bacteriologically satisfactory filtrate, the following alternatives have been considered.

<u>Alternative</u> <u>I</u> :- The filters as also the raw and clear water pumps are designed for continuous 24 hour operation (Fig. 1a).

<u>Alternative</u> <u>II</u> :- The filters are designed for continuous (24 hour) operation while raw water pumping is only for 8 hours divided into two shifts of 4 hours each; 6 am to 10 am and 6 pm to 10 pm. The pumps are designed for a capacity equal to 3 times the hourly output of the filters. The excess raw water is accumulated in a storage tank and fed to the filters by gravity during pump shut down period to ensure continuous filtration.

<u>Alternative</u> <u>III</u> :- This is similar to alternative II except that raw water pumping is for 16 hours divided into 2 shifts of 8 hours each with a four hour break in between. (Fig.1b).

To facilitate cost trade-off analysis of alternative designs, the sizes/capacities of the system components for the three alternatives have been worked out in terms of D, the daily demand in m^3 (Table 1). The cost functions and regression models (based on 1987 prices) are developed for individual components (Table 2) which collectively yield a good estimate of the cost of alternatives under consideration. The values of constants and exponents are subject to change with time and place and hence need to be determined for specific conditions.

The total cost of the system is made up of the cost of civil works and the cost of raw and filtered water pumps including standby units. Cost of civil works (CCW) for any alternative can be written as :

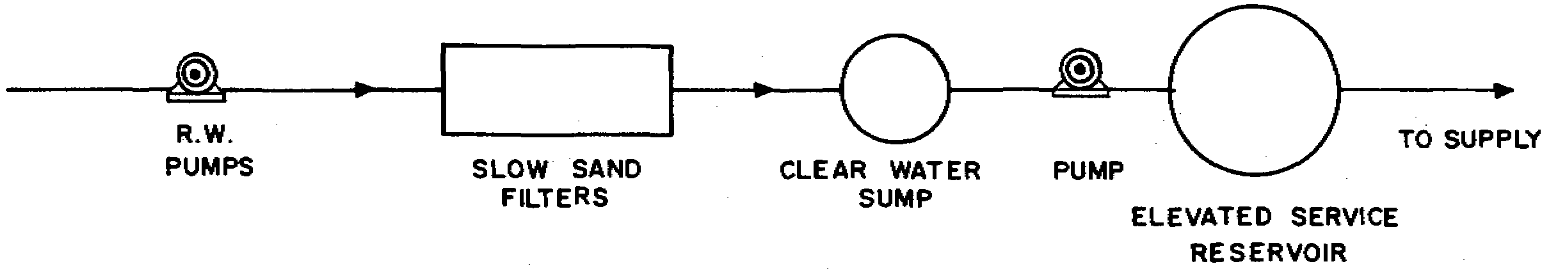

FIG. 1a: FLOW SHEET FOR ALTERNATIVE - I

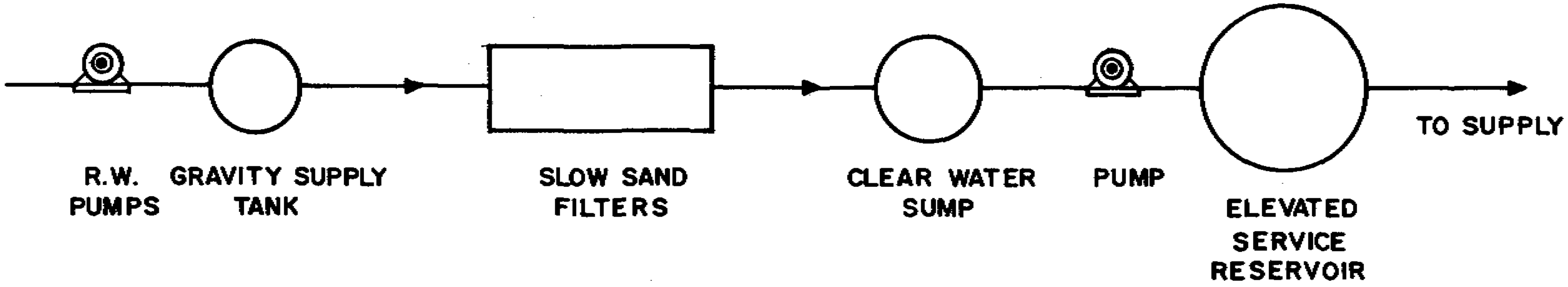

FIG. 1b: FLOW SHEET FOR ALTERNATIVES-II & III

TABLE 1

SIZES / CAPACITIES OF SYSTEM COMPONENTS

System Component	Alternatives		
	1	2	3
Gravity Supply Tank - m^3 (CAPGST)	-	$\frac{D}{3}$	$\frac{D}{6}$
Slow Sand Filter - m^2 (ASSF)	$\frac{D}{2.4}$	$\frac{D}{2.4}$	$\frac{D}{2.4}$
Clear Water Sump - m^3 (SCWS)	$\frac{D}{24}$	$\frac{D}{3}$	$\frac{D}{6}$
Elevated * Service Reservoir- m^3 (SESR)	$\frac{D}{2}$	$\frac{D}{2}$	$\frac{D}{2}$

* Based on mass curve

TABLE - 2

COST FUNCTIONS & REGRESSION MODELS FOR SYSTEM COMPONENTS

System Component	Cost Function	Regression Model
Gravity Supply Tank	$CSTCST=K_1(CAPGST)^{a_1}$	$6658(CAPGST)^{0.668}$
Slow Sand Filter	$SSFCST=K_2(ASSF)^{a_2}$	$2550\ A^{0.887}$
Clear Water Sump	$CWSCST=K_3(SCWS)^{a_3}$	$1250\ (SCWS)^{0.785}$
Elevated Service Reservoir	$CSCRCST=K_4(SESR)^{a_4}$	$8300\ (SESR)^{0.668}$
Pumps	$C\ PUMP=K_5\ (HP)$	$2000\ (HP)$

$CCW_n = GSTCST_n + SSFCST_n + ESRCST_n$

where

GSTCST - Cost of gravity supply tank
SSFCST - Cost of slow sand filters
CWSCST - Cost of clear water storage tank
ESRCST - Cost of elevated service reservoir

The total annual cost functions for the alternatives are written as the summation of costs given in Table 3. Using a computer and substituting appropriate values for the variables (Tables 4 & 5) in the cost functions, total annual costs for plants of capacities 50-2000 m^3/day have been worked out and presented in the Table 6. Based on comparison of the total annual costs of the alternatives, the least cost alternative is selected.

It could be noted from Table 6 that for plant capacities upto 500 m^3 per day (design population of 12,000 at 40 lpcd), alternative II, viz. 8 hour pumping and continuous operation of filters would provide the least cost design. This alternative would also be an ideal solution in the light of the experience that availability of continuous supply of electric power is a major constraint in rural areas. For plant capacities larger than 500 m3/day, alternative I which provides for continuous operation of the plant (pumps and filters) would be cost effective. However, for communities with population more than 12,500 and facing the problem of non-availability of continuous power supply, alternative III, the second lowest cost design, would be the obvious choice.

TABLE 3

TOTAL ANNUAL COST FUNCTION

---

1. Annualized Capital Cost (ACC) @ r % per annum over a period of ´N1´ years ... ACCn = F(TCCn)

$$F = \frac{(1+r)N1 \times r}{(1+r)N1-1}$$

2. Maintenance Cost of Civil Works @ r1 % per annum (DCW) ... DCWn = r1(CCWn)

3. Maintenance & Depreciation on Pumps @ ´r2´ per anum (DP) ... DPMCn = R2(CPUMP)n

4. Energy cost @ ´r3´ per kwh ... ENERGY = r3(kWn) x 365 X Yn

5. Cost of sand scraping @ r per ... SNDSCR = r4 x ASSFn x NS

   NS : No of scrapings/year

6. Salary of staff *

   SALARY1 = 12 x 3 (S1+S2) + 12 (S2+S4)

   SALARY2 = 12 (S1+S2+S3)

   SALARY3 = 12 x 2 (S1+S2) + 12 (S3)

7. Total Annual Cost (TAC)

   TACn = ACCn + DCWn + DPMCn + ENERGY + SNDSCR + SALARYn

   Expressed as cost of water production (CWPn) per 1000 m3

$$CWPn = \frac{TACn}{D \times 365} \times 1000$$

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* Refer Table 5 for staffing pattern

TABLE 4

ASSIGNED VALUES FOR THE VARIABLES USED IN THE COST FUNCTIONS

S.No.	Item	Notation	Value assumed
1.	Total Head on pumps in meters	H	25
2.	Interest rate per year	r	0.12
3.	Interest period in years	N1	25
4.	Rate of depreciation & maintenance on civil works per year	r1	0.02
5.	Rate of depreciation and maintenance on pump per year	r2	0.07
6.	Energy charges in Rs./kw	r3	0.50
7.	Scraping charges in Rs./m2 of filter area	r4	0.50
8.	Salary of pump operator in Rs./pm	s1	550
9.	Salary of filter attendant in Rs./pm	s2	550
10.	Salary of watchman in Rs./pm	s3	400
11.	Hours of Raw/Filtered Water Pumping for Alternatives I, II & III respectively	Y	24, 8 & 16

TABLE 5

STAFFING PATTERN FOR DIFFERENT ALTERNATIVES

Alternative No.	No of Pump operator(s)	No of filter attendant(s)	No. of watchmen
I	3	4	1
II	1	1	1
III	2	2	1

TABLE 6

TOTAL ANNUAL COST OF SLOW SAND FILTER SYSTEMS
(Indian Rupees x 1000)

Capacity (m3/d)	Alternatives		
	1	2	3
50	68.9	42.7	53.2
100	80.9	58.9	67.7
200	102.0	86.5	92.7
300	121.1	111.2	115.2
400	139.3	134.3	136.3
500	156.7	156.3	156.4
600	173.6	177.5	175.9
700	190.1	198.1	194.8
800	206.2	218.1	213.8
900	222.1	237.7	231.4
1000	237.8	257.0	249.2
1100	253.3	275.9	266.7
1200	268.5	294.6	284.0
1300	283.7	313.0	301.1
1400	298.6	331.2	318.0
1500	313.5	349.2	334.7
1600	328.2	367.1	351.2
1700	342.9	384.7	367.6
1800	357.4	402.2	383.9
1900	371.8	419.5	400.1
2000	386.2	436.8	416.1

Annexure 2

COMPUTER PROGRAM FOR SSF SYSTEM DESIGN

```
10 REM PROGRAMME TO SELECT COST EFFECTIVE ALTERNATIVE IN SSF SYSTEMS
15 READ D,C1,C3,C4,C5,HR,HF,R,N1
20 READ R1,R2,R3,R4,R5,R6,R7,FR,K1,K2,E1,E3,E4
25 REM D - Design Capacity in Cu.m / Day , C1, C3, C4 & E1, E3, E4 - Constants
   and Exponents of Cost Models for Gravity Supply Tank, Clear Water Sump and
   Elevated Service Reservoir respectively.
30 REM C5 - Cost of Pump per H.P., HR & HF - Heads on Raw & Clear Water Pumps
   respectively, R - Discount Rate & N1 - Discount Period in Years
35 REM R1 & R2 - Rate of Depreciation and Maintenance of Civil Works & Pumping
   Machinary Per Year respectively, R3 - Energy Cost in Rs./KW, R4 - Cost of
   Scraping Per Sq.m. of Filter Area
40 REM R5, R6 & R7 - Salary of Pump Operator, Filter Attendant & Watchman Per
   Month , FR - Design Rate of Filtration in m/hr, K1 - Cost Per Unit Filter
   Bed Area ( include Base Slab, Media etc.), K2 - Cost Per Unit Length of
   Filter Wall
45 FOR I = 1 TO 3
50 X(I) = 24  : NEXT I
55 Y(1) = 24  : Y(2) = 8 : Y(3) = 16
60 FOR I = 1 TO 3
65 Q(I)= D / X(I)
70 NEXT I
75 REM COMPUTATIONS FOR DETERMINING AREA / SIZE OF VARIOUS UNITS
80 CAPHLT(1) = 0
85 CAPHLT(2) = Q(2) * 8 : CAPHLT(3) = Q(3) * 4
90 FOR I = 1 TO 3
95 ASSF(I) = Q(I) / FR
100 NEXT I
105 GOSUB 505
110 FOR I = 1 TO 3
115 SCWS(I) = (Q(I) / Y(I)) * X(I)
120 NEXT I
125 FOR I = 1 TO 3
130 SESR(I) = Q(I) * X(I) / 2
135 NEXT I
140 FOR I = 1 TO 3
145 REM COMPUTATIONS FOR COSTS OF VARIOUS UNITS
150 HLTCST(I) = C1 * CAPHLT(I) ^  E1
155 SSFCST(I) = C2(I)
160 CWSCST(I) = C3 * SCWS(I) ^ E3
165 ESRCST(I) = C4 * SESR(I) ^ E4
170 CIVIL(I) = HLTCST(I) + SSFCST(I) + CWSCST(I) + ESRCST(I)
175 RKW(I) = .748 * (Q(I) / 3600) * (1000 / 75) * HR * 100 / 60
180 FKW(I) = .748 * (Q(I) / 3600) * (1000 / 75) * HF * 100 / 60
185 PRICE(I) = 2 * C5 * RKW(I)
190 FPRICE(I) = 2 * C5 * FKW(I)
195 CPUMPS(I) = PRICE(I) + FPRICE(I)
200 NEXT I
205 RKW(2) = 3 * RKW(2) : FKW(2) = 3 * FKW(2)
210 RKW(3) = 1.5 * RKW(3) : FKW(3) = 1.5 * FKW(3)
215 FOR I = 1 TO 3
220 TCC(I) = CIVIL(I) + CPUMPS(I)
225 Z = R * ((1 + R)^N1) / (((1+R)^N1)-1)
230 ACC(I) = Z * TCC(I)
```

```
235 DCW(1) = R1 * CIVIL(I)
240 DPMC(I) = R2 * CPUMPS(I)
245 ENERGY(I) = (RKW(I) + FKW(I)) * R3 * 365 * Y(I)
250 FOR J = 1 TO 3
255 NS(J) = 15 : NEXT J
260 SND(I) = R4 * ASSF(I) * NS(I)
265 NEXT I
270 SALARY(1) = 12 * 3 * (R5 + R6) + 12 * (R6 + R7)
275 SALARY(2) = 12 * (R5 + R6 + R7)
280 SALARY(3) = 12 * 2 * (R5 + R6) + (12 * R7)
285 FOR I = 1 TO 3
290 TAC(I) = ACC(I) + DCW(I) + DPMC(I) + ENERGY(I) + SND(I) + SALARY(I)
295 WPC(I) = TAC(I) * 1000 / (D * 365)
300 WTC(I) = (TAC(I) - ACC(I)) * 1000 / (D * 365)
305 NEXT I
310 LPRINT "OPTIMAL DESIGN OF SLOW SAND FILTRATION SYSTEMS"
315 LPRINT : LPRINT
320 LPRINT "WATER DEMAND ";D;"  cu.m. PER DAY"
325 LPRINT : LPRINT
330 GOSUB 550
335 GOSUB 605
340 GOSUB 665
345 GOSUB 725
350 GOSUB 785
355 LPRINT "COST OF TREATMENT AND PRODUCTION  (Rs.)"
360 LPRINT "-------------------------------------------------------------------"
365 LPRINT "  ALT.NO.     DESIGN CAPACITY        COST PER 1000 cu.m. OF WATER"
370 LPRINT "              cu.m. PER HOUR           TREATMENT      PRODUCTION "
375 LPRINT "-------------------------------------------------------------------"
380 LPRINT
385 FOR I = 1 TO 3
390 LPRINT USING "    #           ####.##                  ####.##           ####.#
#";I,Q(I),WTC(I),WPC(I) : LPRINT
395 NEXT I
400 LPRINT "-------------------------------------------------------------------"
405 K = 1 : L = 2
410 IF WPC(K) < WPC(L) THEN 415 ELSE K = L
415 L = L + 1
420 IF L > 3 THEN 425 ELSE 410
425 LPRINT "SELECT ALTERNATIVE  : ";K
430 LPRINT
435 LPRINT "COST OF WATER PRODUCTION / 1000 cu.m. =";USING "####.##";WPC(K)
440 LPRINT
445 LPRINT "CAPACITY OF GRAVITY SUPPLY TANK = ";CAPHLT(K);"  cu.m."
450 LPRINT
455 LPRINT "AREA OF SLOW SAND FILTER = "; : LPRINT USING "####.##";ASSF(K); : LP
RINT " sq.m."
460 LPRINT : PRINT
465 LPRINT "NO. OF UNITS = ";N
470 LPRINT
475 LPRINT "LENGTH = "; : LPRINT USING "###.##";AL(K); : LPRINT "  m." : LPRINT
480 LPRINT "WIDTH = "; : LPRINT USING "###.##";B(K); : LPRINT "  m." : LPRINT
```

```
485 LPRINT "CAPACITY OF CLEAR WATER SUMP = "; : LPRINT USING "###.##";SCWS(K), :
 LPRINT "  cu.m." : LPRINT
490 LPRINT "CAPACITY OF E.S.R. = ";SESR(K),"cu.m." : LPRINT
495 DATA 50,6658,1250,8300,2000,15,20,0.12,25
500 DATA 0.02,0.07,0.5,0.3,550,550,400,0.1,970,1090,0.668,0.785,0.668
505 FOR I = 1 TO 3
510 IF ASSF(I) > 135 THEN 515 ELSE N = 2
515 IF ASSF(I) > 700 THEN 520 ELSE N = 3
520 IF ASSF(I) > 1600 THEN N = 5 ELSE N = 4
525 C2(I) = K1 * ASSF(I) + 2 * K2 * SQR( 2 * ASSF(I) + (N + 1))
530 AL(I) = SQR(2 * ASSF(I) / ( N + 1))
535 B(I) = ( N + 1) * AL(I) / ( 2 * N)
540 NEXT I
545 RETURN
550 LPRINT "----------------------------------------------"
555 LPRINT "ALTERNATIVE NO.     DESIGN CAPACITY(cu.m./hr)"
560 LPRINT "----------------------------------------------"
565 LPRINT
570 FOR I = 1 TO 3
575 LPRINT USING "      #                      ###.##";I,Q(I) : LPRINT
580 NEXT I
585 LPRINT "----------------------------------------------"
590 LPRINT
595 LPRINT
600 RETURN
605 LPRINT "SIZE / CAPACITY OF UNITS " : LPRINT
610 LPRINT "-------------------------------------------------------------------"
615 LPRINT "ALT.NO.    HIGH LEVEL    SLOW SAND     CLEAR WATER   EL.SER.RES."
620 LPRINT "           TANK -cu.m.   FILTER-sq.m.  SUMP-cu.m.    - cu.m.    "
625 LPRINT "-------------------------------------------------------------------"
630 FOR I = 1 TO 3
635 LPRINT USING "   #       ####.#          ####.#         ####.#        ####.#"
;I,CAPHLT(I),ASSF(I),SCWS(I),SESR(I)
640 LPRINT
645 NEXT I
650 LPRINT "------------------------------------------------------------------"
655 LPRINT : LPRINT
660 RETURN
665 LPRINT "CAPITAL COST OF CIVIL WORKS (Rs. IN THOUSAND) :" : LPRINT
670 LPRINT "----------------------------------------------------------------------
"
675 LPRINT "ALT NO.   GRAVITY SUPPLY  SLOW SAND     CLEAR WATER    EL.SER.RES."
680 LPRINT "          TANK            FILTER        SUMP "
685 LPRINT "----------------------------------------------------------------------
"
690 LPRINT
```

```
695 FOR I = 1 TO 3
700 LPRINT USING "  #      ########.#    ########.#    ########.#        ########.
#";I,HLTCST(I)/1000,SSFCST(I)/1000,CWSCST(I)/1000,ESRCST(I)/1000
705 LPRINT
710 NEXT I : LPRINT
715 LPRINT "--------------------------------------------------------------------
"
720 RETURN
725 LPRINT "CAPITAL COST (Rs. IN THOUSAND)
730 LPRINT
735 LPRINT "---------------------------------------------"
740 LPRINT "ALT NO.";TAB(12);"CIVIL WORKS";TAB(28);"PUMPS";TAB(38);"TOTAL"
745 LPRINT "---------------------------------------------"
750 LPRINT
755 FOR I = 1 TO 3
760 LPRINT USING "  #       ########.#  ########.# ########.#      ";I,CIVIL(I)/10
00,CPUMPS(I)/1000,TCC(I)/1000
765 LPRINT
770 NEXT I : LPRINT
775 LPRINT "---------------------------------------------"
780 RETURN
785 LPRINT "ANNUAL COSTS (Rs. IN THOUSAND) :" : LPRINT
790 LPRINT "--------------------------------------------------------------------
-----------"
795 LPRINT "ALT.   ANN.CAP.  DEPRN. ON    DEPRN. ON   ENERGY    SAND     SALARY
  TOTAL"
800 LPRINT "NO.    COST      CIVIL WORKS  PUMPS          ,     SCRAPING"
805 LPRINT "--------------------------------------------------------------------
-----------"
810 LPRINT
815 FOR I = 1 TO 3
820 LPRINT USING " #      ####.#  #######.#  #######.#  #######.#  #####.# ######
.#";I;ACC(I)/1000,DCW(I)/1000,DPMC(I)/1000,ENERGY(I)/1000,SND(I)/1000,SALARY(I)/
1000; : LPRINT USING "     ####.#";TAC(I)/1000
825 LPRINT
830 NEXT I : LPRINT
835 LPRINT "--------------------------------------------------------------------
-----------"
840 RETURN
```

```
OPTIMAL DESIGN OF SLOW SAND FILTRATION SYSTEMS

WATER DEMAND  50   cu.m. PER DAY

-----------------------------------------
ALTERNATIVE NO.    DESIGN CAPACITY(cu.m./hr)
-----------------------------------------

     1                      2.08

     2                      2.08

     3                      2.08

-----------------------------------------



SIZE / CAPACITY OF UNITS

-------------------------------------------------------------
ALT.NO.    HIGH LEVEL    SLOW SAND     CLEAR WATER   EL.SER.RES.
           TANK -cu.m.   FILTER-sq.m.  SUMP-cu.m.    - cu.m.
-------------------------------------------------------------
   1           0.0          20.8           2.1          25.0

   2          16.7          20.8           6.3          25.0

   3           8.3          20.8           3.1          25.0

-------------------------------------------------------------



CAPITAL COST OF CIVIL WORKS (Rs. IN THOUSAND) :

--------------------------------------------------------------
ALT NO.   GRAVITY SUPPLY  SLOW SAND    CLEAR WATER    EL.SER.RES.
          TANK            FILTER       SUMP
--------------------------------------------------------------

  1            0.0          35.1          2.2            71.3

  2           43.6          35.1          5.3            71.3

  3           27.4          35.1          3.1            71.3


--------------------------------------------------------------
```

CAPITAL COST (Rs. IN THOUSAND)

ALT NO.	CIVIL WORKS	PUMPS	TOTAL
1	108.6	1.3	109.9
2	155.2	1.3	156.6
3	136.9	1.3	138.2

ANNUAL COSTS (Rs. IN THOUSAND) :

ALT. NO.	ANN.CAP. COST	DEPRN. ON CIVIL WORKS	DEPRN. ON PUMPS	ENERGY	SAND SCRAPING	SALARY	TOTAL
1	14.0	2.2	0.1	1.5	0.1	51.0	68.9
2	20.0	3.1	0.1	1.5	0.1	18.0	42.7
3	17.6	2.7	0.1	1.5	0.1	31.2	53.2

```
COST OF TREATMENT AND PRODUCTION  (Rs.)
------------------------------------------------------------------
 ALT.NO.       DESIGN CAPACITY         COST PER 1000 cu.m. OF WATER
               cu.m. PER HOUR            TREATMENT      PRODUCTION
------------------------------------------------------------------

   1                2.08                  3004.63          3772.71

   2                2.08                  1247.54          2341.52

   3                2.08                  1950.69          2916.32

------------------------------------------------------------------


SELECT ALTERNATIVE  :  2

COST OF WATER PRODUCTION / 1000 cu.m. =2341.52

CAPACITY OF GRAVITY SUPPLY TANK =  16.66667   cu.m.

AREA OF SLOW SAND FILTER =   20.83 sq.m.

NO. OF UNITS =  4

LENGTH =   2.89  m.

WIDTH =   1.80  m.

CAPACITY OF CLEAR WATER SUMP =   6.25  cu.m.

CAPACITY OF E.S.R. =  25    cu.m.
```

```
OPTIMAL DESIGN OF SLOW SAND FILTRATION SYSTEMS

WATER DEMAND  2000   cu.m. PER DAY

--------------------------------------------
ALTERNATIVE NO.     DESIGN CAPACITY(cu.m./hr)
--------------------------------------------

     1                      83.33

     2                      83.33

     3                      83.33

--------------------------------------------


SIZE / CAPACITY OF UNITS

----------------------------------------------------------------
ALT.NO.     HIGH LEVEL     SLOW SAND      CLEAR WATER    EL.SER.RES.
            TANK -cu.m.    FILTER-sq.m.   SUMP-cu.m.       cu.m.
----------------------------------------------------------------
   1           0.0           833.3           83.3          1000.0

   2         666.7           833.3          250.0          1000.0

   3         333.3           833.3          125.0          1000.0

----------------------------------------------------------------


CAPITAL COST OF CIVIL WORKS (Rs. IN THOUSAND) :

-------------------------------------------------------------------
ALT NO.    GRAVITY SUPPLY  SLOW SAND     CLEAR WATER     EL.SER.RES.
           TANK            FILTER        SUMP
-------------------------------------------------------------------

  1              0.0         897.5          40.2             837.7

  2            512.5         897.5          95.3             837.7

  3            322.6         897.5          55.3             837.7

-------------------------------------------------------------------
```

CAPITAL COST (Rs. IN THOUSAND)

ALT NO.	CIVIL WORKS	PUMPS	TOTAL
1	1775.4	53.9	1829.3
2	2343.0	53.9	2396.9
3	2113.0	53.9	2166.9

ANNUAL COSTS (Rs. IN THOUSAND) :

ALT. NO.	ANN.CAP. COST	DEPRN. ON CIVIL WORKS	DEPRN. ON PUMPS	ENERGY	SAND SCRAPING	SALARY	TOTAL
1	233.2	35.5	3.8	59.0	3.8	51.0	386.2
2	305.6	46.9	3.8	59.0	3.8	18.0	437.0
3	276.3	42.3	3.8	59.0	3.8	31.2	416.2

```
COST OF TREATMENT AND PRODUCTION  (Rs.)
-------------------------------------------------------------------
  ALT.NO.      DESIGN CAPACITY        COST PER 1000 cu.m. OF WATER
               cu.m. PER HOUR           TREATMENT       PRODUCTION
-------------------------------------------------------------------

    1              83.33                 209.61             529.10

    2              83.33                 179.95             598.59

    3              83.33                 191.74             570.20

-------------------------------------------------------------------


SELECT ALTERNATIVE  :  1

COST OF WATER PRODUCTION / 1000 cu.m. = 529.10

CAPACITY OF GRAVITY SUPPLY TANK =  0   cu.m.

AREA OF SLOW SAND FILTER =  833.33 sq.m.

NO. OF UNITS =  4

LENGTH =  18.26  m.

WIDTH =  11.41  m.

CAPACITY OF CLEAR WATER SUMP =  83.33  cu.m.

CAPACITY OF E.S.R. =  1000  cu.m.
```

Annexure 3

EXCERPTS FROM THE REVIEWERS OF THE CARETAKER MANUAL

1. The simple process of purifying water for drinking purposes with the help of sand has been explained in a very interesting and easy to comprehend style. In all, it is an attractive and useful book.

Prof. Mukul Chand Pandey,
Member, Hindi Advisory Committees,
Govt. of India,
ALLAHABAD

2. It is undoubtedly useful not only for the rural population and the general public but also a practical guide for all those engaged in the field of Public Health Engineering and Social Work. Probably, it is the only book in Hindi on the subject.

Dr. Prakash Verma
Incharge, (Official Language),
Inspection Directorate, Burma Mines,
JAMSHEDPUR - 831 007.

3. It is a beautiful and attractive book and also equally useful, particularly for the rural population and filter plant operators for whom it is written.

Mr. Vishambher Prasad,
Technical Editor,
The Journal of the Institution of
Engineers (India), Hindi Edition,
NEW DELHI - 110 034.

Annexure 4

NATIONAL DRINKING WATER MISSION

TRAINING PROGRAMME ON SLOW SAND FILTRATION.

DATES : 16.2.1989 AND 23.6.1989

LIST OF PARTICIPANTS

Sl. No. Name & Address

1. Mr. K.V. Suryanarayana
B.E., MI(PH)
Technical Asst. (AEE)
to Exe. Director
Water Technology Mission
GULBARGA (Karnataka)

2. Mr. B.D. Jadhav
Asst. Exe. Engr.
Zilla Parishad Engineering
Sub-Division
Chittapur
Dist. Gulbarga (Karnataka)

3. Mr. G.D. Desai
Asst. Exe. Engr.
H-No. 1-26/11
Khuba Plot
Gulbarga (Karnataka)

4 Mr. G.K. Hiremath
Junior Engineer
Office of the
Exe. Engineer
Z.P.E. Division,
DHARWAD (Karnataka)

5. Mr. C.B. Gujjari
Assistant Engineer
Office of the
Asst. Exe. Engr.
Z.P.E. Sub-Division,
HUBLI (Karnataka)

6. Mr. H.V. Prahallada
Junior Engineer
Office of the
Asst. Exe. Engr.
Z.P.E. Sub-Division,
HUBLI (Karnataka)

Sl. No. Name & Address

7. Mr. B. Parasuramappa
Junior Engineer
Office of the
Asst. Exe. Engr.
Z.P.E. Sub-Division
KUNDGOL (Karnataka)

8. Mr. K.M. Moinuddin Aijaz
Asst. Exe. Engr.
Technical Asst.
Office of the
Chief Engineer P.H.E.D.
BANGALORE (Karnataka)

9. Mr. V.B. Kanavi
Asst. Exe. Engr.
Z.P.E. Sub-Division
HUBLI (Karnataka)

10. Mr. V.L. Maladkar
Asst. Exe. Engr.
Z.P.E Sub-Division
KUNDGOL (Karnataka)

11. Mr. G.B. Bajantri
Asst. Exe. Engr.
Z.P.E Sub-Division.
NAVALGUND.
Dist.- Dharwad (Karnataka)

12. Mr. D.R. Bheemasena Rao
Assistant Engineer
Office of the Chief Engineer
P.H.E.D.,
BANGALORE (Karnataka)

13. Mr. M.D. Huralikuppa
Asst. Exe. Engr.
Z.P.E Sub-Division
RON. Dist.-Dharwad (Karnataka)

Contd...

(Contd.)

Sl. No.	Name & Address
14.	Mr. D.K. Shantamurthy Asst. Exe. Engr. Z.P.E Sub-Division NARAGUND Dist.- Dharwad (Karnataka)
15.	Mr. G. Akoramaradhya Junior Engineer, Z.P.E Sub-Division NAGAGUND (Karnataka)
16.	Mr. Shivaray Bodke Assistant Engineer, Z.P.E. Sub-Division KUNDGOL (Karnataka)
17	Mr. Abdul Nabi Junior Engineer, Z.P.E. Sub-Division RAICHUR (Karnataka)
18.	Mr. I.S. Hiregoudar Assistant Engineer, Water Technology Mission,Z.P. DHARWAD (Karnataka)
19.	Mr. C.S. Magi Junior Engineer, Office of Asst.Exe.Engr. Z.P.E Sub-Division, MUNDARGI Dist. Dharwad (Karnataka)
20.	Mr. D. Hiriyannaiah Assistant Engineer, Z.P.E Sub-Division NELAMANGALA (Karnataka)
21.	Mr. S.B. Nashi Junior Engineer, O/o. The Asst.Exe.Engr. Z.P.E Sub-Division HUNAGUND Dist.- Bijapur
22.	Mr. G.V. Yadavannavar Junior Engineer, O/o. Asst. Exe.Engr., Z.P.E. Sub-Division RON (Karnataka)
23.	Mr. B.M. Desai Junior Engineer, O/o. Asst. Exe. Engineer, Z.P.E. Sub-Division HUNAGUND Dist. - Bijapur
24.	Mr. B.R. Nanjappa Junior Engineer, O/o Asst. Exe. Engineer, Z.P.E. Sub-Division., NAVALGUND (Karnataka)
25.	Mr. N.D. Dwivedi Assistant Engineer PHE Sub Divn. JAMAI, Dist. Chhindwara - 480 551.
26.	Mr. K.C. Jain Sub Engineer, PHE Sub Divn. JUNNARDES Dist.-Chhindwara - 480 551.

Annexure 5

LIST OF PARTIES SUPPLIED WITH TECHNICAL INFORMATION/ ADVICE ON DESIGN AND CONSTRUCTION OF SLOW SAND FILTERS

.No.	Name and Address of Party
.	The Executive Director, Water Technology Mission, Raichur District, Karnataka.
.	Mr. M.M. Singhvi, Additional Chief Engineer, Public Health Engineering Department, Bikaner, Rajasthan
3.	Mr. R.S. Chordia Superintending Engineer Public Health Engineering Department Churu Circle, Churu (Rajasthan)
.	Mr. A.S. Gupta Superintending Engineer Temporary Construction Circle, U.P. Jal Nigam, Ranikhet - 263 645.
.	Mr. P. Subramanian Embrandiri Asst. Executive Engineer Kerala Water Authority Parappanangadi- 676 303.
6.	Mr. B.D. Jadhav Asst. Executive Engineer, Z.P.E. Sub-Division, Chittapur - 585 211.
.	Executive Engineer Z.P.E. Division Dharwad, Karnataka.
.	Mr. K. Naram Advisor, Netherlands Assisted Projects Office, 1-2-412/9, Gaganmahal Colony, Hyderabad - 500 029.

Contd..

(Contd.)

S.No.	Name and Address of Party
9.	Dr. Ing. Otto R. Kumtschik Hauptstrasse 69 6095 GINSHEM - GUSTAVSBURG 2 FEDERAL REPUBLIC OF GERMANY.
10.	Mr. S. Madhusudan Singh Senior Scientific Officer, Directorate of Science, Technology and Environment, Govt. of Manipur
11.	Mr. J.D. Joysingh Technical Member, Kerala Water Authority, Trivandrum - 695 033.
12.	Mr. R.A. Bhat Chief Engineer, Gujrat Water Supply & Sewerage Board, Rajkot, Gujarat.

22 January, 1990/js adv/ssf-memoneer.001

MEMORANDUM

to : Jan Teun
from : Jo
date : 22 January, 1990

BRIEF COMMENTS FINAL REPORT SSF PHASE IV FROM NEERI INDIA

After quick review, the following remarks are made:

General points:

- layout and presentation of report is very nice;
- reported data of tests etc. are very complete, but in main body of report only summaries of data and/or averages should be included; others in appendices;
- writing style of report is very elaborative; I think the major findings could be reported in about five to ten pages, including some figures. Though some findings are interesting they are drown in the less important data. this makes reading of the document tiring, and so less attractive

On findings: 6

SSF - positive that inlet-controlled filters perform equally well as outlet-controlled filters: for all parameters including algae;

–

Pre-filtration:

- conclusions is that HRF performes better than URF, but the design of HRF is greatly over-dimensioned: each of the three compartments is 3 m long, makes total of 9 m, while URF has only 3 m (still quite high);

need for design-optimization!

- one of the negative findings for URF is the growth of algae in supernatant; this is solved by adding more filter medium (up to above collectors);
- positive results on upflow filter with fine medium; check negative aspects;

- the design includes a de-silting tank, and storage tank with extensive storage time; this results in a decrease of turbidity before coarse gravel treatment, which should be avoided as in reality optimization of designs would go for no pre-storage to reduce investment cost (expensive construction);

- report is a bit negative on Cali URF results, and does not refer much to these; it is true that not much has been officially published on first results; Cali

- the use of the parameter: colloidal turbidity (=turbidity after centrifuging (how long?, at ??rpm?), should be checked for further use; scientifically applied before?

- DO dropped seriously, rendering the effluent = influent for SSF too low O_2 concentration too low for biological SSF process; why so big depletion? aeration needed!

- no good experience with fast-drainage; why? Design? In-situ flushing (pouring water per bucket over drained bed) better result but not very feasible in practical situation.