Performance Testing

of

Naiade UV Disinfection System

(Final Report)

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UNESCO-IHE
Institute for Water Education

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1. Introduction

1.1 Background

Safe drinking water is the basic need for human survival. Despite the efforts of governments and international development agencies, more than 1.1 billion people in the world still do not have access to safe and improved drinking water supply. Millions of people die every year due to several water borne diseases like cholera, diarrhoea, typhoid fever, hepatitis, dysentery etc. Most of these "unserved" live in the rural and urban-poor areas of Asia, Africa and Latin America, where there are often no centralized piped water supply systems. Therefore, the provision of community level or point-of-use (household-level) water treatment systems is an important strategy in providing safe drinking water to the unserved.

Among others, the most important aspect of safe water supply is that "the drinking water should be free of pathogenic organisms". This highlights the importance of disinfection in water treatment processes. Of the different methods available for disinfection of drinking water, Ultraviolet (UV) disinfection is gaining increasing popularity these days due to its high effectiveness in removing a wide range of pathogens and no chemical use or by-product formation.

Naiade UV disinfection system developed by NEDAP NV, The Netherlands, is a community level water disinfection system, which uses UV technology for the removal of pathogenic organisms from water supply sources. According to the supplier, Naiade is a stand-alone water disinfection system, which can perform independently without the need to be connected to the water main or electrical energy, and without any chemical addition. Such a water treatment unit could help to increase the provision of safe water supply to the unserved.

1.2 Scope of the study

This report presents the results of the testing of the performance of Naiade UV disinfection system conducted at UNESCO-IHE, Delft in The Netherlands from 19 October to 2 December 2004. As requested by the supplier, the study was mainly focussed on the removal of the selected microorganisms (Total coliform, E-coli and Total plate count) under the given test conditions and the effect of this treatment system on the other selected standard water quality parameters. However, the analysis of the removal of other pathogenic microorganisms namely *Cryptosporidium*, *Giardia* and viruses and other aspects like long-term performance of the system (including that of UV lamp, solar panel and battery) and hydraulic capacities of the system under different water quality and water use conditions are beyond the scope of this testing. Furthermore, the duration of the test, mode of operation as well as number and frequency of samples were as suggested by the supplier.

2. Materials and Methods

2.1 Description of Naiade UV disinfection system

According to the supplier, Naiade is a mobile water purification installation for the production of drinking water with the daily average capacity of the system of 2500 litres. The disinfection is achieved with use of a 16 watt UV lamp. A solar panel of 80 watt is to be attached to the unit so that it can perform independently even in remote area without access to electrical energy. The unit has the total weight of 44 kg with the dimensions of 54 x 75 x 140 cm (excluding the solar panel). A photograph of the Naiade UV disinfection system and its schematic diagram are presented in Figure 1 and 2 respectively. As reported by the supplier, the UV lamp-life is about 12,000 hrs and the UV dose is calculated to be 40 mJ/cm^2 (at UV transmittance of the water > 80% in 1 cm at end of lamp-life and at a flow of 6 l/min). An optional turbulator (spiral coil) could be provided around the UV lamp in order to increase the turbulence in the reactor around the lamp and to avoid short-circuiting and laminar flows.

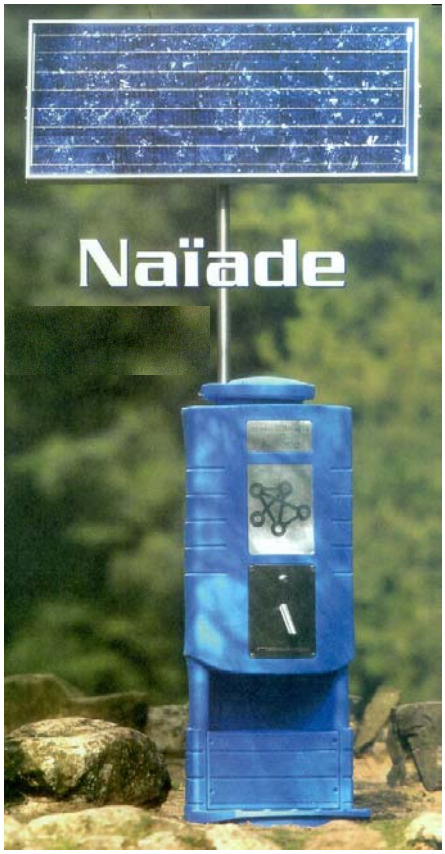

Fig. 1 Naiade UV disinfection system

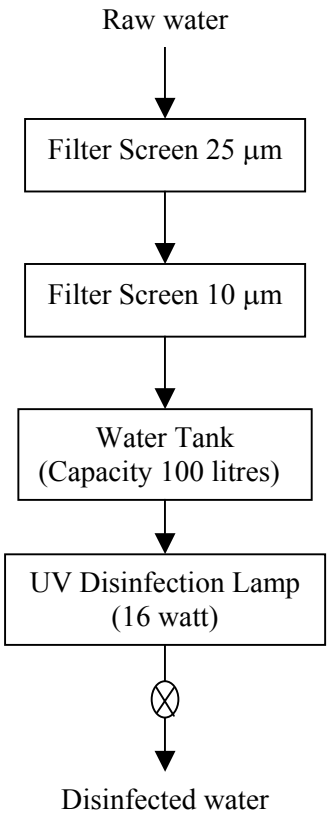

Fig. 2 Schematic of Naiade UV disinfection system

The raw water from the source is first poured into the system by opening the cover at the top, which then passes through two filter screens of sizes 25 μm and 10 μm respectively. The pre-filtered water is then stored in a water tank of 100-litre capacity. When the system is switched on, the water passes through the UV disinfection reactor after a warm-up period of the lamp of 2 minutes, when the operating button is activated, and then the disinfected water could be collected from the spout.

2.2 Test conditions and procedure

The Naiade UV disinfection system was tested from 19 October to 2 December 2004 to check its performance with respect to removal of selected microorganisms (Total coliform, E-coli and Total plate count). For this test the water from Delft Canal was used as a raw water source. In order to obtain the desired raw water quality, for some test runs the required amount of E-coli were spiked to the Delft canal water using E-coli standard solution of 10^9 cfu per mL. Furthermore, some kaoline was added to raw water for some test runs in order to increase the turbidity of the raw water (from 20 to > 300 FNU) to examine the effect of increased turbidity on removal efficiency. The detailed raw water quality parameters are presented in the Appendices.

During this test, the system was operated intermittently for 6 weeks. Every week it was operated 2 times (in 2 days) for about 1 hour. Therefore, the total operation time of the system during this performance test was 12 hours only. After obtaining the raw water from the Delft Canal, the required amount of kaoline (0 – 1600 mg/L) was properly mixed and then it was poured into the UV disinfection system. After pouring the water from the top through the pre-filters, the filter nets were removed and required amount of E-coli was added (0- 1000 per mL) and mixed thoroughly for about 1 minute and then the influent samples were taken.

After that the system was switched on (by pressing the knob) and allowed to run for 2 minutes with water coming out of the spout/tap. Then the spout was sterilized with the help of burner, the system was operated again for 10 secs and then effluent samples were taken for analysis. The system (water tank) was made empty at the end of each test run.

It is to be noted that performance tests were conducted in the laboratory using power from the 12 V car battery. The solar panel could not recharge the battery due to the location of the unit in the laboratory (in the basement of the building). The battery was recharged using a conventional car-battery charger.

2.3 Parameters analysed

Selected bacteriological and physico-chemical parameters of the raw water and the treated water were determined during the test.

- For bacteriological analysis the numbers of E-coli, Total coliform and Total plate count were measured 2 times per week for 6 weeks, both for raw water (influent) and treated water (effluent). In this procedure, first the presumptive tests for coliforms were conducted to check the presence of any coliforms in the samples and when this value was <0.01 per mL, no Total coliform measurements (confirmed

tests) were done. However, for each sample E-coli and Total plate counts were always measured.

- For physical/chemical parameters, 21 standard parameters were analysed 3 times, both for raw water and treated water.

2.4 Methods of analysis

All the inorganic parameters were analysed using the procedures prescribed in Standard Methods for the Examination of Water and Wastewater, 20th Edition (1998). Most of the parameters were analysed at the laboratory of UNESCO-IHE Delft using various measuring instruments including AAS Perkin Elmer 3110, Perkin Elmer Lamba 5 UV/VIS Spectrometer, Dionex 4500i ion chromatograph and TOC Analyser Model 700 (O-I Corporation, Texas, USA).

Analysis of some selected bacteriological parameters namely Total coliform, E-coli and Total plate count were conducted at Aqualab, Werkendam, The Netherlands, which is a certified laboratory in the Netherlands for specific bacteriological analysis.

3. Results and Discussion

3.1 Removal of microorganisms

In the first set of test, the raw water from the Delft Canal was used directly (without adding kaoline or E-coli) to analyse the performance of Naiade UV disinfection system. Table 1 summarizes the removal of different microorganisms by the Naiade UV disinfection unit for two samples. This set of test was conducted without turbulator in place.

Table 1: Removal of different organisms from Delft Canal water (without spiking)

Sample		Total Coliforms 37 °C Confirmed cfu/mL	Total Coliforms 44 °C Confirmed cfu/mL	E-coli Direct plating cfu/mL	Total Plate Count 22 °C 3 days cfu/mL
1	Influent	10	1.5	1.8	12000
	Effluent	<0.01	<0.01	<0.01	280
2	Influent	2.9	0.21	0.06	7000
	Effluent	<0.01	<0.01	<0.01	1200

It was found when Delft canal water was used as influent, the number of total coliform and E-coli in the effluent were both <0.01 per mL. This corresponds to at least 2-3 log removals of total coliforms and more than 1 log removal of E-coli.

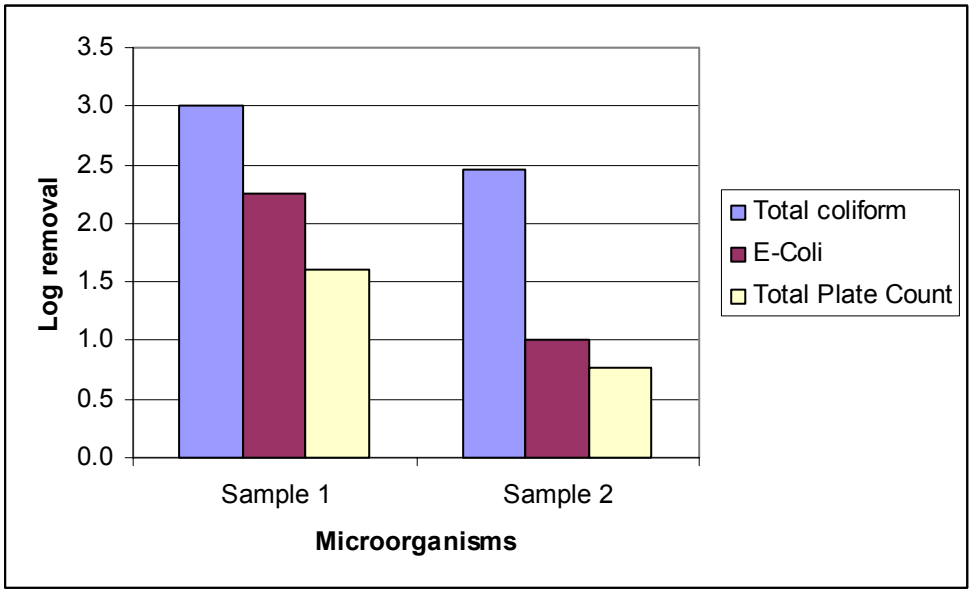

Fig. 3 Log removal of different organisms from Delft Canal water by Naiade UV disinfection system (without spiking E-coli and kaoline)

In the second set of tests, additional numbers of E-coli were spiked to the water (theoretically 100 per mL and 1000 per mL respectively) and the removals of different organisms were monitored. It was observed that even at higher E-coli concentrations, there was 4 to 5 log removal of Total coliforms and E-coli (Table 2). These results demonstrate that under the conditions applied Naiade UV disinfection system is very effective in Total coliform and E-coli removal. However, it is to be noted that the log removal of different organisms is related to their initial concentration in the influent.

Table 2: Removal of different organisms from Delft Canal water (with E-coli spiking)

Sample		Total Coliforms 37 °C Confirmed cfu/mL	Total Coliforms 44 °C Confirmed cfu/mL	E-coli Direct plating cfu/mL	Total Plate Count 22 °C 3 days cfu/mL
3	Influent	160	170	190	8400
	Effluent	0.01	<0.01	<0.01	900
4	Influent	2100	1300	1400	8100
	Effluent	<0.01	<0.01	<0.01	650

3.2 Effect of turbidity on removal efficiency

In order to analyse the effect of turbidity on the microorganism removal efficiency, kaoline was added in different concentrations keeping the additional E-coli dosing constant at 100 per mL. These tests were conducted with turbulator in place. Detailed results for this set of tests are presented in the Appendix A and B.

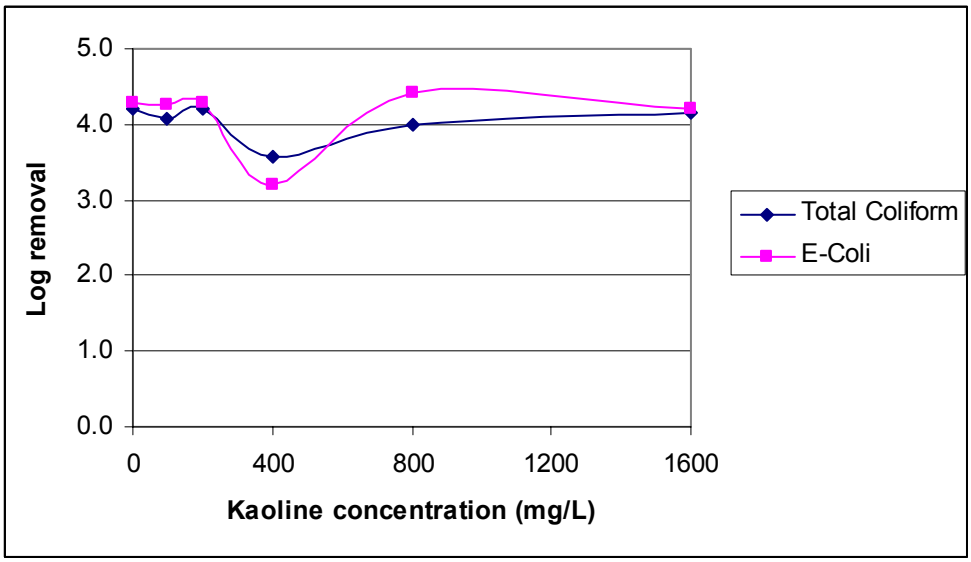

Fig. 4 Effect of kaoline concentration (turbidity) on removal of microorganisms by Naiade UV disinfection system.

It was observed that even when the turbidity of the water was increased from 20 FNU to > 300 FNU (corresponding to kaoline concentration of 0 mg/L to 1600 mg/L) there was more than 3 log removal of E-coli and Total coliform. This suggests that within the range of E-coli and Total coliform level tested (100 – 300 cfu/mL) there was no significant adverse effect of increasing turbidity (corresponding to kaoline concentration of 0 mg/L to 1600 mg/L) on the efficiency of UV disinfection system.

3.3 Effect of turbulator on removal efficiency

In the Naiade UV disinfection reactor a turbulator (spiral coil) can be added around the UV lamp in order to increase the turbulence and to avoid laminar flow around the lamp. One set of test was conducted with and without the turbulator to examine the effectiveness of the turbulator, for the same raw water maintaining the kaoline concentration at 400 mg/L and additional E-coli spiked as 100 per mL. The results are summarised in Table 3 and Figure 5.

Table 3: Effect of turbulator on removal of different organisms

Sample		Total Coliforms 37 °C Confirmed cfu/mL	Total Coliforms 44 °C Confirmed cfu/mL	E-coli Direct plating cfu/mL	Total Plate Count 22 °C 3 days cfu/mL
With turbulator in place	Influent	210	200	190	14000
	Effluent	<0.01	<0.01	0.01	500
Without turbulator	Influent	160	240	230	12000
	Effluent	0.01	<0.01	<0.01	1000

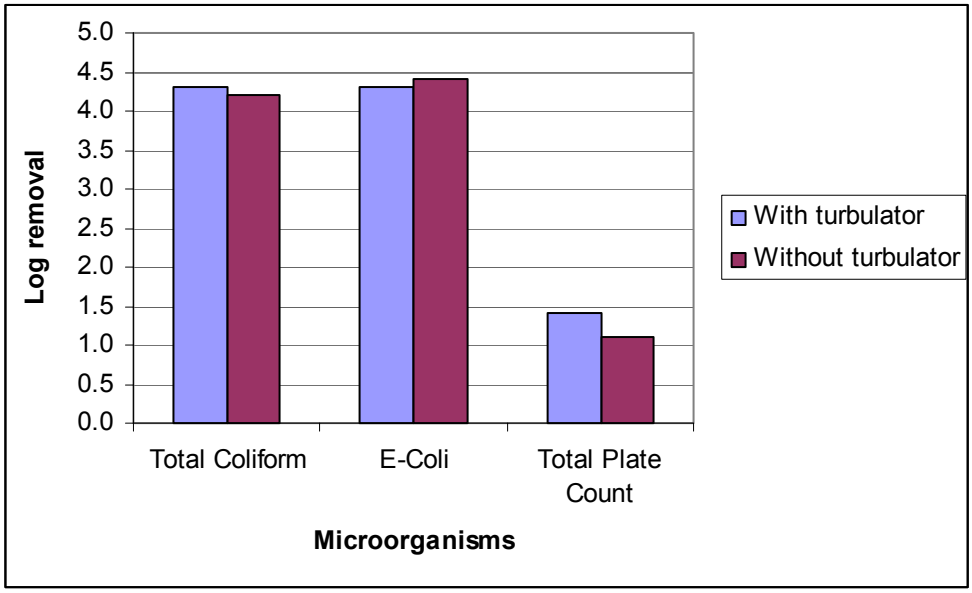

Fig. 5 Log removal of microorganisms with and without turbulator around the UV lamp in Naiade UV disinfection system.

When the UV disinfection system was operated with the turbulator in place, the log removals of Total coliform, E-coli and Total plate count were 4.3, 4.3 and 1.4 respectively. When the turbulator was removed and the samples were taken and analysed the log removals of Total coliform, E-coli and Total plate count were found to be 4.2, 4.4 and 1.1 respectively. These results imply that in general under the conditions tested there was no significant difference in the results with or without turbulator. However, further test should be conducted at higher concentrations of microorganisms and at higher turbidity level to verify the role of the turbulator.

3.4 Change in other water quality parameters.

The concentrations of 21 different standard parameters were analysed three times during this test both for raw water and effluent from the UV disinfection system. The results are presented in Appendix A.

There was no significant change in any of these 21 standard parameters after the raw water passed through the UV disinfection system. Changes or removals were observed only in the microbiological parameters. This indicates that Naiade UV disinfection system is effective in removing selected microorganisms, without changing other 21 standard physical/chemical water quality parameters significantly.

It is to be noted that there was no significant change in turbidity (due to added kaoline) when the water was treated with this unit. This implies that the pre-filters provided are not effective in removing the turbidity. Furthermore, these pre-filters do not contribute to any pathogen removal. For effective pathogen removal by UV disinfection system, it is beneficial to provide a microfiltration (MF) or ultrafiltration (UF) system before the UV reactor.

4. Summary and Conclusions

Naiade UV disinfection system developed by NEDAP NV, The Netherlands, is a stand-alone, community level water disinfection system, which uses the UV technology for the removal of pathogenic organisms from water supply sources. Naiade UV disinfection system was tested in the laboratory of UNESCO-IHE, Delft, The Netherlands from 19 October 2004 to 2 December 2004 and its selected microorganism removal efficiency was analysed. The system was operated using raw water from Delft canal, which was spiked with E-coli and kaoline to increase the bacteriological counts and turbidity of the influent. The system was operated intermittently for 6 weeks. Every week it was operated 2 times (in 2 days) for about 1 hour. The selected microbiological parameters (Total coliform. E-coli and Total plate count) were analysed for every test runs (12 times) whereas 21 standard physical/chemical parameters were analysed three times for both influent and effluent. The system was operated powered by the built-in 12 V car battery.

Under the conditions tested it was found that Naiade UV disinfection system could remove Total coliform and E-coli from the raw water up to 3 to 4-log removal. The system was equally effective its terms of Total coliform and E-coli removal when the E-coli concentration was increased from 2 to 2000 cfu per mL.

There was no significant effect of increasing the turbidity of the water from 20 to > 300 FNU (corresponding to kaoline concentration of 0 to 1600 mg/L) on the microorganism (Total coliform and E-coli) removal efficiency of the Naiade UV disinfection system. No significant change in the microorganism removal efficiency was observed when the system was operated with or without turbulator (spiral coil) around the UV disinfection lamp.

Furthermore, there was no significant change in 21 standard physical/chemical parameters measured when the raw water was treated with this disinfection system. The pre-filters provided with this system were not effective in removing the turbidity due to kaoline (0 to 1600 mg/L).

It is to be noted that performance tests were conducted as prescribed the by supplier and this study was not designed to analyse the effectiveness of the system for disinfection of water and the long-term performance of the system and its components. The removal of the other pathogenic microorganisms namely *Cryptosporidium*, *Giardia* and viruses were also not analysed.

APPENDICES

- Appendix A: Physical/chemical water quality parameters
- Appendix B: Microbiological water quality parameters

Appendix A. Physical/Chemical Water Quality Parameters

Parameter	9/11/2004		18/11/2004		2/12/2004	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	8.0	8.0	8.0	7.9	7.9	8.0
temperature	11.5	12.5	12	12	8	8.6
O2 (mg/L)	8.1	9.3	8.9	9	9.1	9
HCO3 (mg/L)	268	272	314	318	298	284
Concuctivity (us/cm)	968	964	990	989	987	981
Na (mg/L)	68	67	66	66	55	55
K (mg/L)	21	21	19	19	17	17
Ca (mg/L)	119	122	128	126	126	125
Mg (mg/L)	22	20.5	21	21.5	20.5	20.5
Fe (mg/L)	0.18	0.21	0.84	0.76	0.35	0.36
Mn (mg/L)	0.18	0.06	0.11	0.11	0.19	0.21
NH4-N (mg/L)	0.18	0.22	0.24	0.26	0.37	0.44
Cl (mg/L)	92	95	86	89	81	82
NO3-N (mg/L)	2.12	1.98	2.18	1.91	2.78	2.79
SO4 (mg/L)	161	182	126	118	147	146
PO4-P (mg/L)	0.46	0.53	0.32	0.31	0.23	0.24
TDS (mg/L)	690	610	710	640	620	680
TSS (mg/L)	57	80	165	206	233	228
Turbidity (FNU)	83	75	> 300	> 300	233	236
TOC (mg/L)	19	19	20	21	18	16
UV Abs/m at 254 nm	18	23	165	145	44	45
Added Kaoline (mg/L)	100		800		400	

Appendix B – Microbiological Water Quality Parameters

Date		Added E.coli theoretical per mL	Added kaoline mg/L	Turbidity FNU	UV 254 abs/m	Total Coliforms 37C, conf. cfu/mL	Total Coliforms 44C, conf. cfu/mL	Total E-Coli direct plating cfu/mL	Total Plate Count 22C, 3 days cfu/mL	Presumptive Test for coliform 37C cfu/mL	Presumptive Test for coliform 44C cfu/mL	Turbulator (spiral) inserted
19/10/04	Influent 1	0	0		9.8	10	1.5	1.8	12000	10	1.5	
	Effluent 2				9.2			< 0.01	280	< 0.01	< 0.01	no
22/10/04	Influent 3	0	0		9.2	2.9	0.21	0.06	7000	9.8	0.69	
	Effluent 4				11.2			< 0.01	1200	< 0.01	< 0.01	no
28/10/04	Influent 6	100	0	18	9.8	160	170	190	8400	160	170	
	Effluent 5			16	9.2	0.01		< 0.01	900	0.01	< 0.01	yes
04/11/04	Influent 7	1000	0	15	9.2	2100	1300	1400	8100	2100	1300	
	Effluent 8			27	11.2			< 0.01	650	0.13	< 0.01	yes
09/11/04	Influent 10	100	100	135	18	120	150	180	3500	120	150	
	Effluent 9			140	23	< 0.01		< 0.01	850	0.22	< 0.01	yes
11/11/04	Influent 11	100	200	153	26	160	160	190	7700	160	160	
	Effluent 12			145	27	0.01		< 0.01	750	0.03	< 0.01	yes
16/11/04	Influent 13	100	400	233	44	190	150	180	11000	190	150	
	Effluent 14			236	44	0.05	0.07	0.11	550	0.12	0.07	yes
18/11/04	Influent 15	100	800	> 300	165	100	120	260	8900	200	160	
	Effluent 16			> 300	145	< 0.01		0.01	630	0.09	< 0.01	yes
23/11/04	Influent 18	100	1600	> 300	195	140	220	140	2400	140	220	
	Effluent 17						0.12	< 0.01	420	< 0.01	0.12	yes
25/11/04	Influent 19	100	1600			200	160	180	3300	200	160	
	Efflluent 20					0.01	0.01	0.01	180	0.02	0.01	yes
30/11/04	Influent 22	1000	1600			1900	1200	1600	3700	1900	1200	
	Effluent 21					0.05	0.02	0.04	740	0.05	0.02	yes
02/12/04	Influent 23	100	400			210	200	190	14000	200	210	
	Effluent 24							0.01	500	< 0.01	< 0.01	yes
	Influent 25	100	400			160	240	230	12000	240	160	
	Effluent 26					0.01		< 0.01	1000	0.01	< 0.01	no