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DEPARTMENT OF ENVIRONMENTAL HEALTH

WATER FILTRATION THROUGH A RIVER BED

"This paper was prepared to fulfill part of the requirements for the M.A. degree in Environmental Health Sciences from the Faculty of Biosocial Sciences and the Graduate School of Public Health, Medical Sciences Campus, University of Puerto Rico."

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I certify that the research project contained in this thesis, entitled Water filtration through a river bed, which has been performed by Carmen Gisela Román Nieves complies with all the requirements of the Department of Environmental Health.

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DEDICATED TO
MY PARENTS AND BROTHERS

ABSTRACT

The present study was designed to test the viability of producing drinking water by installing a filter in a river bed. The intent was to determine the changes in the rate of flow through the filter; the rate of filter media permeability loss (head loss); as well as the quality of the water produced by the filter media. In order to measure the results of the filter installation the conditions of the river were simulated at another site. A filter, composed of a sack filled with sand and a drainage system, was constructed in a 55 gallon drum. Untreated water from the "río Piedras" (Stone river), was stored in three other 55 gallon drums and circulated through the container with the filter.

Untreated and filtered water quality was tested using the Standard Methods (1985) for turbidity, fecal and total coliform. The flow was measured using a 1,000 ml graduated cylinder and a chronometer. On the average the filter removed turbidity up to 96.38%, and 99.95% and 99.34% total and fecal coliforms were removed, respectively. The capacity of the filter media to remove turbidity and coliforms increased with time while the flow rate decreased.

The water produced should be of drinking quality after disinfection, or after slow-sand filtration. This is a simple system, requiring little maintenance, and can be useful to small communities.

I. INTRODUCTION

The amendments to the Safe Drinking Water Act of 1986 require filtration and disinfection for drinking water treated in public treatment systems whose source is surface water. These two types of treatment will ensure that Giardia cysts, viruses, and Legionella-type bacteria are eliminated or inactivated.

There are many treatment methods capable of removing the Giardia cysts, viruses, Legionella-type bacteria, and other pathogens that might be present in the water. The methods include the following: diatomaceous earth filtration; sand filtration; direct filtration, consisting of a pressure filter preceded by pretreatment with a chemical coagulant. Conventional treatment is another method that includes such processes as rapid mix, chemical coagulation, flocculation and sedimentation followed by filtration. Similar treatments can also be offered by small systems.

In addition to being very effective in producing drinking water, some of these methods require substantial financial resources for their design, construction, operation and maintenance. Such is the case with direct filtration, small systems, and conventional treatment. All require pretreatment, chemical products, major physical structures, and knowledgeable personnel to manage them, as well as constant maintenance. All these requirements entail expenditures and considerable investments, while filtration through diatomaceous earth and through sand do not require pretreatment, or constant maintenance, which reduces the cost. The annual cost to operate a small system of 0.10 mgd in the United States is $11,000, while that of slow sand filtration of 0.10 mgd is $7,100 (Logsdon, et al., 1990).

The high cost of some of these methods and the constant maintenance they require have created serious problems for the people served by small plants. Frequently these individuals do not have sufficient financial resources for treatment installation, lack experts who are knowledgeable about the development and management areas of specialized techniques, or do not have people capable of operating the systems (Leland and Damewood, 1990).

In Puerto Rico for example, it is estimated that between 80,000 to 100,000 people are not served by the Aqueduct and Sewer Authority. A major portion of this group is served by their own systems which for the most part, consist of structures to gather and store water and a distribution pipeline. Much of the time such systems are poorly-constructed, they receive little or no maintenance; water is gathered from uncovered basins, and the person in charge, if there is such an individual, does not have the knowledge to operate the system. In spite of the fact that this population suffers from chronic diarrhea and gastroenteritis, it is difficult for them to improve their treatment systems out of ignorance and for the aforementioned reasons (Folch, et al., 1989).

In order to find a solution to this problem, various treatment techniques have been studied involving small capital costs, ease of operation, and little maintenance that make it possible to use small systems (Logsdon, et al., 1990). The present study evaluated an inexpensive technique that requires little maintenance, and that can be used by those people that do not have access to treated water in their homes.

II. PURPOSE

The present study was designed to test the viability of producing drinking water by installing a filter in a river bed (Figure 1). The intent was to determine the changes in the rate of flow through the filter; the rate of filter media permeability loss (head loss); as well as the quality of the water produced by the filter media.

Figure 1. Longitudinal view of filter installed in a river bed.

III. LITERATURE REVIEW

Filtration is a physical process involving the removal of suspended solids passed through a layer of granular or porous media such as sand. As the material flows through the filter media the suspended solids are trapped between the porous spaces of the filter media Nathanson, 1986).

Applications in potable water filtration date from 1829 when a slow-sand filter was used for the first time to treat water for the Chelsea Water Company in England. By 1852 this method was already established, and the Metropolis Water Act required that water from the Thames River be filtered. During this time filters were considered mechanical instruments that removed suspended solids and turbidity. However, their effectiveness in the removal of pathogens was unknown (Huisman and Wood, 1974). It was not until 1892 that the effectiveness of sand filters was demonstrated conclusively in the removal of bacteria. In Hamburg, Germany, where water was untreated, there were 7,500 deaths from cholera while in Altona, a neighboring city, where the same water was filtered, there was a small number of deaths (Bellamy, et al., 1985).

From that time on, filtration has been a very important treatment for potable water production, and thus various types of filters have been developed. There are two basic types of filters: pressure filtration and gravity filtration.

Gravity filtration entails an open tank (usually concrete) with drainage at the bottom, filled with filter media, usually sand. The filtration process is achieved by allowing untreated water to flow downward, under the force of gravity, through the filter. The two basic types of gravity filters are known as "slow" and "rapid".

Slow-sand filters function as biological filters because they depend on biological growth at the head and on the passage through the filter media. This acts as the surface to retain the solids. These types of filters use fine sand with particles of approximately 0.15-0.30 mm effective size and a uniformity coefficient of less than 5. Effective size of granular media is that size below which 10% by weight of the media is "finer than". The uniformity coefficient shows the distribution of the granular media, and is the ratio of the 60% "finer than" size to the 10% "finer than" size (AWWA, 1975). To ensure adequate schmutzdecke (muddy material of organic origin that is found on the surface of the sand) the rate of filtration should be quite slow: from 0.1-0.2 $m^3/m^2/h$ (0.05-0.08 gpm/ft^2), (Visscher, 1990).

Slow-sand filters are very easy to maintain. They can operate for weeks and even months without having to be cleaned. The cleaning process entails removing the surface of the filter media at least once a month. It is recommended that all the sand be removed from the filter every two years or less (Visscher, 1990). Finally, this type of filter has two major disadvantages: it requires a large area (approximately 1,000, m^2 for a flow of $100m^3/h$) and turbidity of less than 10 ntu for water filtration. These conditions are required because the fine sand has small empty spaces which fill-up quickly (AWWA, 1984).

The rapid or mechanical filters have a filtration rate in the order of 40 times the filtration of a slow filter, from 5-15 m^3/m^2 /h (2-6 gpm/ft^2). The most effective size of the sand is from 0.4 to 0.6 mm, and accordingly the spaces between the particles of sand are larger, providing less resistance and greater flow rates in the rapid filters (AWWA, 1984). Consequently, impurities are forced to greater depths by means of the filter media. Cleaning is required more frequently (at least once a day). Cleaning consists of a reverse flow of clean water and compressed air to fluidize the filter media. Mechanical agitation is also used to mix the individual grains to remove any impurities (Huisman, 1974).

The rapid filters are often used in conjunction with other forms of treatment such as flocculation and sedimentation. Where rapid filtration is the only treatment, disinfection is not very effective due to the short period of contact time between the water and sand (Huisman, 1974).

Another gravity-type filter is known as the high rate filter. The high rate filter operates at 3 to 4 times the filtration rate of the rapid filters, from 7.3 to 19.5 m^3/m^2 /h (3-8 gpm/ft^2), (AWWA, 1984). This type of filter is characterized by the combination of filter media that is used, but it is otherwise the same as the rapid filters. There are two types of high rate filters, those that use sand and carbon (anthracite coal) which are known as a double-filter media, and those that use three or more filter media such as silica sand, anthracite coal and garnet sand, known as mixed-media filters.

In high rate filters, the coarser grains are at the surface and the finer grains are at the bottom, in contrast to rapid filters. Using fine particle size media with a high specific gravity and average particle size media with a lower specific gravity, can cause the coarser grains to remain at the surface and the finer ones to remain at the bottom. Typically sand would have approximately 2 mm-effective size at the surface to 0.2-mm at the bottom (Nathanson, 1986). This allows better samples and higher filtration rates because the rate loss (the difference in water level over the filter and water in the effluent pipe) will not be as fast as with rapid filters (AWWA, 1984).

There are two types of pressure filters: the sand and pressure filters, and the diatomaceous earth filters. The sand and pressure filter is similar to a basic rapid filter, except that the sand is in a metal tank and the filter operates by pressure. The filter media is sand or mixed-media. The great disadvantage of this method is that the filtering operation cannot be viewed. As a result the sand may crust or mud balls may form in the filter and go undetected for a long period of time (AWWA, 1984).

The filter medium of the diatomaceous earth filter are the skeletons of diatomaceous algae. The particle size ranges from 0.005-mm to 0.1-mm. This filter uses a coat of diatomaceous earth 0.32 centimeters thick, while in the sand filter, the bed is from 61 to 100 centimeters deep. The filtration rate of 2.4 m^3/m^2 /h (1 gpm/ft^2) decreases, which reduces the need for pretreatment. However, lower levels of turbidity (less than 5 ntu) are needed for water treatment (Hansen, 1988).

Cleaning can be with air or water pressure, or by reverse flow, once the maximum allowable filtration rate is reached--

25-30 lb/in^2 for pressure filters, and 15 inches of mercury for vacuum filters. The use of diatomaceous earth filters for the treatment of drinking water has been limited due to the difficulty of maintaining diatomite filter coating. In order to maintain the coating of diatomaceous earth, it is recommended that water flow be maintained through the filter or recirculated at a lower rate of no less than 0.24 m^3/m^2 /h (0.1 gpm) during interruptions (AWWA, 1984).

It is not sufficient to require a filtration process for every public water supply system, but also such system should have the capacity to comply with the standards established by the Environmental Protection Agency. For example, the drinking water systems that use conventional treatment methods should comply with the standard for turbidity of or less than 0.5 ntu in 95% of monthly samples. The standard for coliform bacteria is 0 colonies. In addition, drinking water systems should be capable of removing or inactivating 99.9% of the Giardia cysts and 99.99% of all enteric viruses (Letterman, 1987).

Of the aforementioned filters, the slow sand filter is the most frequently used for small aqueduct systems. It is used because of its great simplicity, efficiency and economy in comparison with the other filters that are more complex and costly (Visscher, 1990). Recent studies in the United States have demonstrated the efficiency of this filter for the removal of turbidity, coliform, Giardia cysts and viruses, as well as for innumerable organic and inorganic contaminants (Pyper, 1985; Bellamy, 1985; Hansen, 1988; Leland, 1990, Tanner, 1990, etc.).

In Colorado, a project was carried out using three slow sand filters, which operated with different hydraulic rates. The three filters were fed with the same influent, that is, the same quantity of Giardia cysts, coliforms, bacteria and particles. Findings showed that the filters removed almost 100% of the cysts, 99% of the coliforms, 96% of the bacteria, 98% of the particulates, and 39% of the turbidity. The low percentage of turbidity is explained by the presence of clay particles in the untreated water. It was observed that an increase in the hydraulic rate lowered the percentage removed. It was also found that the formation of schmuzdecke improved the removal of coliforms, but that its presence or absence did not influence the removal of Giardia cysts (Bellamy, et al., 1985).

In Vermont, another study was done to compare two simple methods of filtration for use in small systems: slow sand filtration and diatomaceous earth filtration. Both systems were very effective in the removal of bacteria, Giardia cysts and turbidity. For example: the levels of turbidity in the effluent were maintained below 1 ntu and 99% of bacteria and cysts were removed. In addition, in neither of the two systems was there an appreciable reduction of precursory trihalomethanes. It was concluded that the diatomaceous earth filter is a system which requires a great deal of attention during operation, in contrast to the slow filters that require little attention (Pyper, 1985).

In 1971, Bernard and Johnson evaluated the efficiency of the sand filter to remove Schistosome cercaria. A horizontal filter was used in that study. The water moved downward and laterally, while the cercaria moved upward and downward (a factor which facilitated their removal). The results showed that the smaller the grains of sand, the more the cercaria diminished in the effluent. An increase in the filtration rate brought a greater number of cercaria in the effluent when the size of the sand was greater than 0.35 mm.

In Idaho, the functions of slow sand filters were evaluated, both as to their ability to produce good quality water, and to determine the effects of design and operation. The results demonstrated that if the filters are designed and operated in accordance with established standards, they should provide a very effective treatment; otherwise, the opposite will occur (Tanner and Ongerth, 1990).

A number of small communities in Oregon are using slow sand filters. For example, one has been installed in the town of Westfir and it has been a very effective and appropriate drinking water system. The results demonstrate complete removal of fecal coliforms, and 95-100% removal of total coliforms. Turbidity removed during the pilot study averaged 50%. There was no rate loss in more than 6 months of filter operation, due to the high quality of the untreated water (Leland and Damewood, 1990).

New pretreatment techniques have been developed that may be useful for small communities for the treatment of their drinking water. A paper of the International Water and Sanitation Centre entitled Pretreatment Methods for Community Water Supply, describes various water supply techniques. One of these is filtration through a river bed. It is based upon the filtration of surface water through the permeable layers of the river bed itself. The physical, biological and chemical processes improve the quality of the water as it passes through the filter to the extraction system. It also describes various filtration systems through the river bed such as: a longitudinal drainage system, a lateral drainage system connected to a well, vertical filtration, and the pressure system. The latter is the type of system studied in the present project. In a study carried out in Colombia, this type of filter removed 85-95% of bacteria, and 98.3% of turbidity. It was found that during high flow periods, the filter functioned poorly due to the need for constant cleaning (sometimes three times per day). It was recommended that this type of filter be used for waters with moderate levels of turbidity (Smet, J.E.M., et al., 1989).

IV. MATERIALS AND METHODS

To facilitate the determination of results from using sand filters in a river, the river conditions were simulated outside the river itself. The simulation apparatus consisted of four 55 gallon drums , set up horizontally over a shelf of steel drums. The simulator was installed near the Piedras river at the Agriculture Experiemnt Station of the University of Puerto Rico, in Rio Piedras. Three of drums served to store the untreated water supplied from the Piedras river, while the other drum contained the filter (Fig. 2).

The sand filter was constructed in the laboratory of the Department of Environmental Health of the Graduate School of Public Health. The filter consisted of a sack of jute plant fiber cloth of approximately 88 cm in length, which was filled with river sand. Fine river sand was used as the filter media. Prior to the project, the sand size was analyzed using a screen in the laboratory of "Empresas Terrasa" (Table 1 and Fig. 3). As can be seen in Figure 3, 10% of the sand corresponds to an effective screen size of 0.23 mm, which is therefore the effective size of the sand. Another characteristic of the sand is the uniformity coefficient. Since 60% of the sample is finer than 0.89 mm and the effective size is 0.23mm, the uniformity coefficient is 0.89/0.23, or 3.87.

A constant rate porosity meter was constructed in the laboratory of the Department of Environmental Health of the Graduate School of Public Health, according to the method proposed by Cedergren, 1989, in order to determine the porosity of the sand. This was calculated by adapting the Darcy Law as follows: $K+(Q \times L)/(h \times A)$. Here Q represents the flow rate; L the height of the sand column; h = hydraulic gradation; and A = the area covered. The permeability of the sand was 29.42 cm/sec.

Two perforated polyvinyl chloride (PVC) pipes, 5.08 cm in diameter by 68.58 cm in length, were placed in the sand filter. These pipes were used as a drainage system. In order to prevent sand and other particles from entering these drainage pipes after perforation, they were covered with plastic screen cloth. The filter was placed within two plastic pipes, also perforated, having a capacity of 20 liters, to facilitate water flow and to provide rigidity to the filter (Fig. 4).

Figure 2. River bed sand filter simulator.

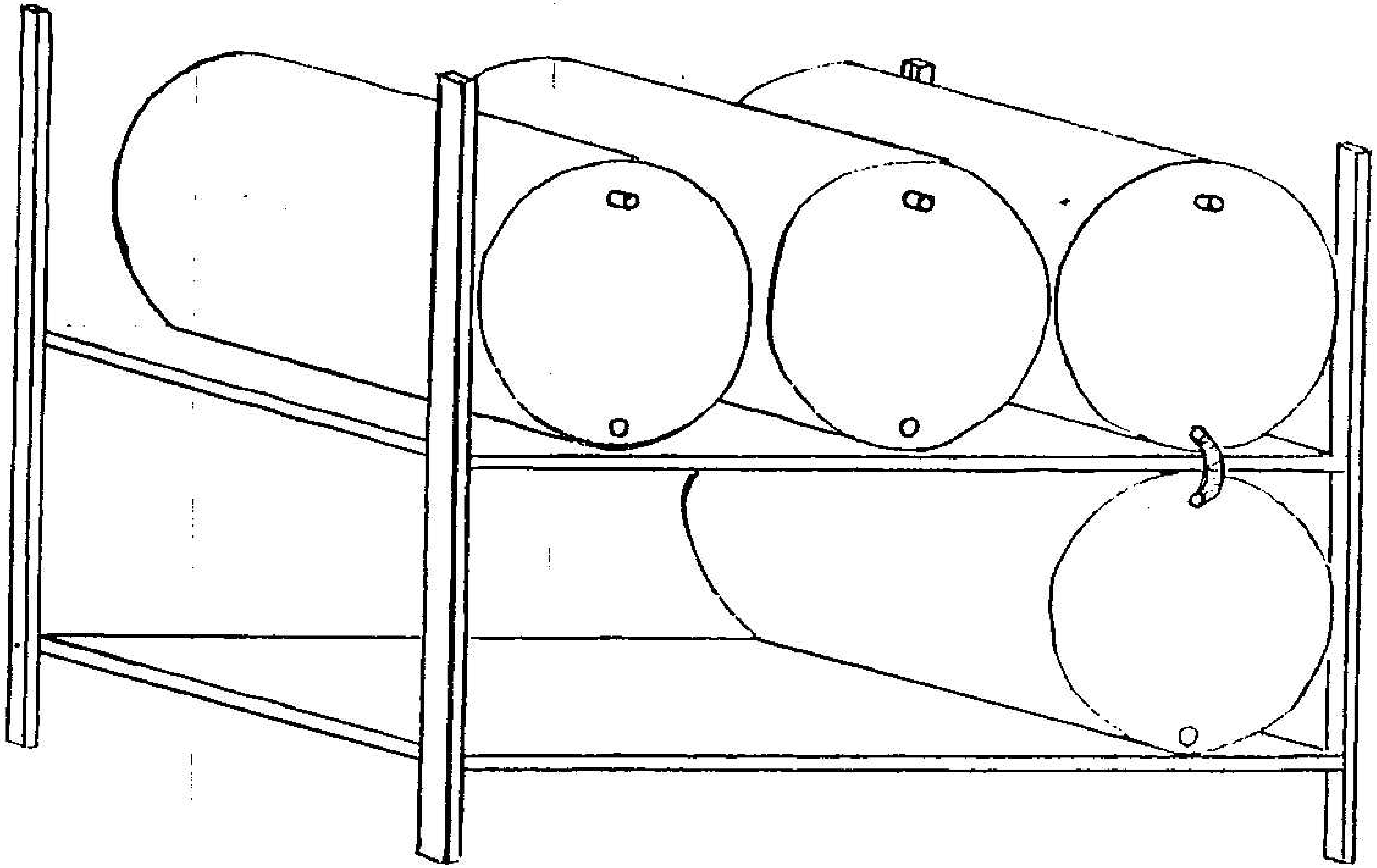

Figura 2. Simulador del filtro de arena sobre el lecho del rio.
Figure 2. River bed sand filter simulator.

Table 1. Sand Size Analysis

Sieve #	Sieve size mm	Weight gm	%Unit Retained	% Cumul. Retained	% Passing	Manufactured Sand Specs.	Natural Sand Specs.
3/8"		0	0	0	100	100	100
no. 4	4.75	7	1.5	1.5	98	95-100	95-100
no. 8	2.36	48.8	10.8	12.3	88	80-100	80-100
no. 16	1.18	75.9	16.8	29.1	71	50-85	50-85
no. 30	0.6	121.5	26.9	56	44	25-60	25-60
no. 50	0.3	125.8	27.8	83.8	16	10-30	10-30
no. 100	0.15	60.7	13.4	97.2	3	2-10	2-10
no. 200	0.075	0	0	97.2	3	0-7	0-5
pan		12.6	2.8	100	0		

Figure 3. Percentage of sand that passed through a particular sieve

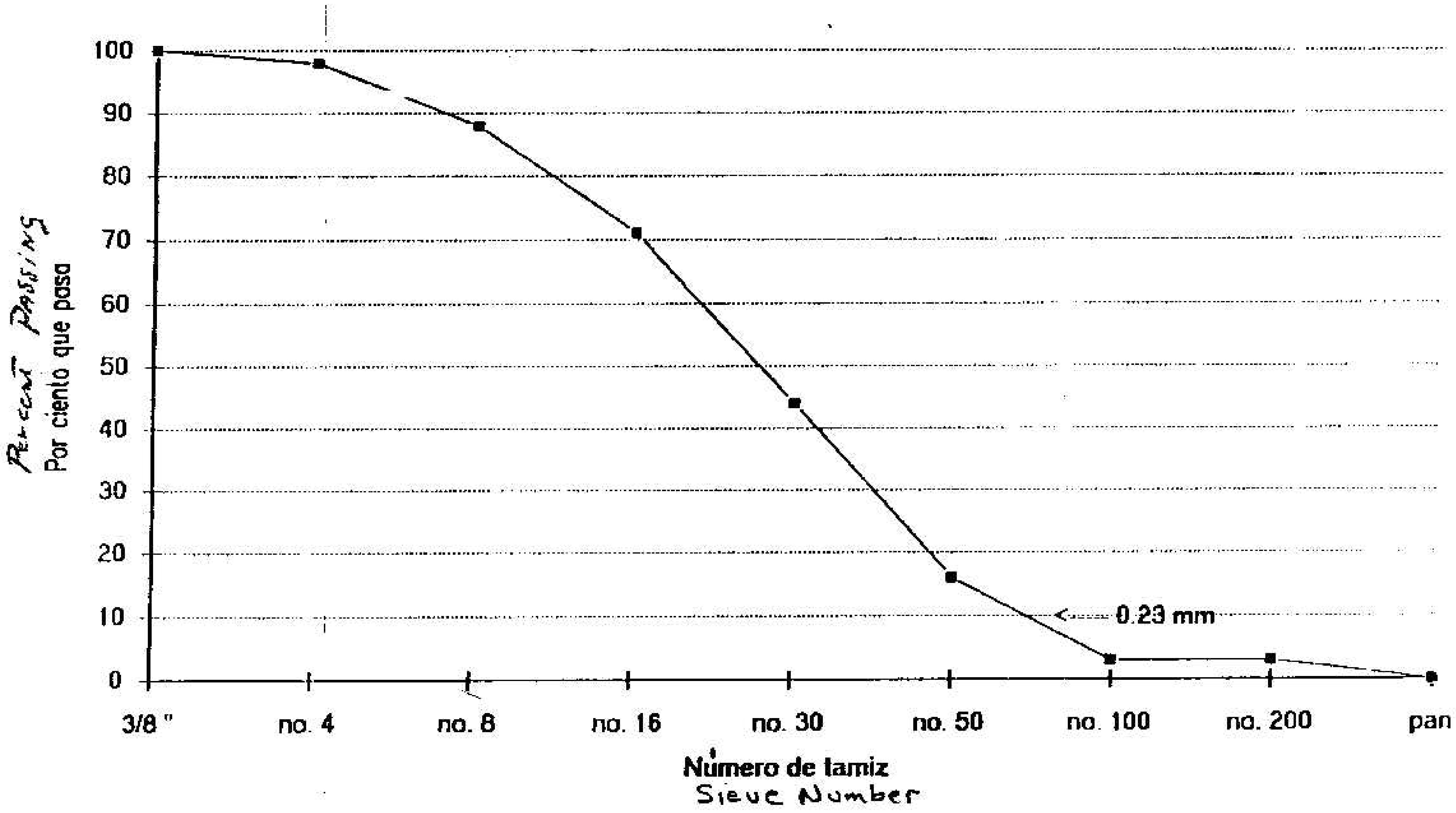

Figura 3. Por ciento de arena que pasaba por un tamiz particular.
Figure 3. Percent of SAND passing through a particular sieve.

The filter tests were made after pumping water from the Piedras river, which was stored in the storage drums. Since one drum per day was filtered, it would take between one and two days to filter the two remaining drums in order to allow sedimentation to occur. A total of 30 samples were taken during the months of December to April, 1990-1991. During this process the flow was measured using a graduated cylinder (1,000 mm) and a chronometer, allowing a determination of the rate of flow over time.

In addition, the quality of the untreated and the filtered water was analized for turbidity and fecal and total coliforms. Spontaneous samples were taken for both factors during the filtration process. The turbidity was measured on site according to method 214.A of Standard Methods, 1985; using a portable nephelometer. Fecal and total coliforms were analyzed in the laboratory of the Department of Environmental Health of the Graduate School of Public Health. Once the samples of untreated and filtered water were obtained, they were preserved in a refrigerator at 2-4° C, in the laboratory of the Aqueduct and Sewer Authority at the Experiment Station. The samples remained there until that days filtration process ended, usually for three hours. Subsequently they were taken to the Department of Environmental Health in a portable cooler filled with ice in order to preserve them. Once at the laboratory, the samples were immediately cultured. For the analysis of total and fecal coliforms, the membrane filtration method was used as set forth in sections 909. A and 909.C of Standard Methods, 1985.

A descriptive analysis described the results, which included a statistical analysis (average, mean). Measurements were also taken of the filtration capacity, the changes in flow, and the quality of the water produced by the filter, according to the number of samples taken and elapsed time. Microsoft Excel 2.1 software was used for the descriptive analysis.

Figure 4. Sand filter.

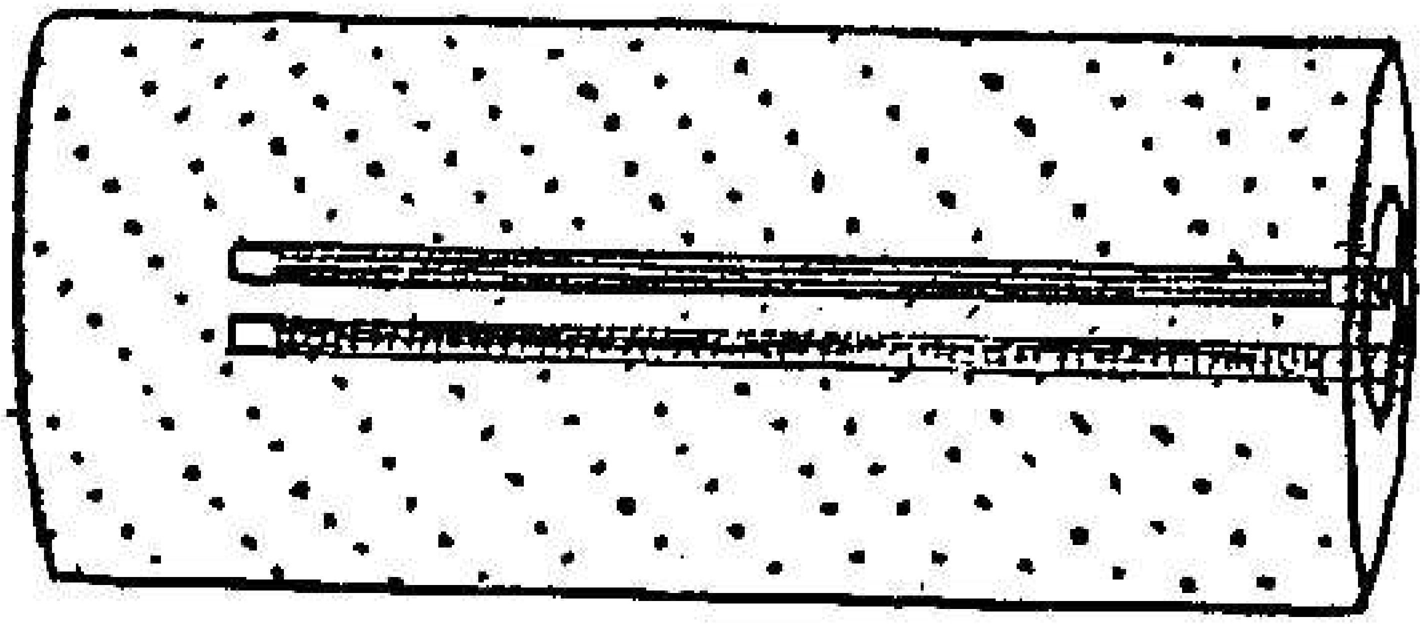

Figura 4. Filtro de arena.
Figure 4. Sand filter.

V. FINDINGS AND DISCUSSION

Tables 2 and 3 show the results obtained between December 11, 1990 and April 10 1991, including the following: total filtration time, the average flow, the turbidity values for the untreated and filtered water, and the number of total and fecal coliforms found in the untreated and filtered water per 100 ml. The decrease of these constituents is given as a percent.

The results of 30 samples taken during a period of 120 days are discussed in the following sections. The average flow through the filter tended to decrease with time, and thus during the 30 samples taken. For example, during the month of December, when the first four samples were taken, the average flow was 1.2 liters per minute. As of the April 1, after 11 days had elapsed since the first sample, or after 25 samples, the average flow was 0.40 liters per minute (see Table 2 and Figure 5). Theoretically, the reason that the flow lessens with the passage of time, while filtration continues, is because the particles carried in the water are deposited by means of the filter media. In this way, the spaces between the grains of sand are filled with these particles, which causes an increase in resistance to the flow. This causes the filtration time to increase with each sample. For example, at the beginning of the period during which samples were taken (December 11), the filter filtered approximately 55 gallons of water in 45 minutes, and 47.59 liters per second. While at the end of the sampling period, when a substantial amount of particles had accumulated in the filter, the filtration time (as of April 10) was 165 minutes, and 156.42 liters per second.

The turbidity of the untreated water varied according to the characteristics of the weather. Under normal conditions (periods without rain or when the river had not risen), the turbidity of the untreated water was below 13 ntu. Nevertheless, during rain and peak periods, such as occurred between February 12-21, values were greater than 13 ntu. On February 19 the water reached a turbidity of 160 ntu. The mean and average for the turbidity of the untreated water was 8 and 28.34 ntu, respectively. The average turbidity of the filtered water under normal conditions was less than 2 ntu; while during rain and peak periods, there was a maximum value of 32.92 ntu. The mean and average were 1.63 and 4.73, respectively (Table 2).

Table 2. Summary of Flow and Turbidity Data.

Sample Date: Month-day, 1990-91	Total filtration time (minutes)	Average Flow during samples (l/min.)	Turbidity untreated water (ntu)	Average turbidity filtered water (ntu)	turbidity decrease (%)	# filtered drums (55 gal.)
Dec. 11	45	1.266	10	2.52	74.80%	1
Dec. 13	50	1.196	1.8	0.97	46.11%	2
Dec. 18	100	1.171	18.9	4.33	77.09%	3
Dec. 19	43	1.005	6.22	1.85	70.26%	4
Dec. 20	79	1.057	4.43	1.36	69.30%	5
Jan. 15	122	0.85	27.5	4.76	82.69%	6
Jan. 16	65	0.773	11.04	3.23	70.74%	7
Jan. 17	82	0.836	4.92	1.31	73.37%	8
Jan. 22	135	0.803	8.93	1.69	81.08%	9
Jan. 24	85	0.874	2.36	0.82	65.25%	10
Jan. 25	120	0.888	2.53	0.67	73.52%	11
Jan. 29	120	0.865	28.4	2.72	90.42%	12
Jan. 30	135	0.748	7	1.25	82.14%	13
Jan. 31	160	0.694	3.48	0.69	80.17%	14
Feb. 5	150	0.599	13.9	1.56	88.78%	15
Feb. 6	145	0.800	6.13	1.22	80.10%	16
Feb. 7	150	0.803	4.53	0.67	85.21%	17
Feb. 12	135	0.769	79.9	7.76	90.29%	18
Feb. 13	130	0.764	34.4	4.81	86.02%	19
Feb. 19	135	0.741	160	32.92	79.43%	20
Feb. 20	135	0.742	158.8	30.91	80.54%	21
Feb. 21	135	0.688	82.3	18.77	77.19%	22
Feb. 27	110	0.557	7.1	1.48	79.15%	23
Feb. 28	115	0.547	5	1.02	79.60%	24
April 1	105	0.401	63.6	2.30	96.38%	25
April 2	126	0.366	11.41	2.41	78.88%	26
April 3	110	0.395	8.8	1.49	83.07%	27
April 8	90	0.367	50.7	2.61	94.85%	28
April 9	125	0.358	13.4	2.62	80.45%	29
April 10	165	0.384	12.7	1.28	89.92%	30
Mean	120	0.767	8	1.63	79.47%	
Average	113.40	0.84	28.34	4.73	79.58%	

Figure 5. Flow through the filter.

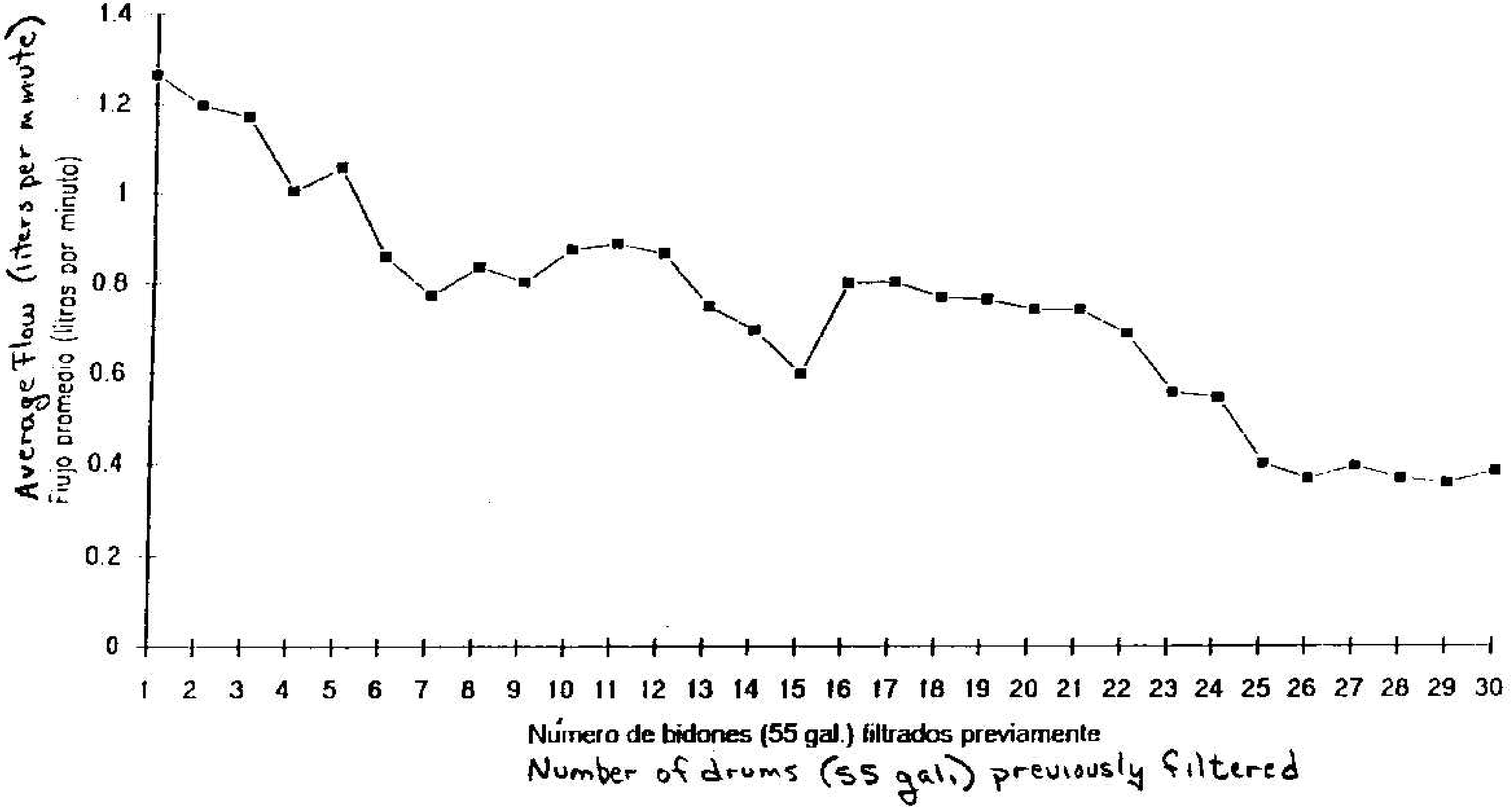

Figura 5. Flujo a través del filtro.
Figure 5 Flow through the filter

Figure 6 shows the pronounced peaks in the curve that represents the turbidity of the untreated water, this demonstrates the rain and peak periods. There was a direct correlation of the turbidity of the unfiltered water to the filtered water. For example: on December 18 (sample # 3), the turbidity of the untreated water increased, and accordingly, the turbidity of the filtered water also increased but to a lesser extent; and on December 19 (sample # 4), the turbidity decreased in both the untreated water and the filtered water. This phenomenon and the percent decrease of turbidity, indicate that the filter was operating well hydraulically. It was expected that the sand would remove the turbidity according to the quality of the untreated water entering the filter and depending upon the number of samples taken (the more samples, the greater the removal).

Turbidity removal by the filter was 96%, 79.47% mean, and 79.58% average. In the periods of rain and peak (February 12 to 21), removal by the filter was up to 90%. The removal of turbidity increased with according to the elapsed time during the sampling period (Figure 7), because as the samples progress, an increasingly quantity of particulates are trapped and deposited in the sand, which contributes to the filtration process.

In terms of bacterial indicators the results were as follows. The quantity of total coliforms in the untreated water varied between 300 to 800,000 org/100 ml, with an average of 70,963 org/100 ml. In the filtered water, the amount was from 10 to 270,00 org/100 ml, with an average of 16,032 org/100 ml. The mean values for the untreated and filtered water were 20,000 and 3,500 org/100 ml, respectively (Table 3).

Figure 8 shows the amount of total coliforms found in the untreated and filtered water during the sample period. In samples #15, 16, 17, 20 and 23 (taken on February 5, 6, 7, 19, and 27), more organisms (total coliforms) were found in the filtered water than in the untreated water. A possible cause may have been the presence of other microorganisms such as Streptococcus, species of Pseudomonas, etc. in the untreated water that inhibited the growth of total coliforms (see section on recommendations); or possibly, the same particles served as a protection for the organisms. In addition, some bacterial growth may have occurred within the filter; as a result, less total coliforms than really existed would be reflected

Figure 6. Turbidity of untreated and filtered water.

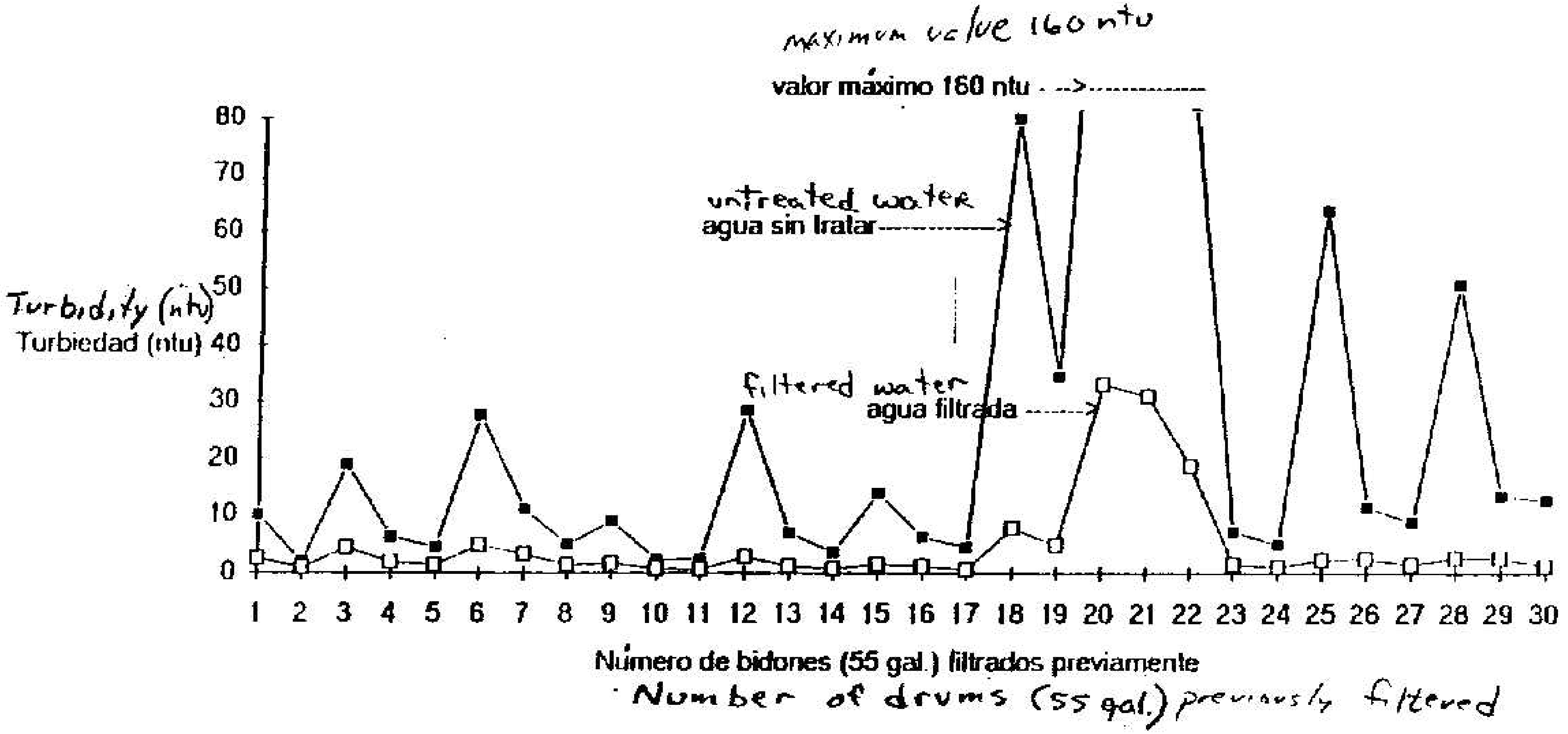

Figura 6. Turbiedad del agua sin tratar y filtrada

Figure 6 Turbidity of the untreated and
filtered water

Figure 7. Percent turbidity decrease.

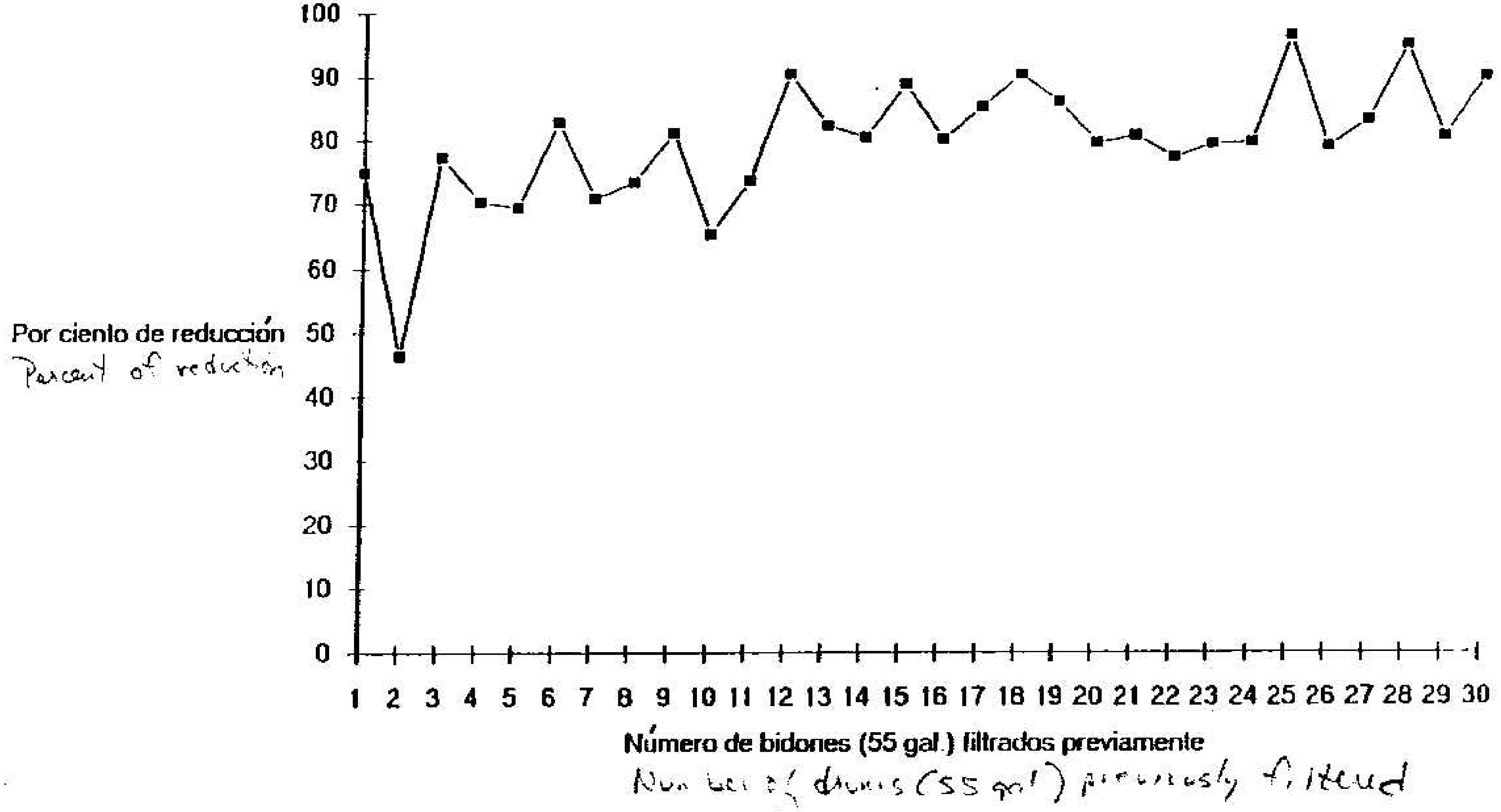

Figura 7. Por ciento de reducción de turbiedad

Figure 7 Percentage turbidity reduction

Table 3. Summary of Bacterial Data Indicators.

Sample Date: Month-day, 1990-91	Total coliform in untreated water (org/100 ml)	Total coliform in filtered water (org/100 ml)	% decrease in total coliform	Fecal coliform in untreated water	Fecal coliform in filtered water	% decrease in Fecal coliform	# filtered drums (55 gal.)
Dec. 11	8000	8000	0.00%	600	162.5	72.92%	1
Dec. 13	34000	3000	91.18%	13000	1000	92.31%	2
Dec. 18	50000	39000	22.00%				3
Dec. 19	31000	3000	90.32%	3300	300	90.91%	4
Dec. 20	7700	1100	85.71%	2100	300	85.71%	5
Jan. 15	57000	8000	85.96%	6300	3700	41.27%	6
Jan. 16	73000	5200	92.88%	4100	1950	52.44%	7
Jan. 17	13000	1100	91.54%	3300	500	84.85%	8
Jan. 22	73000	3600	95.07%	6000	3500	41.67%	9
Jan. 24	4500	700	84.44%	800	80	90.00%	10
Jan. 25	3100	240	92.26%	640	80	87.50%	11
Jan. 29	20000	10	99.95%	6000	600	90.00%	12
Jan. 30	3300	100	96.97%	14300	2600	81.82%	13
Jan. 31	60000	1000	98.33%	21000	367	98.25%	14
Feb. 5	2000	6500	-225.00%	49000	4000	91.84	15
Feb. 6	5000	6300	-26.00%	37000	1440	96.11%	16
Feb. 7	300	500	-66.67%	44000	380	99.14%	17
Feb. 12	30000	5200	82.67%	60000	5200	91.33%	18
Feb. 13	74000	3500	95.27%	97000	2100	97.84%	19
Feb. 19	2000	8000	-300.00%	730000	6000	99.18%	20
Feb. 20	800000	270000	66.25%	530000	50000	90.57%	21
Feb. 21	460000	70000	84.78%	320000	2100	99.34%	22
Feb. 27	8000	8700	-8.75%	20950	760	96.37%	23
Feb. 28	5000	1000	80.00%	3200	80	97.50%	24
April 1	43000	4800	88.84%	3100	700	77.42%	25
April 2	43000	2900	93.26%	10000	2900	71.00%	26
April 3	14000	1800	87.14%	3300	1100	66.67%	27
April 8	80000	8400	89.50%	6000	3600	40.00%	28
April 9	80000	8400	89.50%	33000	1800	94.55%	29
April 10	45000	900	98%	12000	200	98.33%	30
Mean	20000	3500	85.71%	13000	1000	90.91%	
Average	70963	16032	48.51%	70344	3362	83.34%	

in the samples. In the other samples there was a direct relationship between the amount of total coliforms in the untreated and filtered water.

The decrease in the concentration of total coliforms varied from 0% to 99.95%, exécept for the aforementioned samples where the value was negative. The mean was 85.71% and the average was 48.51%. The percent decrease rose with as time elapsed, remaining at about 90% (except for samples 15, 16, 17, 20 and 23), as shown in Figure 9. This phenomenon may be explained as follows: as the sample period progressed and time elapsed, particles and organic materials were deposited through the filter until a cap of slimy material called schumutzdecke formed on the surface of the sand within two weeks. This cap, by means of the action of other bacteria, helps to trap, digest and break-up the organic material present in the untreated water. Thus, the process of bacteria removal is more efficient. In the January 30 and February 5 to 27 samples, more fecal than total coliforms were found in the untreated water (see Table 3). This should not occur since fecal coliforms are part of the group of total coliforms and therefore, the values for total coliforms should have been higher. Again there is the possibility that there were other microorganisms in the untreated water that were inhibiting the growth of total coliforms. In addition, it is possible that the samples were not always characteristic, and due to the dilution factor, any difference would be multiplied numerous times.

In terms of fecal coliforms, from 600 to 730,000 org/100 ml were found in the untreated water, with an average 70,344 org/100 ml. In the filtered water, 80 to 50,000 org/100 ml were found, with an average 3,362 org/100 ml. The mean values for the untreated and filtered water were 13,000 and 1,000 org/100 ml respectively (Table 3). There is a direct proportional correlation between the coliforms found in the untreated water and those in the filtered water (Figure 10).

The decrease in the concentration of fecal coliforms ranged between 40 and 99.34 percent. The average and the mean were 83.34% and 90.91%, respectively. Initially (samples 1-10), the removal of coliforms varied (Figure 11). This is perhaps because not enough time had elapsed to allow the aforementioned slimy material to form. Later, as the sampling progressed, the remained at approximatley 90%, execpt for samples 25 - 28. During this period

Figure 8. Total coliforms in the untreated and treated water.

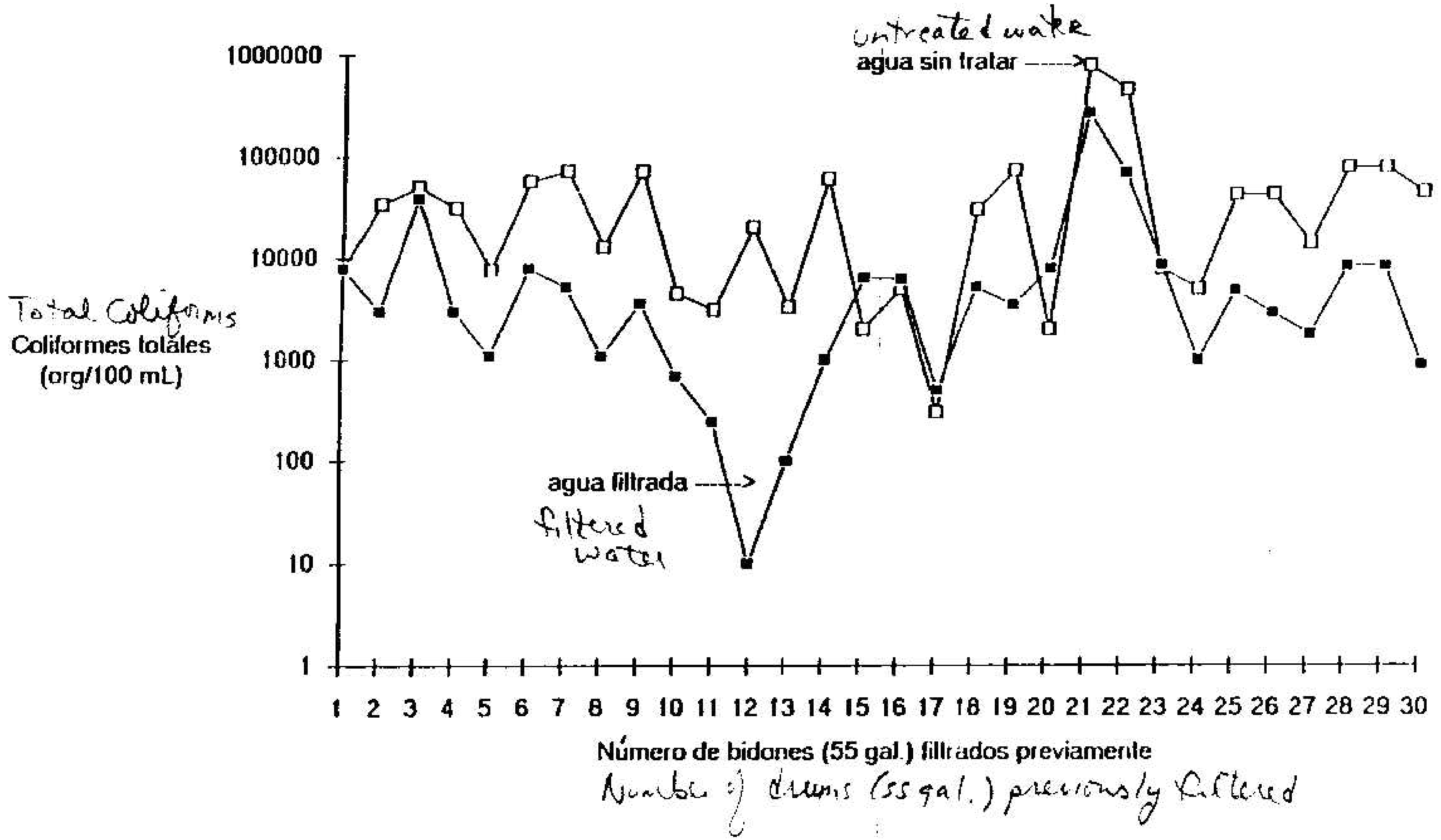

Figura 8. Coliformes totales en agua sin tratar y filtrada

Figure 8 Total Coliforms in the untreated and filtered water

Figure 9. Percent decrease in total coliforms.

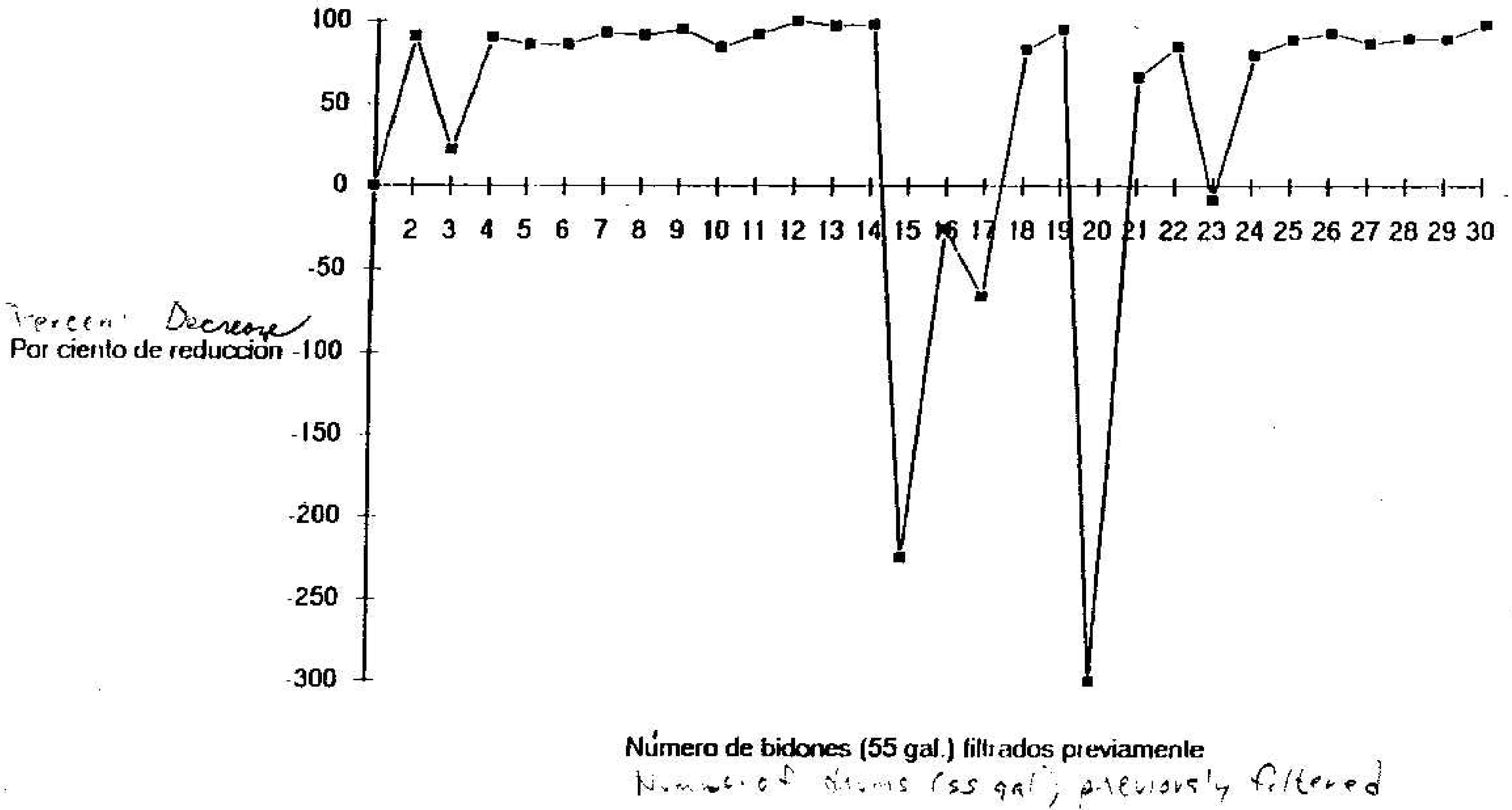

Figura 9. Por ciento de reducción de coliformes totales

Figure 9. Percent decrease in Total Coliforms.

Figure 10. Fecal coliforms in untreated and filtered water.

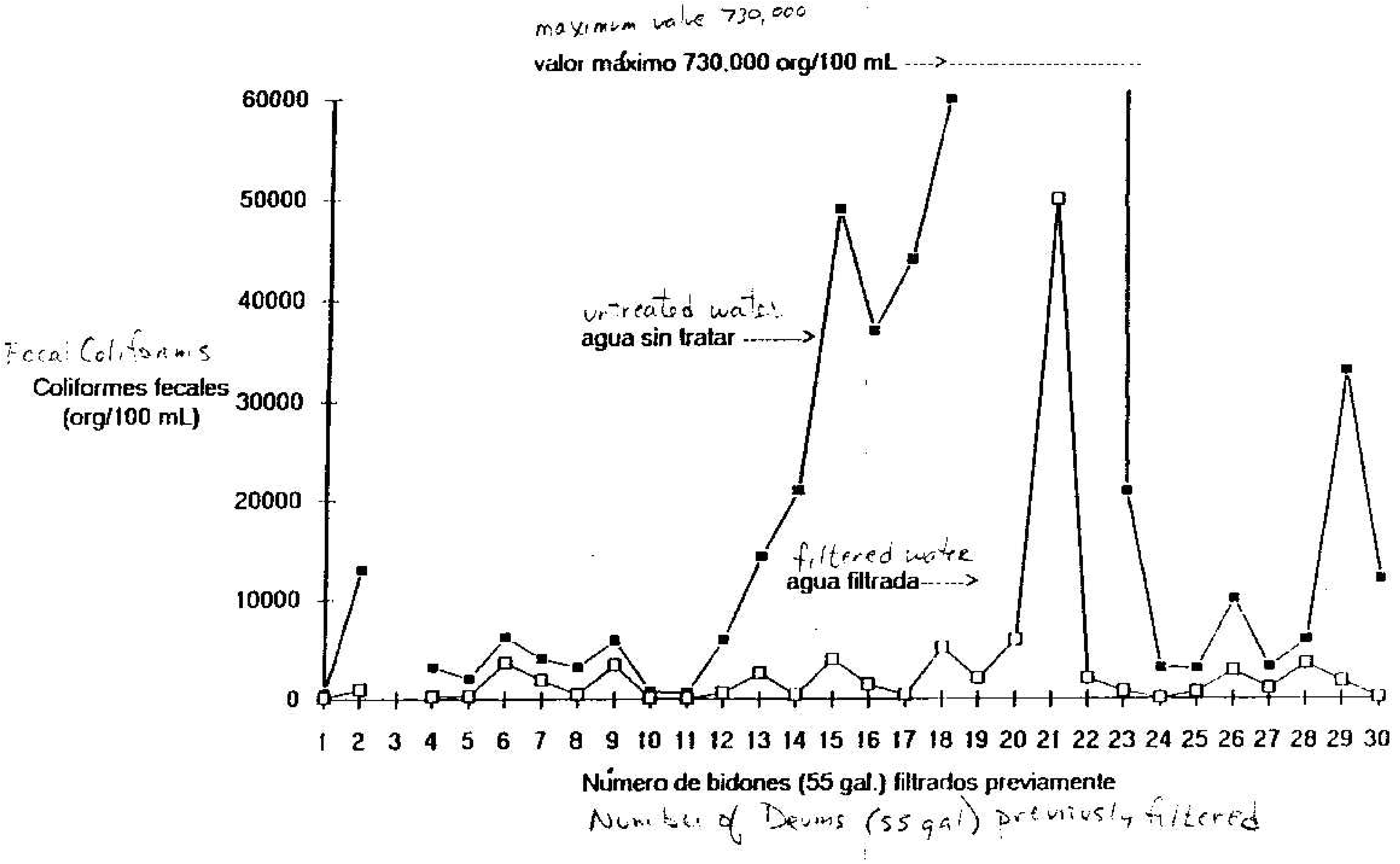

Figura 10. Coliformes fecales en agua sin tratar y filtrada.
Figure 10 Fecal Coliforms in untreated and
Filtered Water

the percent decrease was less. A possible cause is the presence of other microorganisms (e.g. coliphage) in the filter media (see recommendations section).

Another factor that might explain this is that the filter was not functioning for one month. When operating again, the most appropriate conditions for fecal coliform removal were not present, although this was not the case for total coliforms (see recommendations section and Figure 9).

If there was something physically wrong with the filter, the percent of residual turbidity would also have been affected (physical process), which did not occur. It is precisely on April 1 (sample 25) that turbidity decreased 96.38%, and subsequently continued to decrease at about 90% (Figure 7). This also occurred with the flow pattern, which continued to diminish during that period (Figure 5). Generally, the level that fecal coliforms were reduced increased as time elapsed, except for the aforementioned samples that were taken.

VI. CONCLUSIONS AND RECOMMENDATIONS

The filter was very efficient in removing turbidity and coliforms. The capacity of the filter media (fine sand) to trap particles and coliforms increased with as time elapsed, while the flow decreased. The filter did not produce drinking water that complied with the standards for drinking water quality established by EPA, although it removed up to 96.38% of turbidity and up to 99.95% and 99.34% of total and fecal coliforms, respectively (the specified standard for coliforms is 0 organisms and for turbidity is 1 turbidity unit). This is due mainly to the poor quality of the Piedras river water. The river exceeds the surface water standards established by the Environmental Quality Board, which are 10,000 org/100 ml and 2,000 org/100 ml for total and fecal coliforms, respectively. n addition, the tests were made without disinfecting, which would have eliminated or reduced the microbiological contaminants that passed through the filter. This would not be the case if a filter were installed to serve a community.

Very little maintenance was required for the filter. Even with 30 samples taken during 120 days, the sand had not blocked to the extent that it needed cleaning. The filter continued to remove coliforms and turbidity efficiently.

It is expected that this filter would function more efficiently if it were installed in a river bed, because it would be of a higher volume than that used in this project. Also, a larger cap of filtering material would form that would result in greater retention of particles and coliforms, as the water passed through the filter media. In addition, there would be the advantage that the river itself would transport particles that would be deposited over the filter, which would assist in the filtration process. Furthermore, the river would remove sediments during periods of rainfall, thereby helping to clean the filter. The quality of the filtered water would be fit for human consumption if a low cost disinfection process were added, whether through the use of chlorine tablets or a heating system, such as a solar heater, that would at least reduce the microbiological contaminants that managed to pass through the filter.

In addition to improving the water used by small communities that lack a water treatment plant, the filter could also be used to provide pretreatment for other systems, such as slow filters or solar water heaters. This pretreatment would extend the function of the other treatment systems by reducing the turbidity and the concentration of coliforms in the untreated water, as well as reducing the operation and disinfection costs.

The following are recommended for future research:

- Design a filter in such a way that samples can be taken at different depths in the filter media. Thus the flora that develops during operation may be examined to determine if there are some microorganisms that are inhibiting or reducing the growth of other microorganisms (such as might have occurred with the total coliforms); and to determine bacteria growth that interfere with the quality of the filtered water. See the study conducted by Lloyd, (1973) The Construction of a Sand Profile Sampler.

- Evaluate the efficiency of the filter in removing *Giardia lamblia* cysts.

- Conduct a study to analyze various filter media; for example, combinations of sand and stone or other types of material such as coconut shells or other materials. See paper by Richard Frankel, (1974) Series Filtration using Filter Media.

- Evaluate the filter in a river bed to see if it complies with the quality standards for surface waters or whether a disinfection process should be added.

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