"EVALUATION OF THE REMOVAL OF GIARDIA lamblia BY SLOW SAND FILTERS UNDER TROPICAL CONDITIONS AND ITS RELATION TO OTHER FECAL CONTAMINATION INDICATOR ORGANISMS"

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Abstract

In Puerto Rico, there are approximately 294 rural communities which are not served by the Puerto Rico Aqueduct and Sewer Authority (PRASA). These communities have their own water supply and distribution systems and do not provide any treatment to the water, except chlorination at the most.

Giardia lamblia is a parasitic protozoan that is present in surface waters contaminated with fecal matter. This enteric protozoan causes a chronic diarrheal illness. Some surface waters in Puerto Rico have shown to be contaminated with Giardia cysts, the form in which this microorganism is found in the environment. This fact and the state of fecal contamination of surface waters in Puerto Rico poses a serious health threat to the rural communities which are not served by PRASA.

The principal aims of this investigation were to evaluate the capability of a compact, prefabricated, pressure driven slow sand filter to produce potable or near potable water and to evaluate its capacity to remove Giardia cysts under tropical conditions. It was intended, in this way, to evaluate the applicability of this technology to the rural communities not served by PRASA.

Eight filtration runs were carried out using surface waters from two rivers in the western area of Puerto Rico, which were known to be contaminated with Giardia, as the influent of the filter . However, Giardia cyst concentrations in these rivers were low, being 8 cysts/100l the maximum. For this reason, cysts were injected to the influent of the filter simulating higher concentrations actually found in surface waters of Puerto Rico.

For the eight filtration runs studied, four filtration rates were used: 0.02, 0.04, 0.06 and 0.08 gpm/ft^2. Four runs were carried out using these filtration rates and a piece of unwoven geotextile on top of the sand bed in the filter. The other four were carried out using those filtration rates without the geotextile. The following parameters were measured at the influent and the effluent of the filter: Giardia cysts, fecal and total coliforms, temperature, pH, alkalinity, electrical conductivity, turbidity, suspended solids and chemical oxygen demand. Dissolved oxygen was measured on the last four runs (on which the geotextiles were used).

Throughout the eight filtration runs, Giardia cysts were completely removed. The filter was effective providing near potable water in terms of the water quality standards of the United States Environmental Protection Agency (EPA), provided that influent turbidity was less than 23 NTU without using the geotextiles and 37 NTU using them. This demonstrates the additional removal capacity of the geotextiles.

The quality of the effluent did not seem to deteriorate as the filtration rate was increased; rather, it seemed to deteriorate as influent turbidity increased. Fecal coliforms were removed to a level that could be eliminated with the additional step of disinfection.

Biochemical Oxygen Demand tests performed on the influent, effluent and on the biological growth that occurs on top of the sand bed, suggested that there was toxicity present in the water sometimes. Part of this toxicity was apparently removed, while part of it was escaping in the effluent. This implies a serious health threat when these waters are used as a source for water supply systems, and it should be studied further.

Resumen

En Puerto Rico hay aproximadamente 294 comunidades rurales que no son servidas por la Autoridad de Acueductos y Alcantarillados de Puerto Rico (AAA). Estas comunidades tienen sus propios sistemas de suministro y distribución de agua y no proveen ningún tratamiento al agua, excepto cloración a lo sumo.

Giardia lamblia es un protozoario parásito que está presente en aguas superficiales contaminadas con materia fecal. Este protozoario entérico causa diarreas crónicas. Algunas aguas superficiales en Puerto Rico han demostrado estar contaminadas con quistes de Giardia, la forma en la cual este microorganismo se encuentra en el medio ambiente. Este hecho y el estado de contaminación fecal de las aguas superficiales en Puerto Rico plantean una seria amenaza a la salud a las comunidades rurales que no son servidas por la AAA.

Los propósitos principales de esta investigación fueron evaluar la capacidad de un filtro lento de arena compacto, prefabricado e impulsado por presión para producir agua potable o casi potable y evaluar su capacidad para remover quistes de Giardia bajo condiciones tropicales. Se intentaba, de esta manera, evaluar la aplicabilidad de esta tecnología a las comunidades rurales que no son servidas por la AAA.

Ocho corridas de filtración se llevaron a cabo usando aguas superficiales de dos ríos en el área oeste de Puerto Rico, que se conocía que estaban contaminados con Giardia, como el afluente del filtro. Sin embargo, las concentraciones de quistes de Giardia en estos ríos eran bajas, siendo 8 quistes/100l la máxima. Por esta razón, se inyectaron quistes al afluente del filtro simulando concentraciones más altas actualmente encontradas en aguas superficiales de Puerto Rico.

Para las ocho corridas de filtración estudiadas, cuatro razones de filtración se usaron: 0.02, 0.04, 0.06 y 0.08 gpm/ft^2. Cuatro corridas se llevaron a cabo usando estas razones de filtración y un pedazo de geotextil no tejido en el tope del lecho de arena en el filtro. Las otras cuatro se llevaron a cabo usando esas razones de filtración sin el geotextil. Los siguientes parámetros se midieron en el afluente y el efluente del filtro: quistes de Giardia, coliformes totales y fecales, temperatura, pH, alcalinidad, conductividad eléctrica, turbidez, sólidos suspendidos y demanda química de oxígeno. El oxígeno disuelto se midió en las últimas cuatro corridas (en las cuales se usaron los geotextiles).

A lo largo de las ocho corridas de filtración, los quistes de Giardia se removieron completamente. El filtro fue efectivo en proveer agua casi potable en términos de los

estándares de calidad de agua de la Agencia de Protección Ambiental de los Estados Unidos (conocida como EPA por sus siglas en inglés), siempre que la turbidez del afluente fuera menor que 23 NTU sin usar los geotextiles y 37 NTU usándolos. Esto demuestra la capacidad adicional de remoción de los geotextiles.

La calidad del efluente no pareció deteriorar a medida que se aumentaba la razón de filtración; más bien pareció deteriorar a medida que aumentaba la turbidez del afluente. Los coliformes fecales se removieron a un nivel que podría ser eliminado con el paso adicional de desinfección.

Las pruebas de demanda bioquímica de oxígeno realizadas en el afluente, efluente y en el crecimiento biológico que ocurre en el tope del lecho de arena, sugirieron que había toxicidad presente en el agua a veces. Parte de esta toxicidad fue removida aparentemente, mientras que parte de la misma estaba escapando en el efluente. Esto implica una seria amenaza a la salud cuando estas aguas son usadas como fuente para sistemas de suministro de agua, y debería ser estudiado más allá.

Dedication

This work is dedicated to the People of Puerto Rico who, for many years have been suffering from chronic problems of water pollution in their raw water sources and even in their potable water supplies in spite of the modern technology used by the Puerto Rico Acqueduct and Sewer Authority for producing potable water. This work is also dedicated in particular to the Rural Communities of Puerto Rico that have water supply systems with little or no treatment whatsoever. We know this work provides an alternative for an adequate treatment system for producing potable water from virtually any water source, and it is for the people of Puerto Rico, their welfare and their public health that the fruits of this work is intended.

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1. Introduction

1.1. The Problem of Surface Water Contamination in Puerto Rico

Inadequate water supply and poor sanitation account for approximately 30,000 deaths daily in the world (Pescod, et al., 1985), many of them infants, and several hundreds of millions of people are suffering from water-related illnesses at any one time (Pescod, et al., 1985). It has been estimated that up to five million people die each year from waterborne diseases worldwide (Evans, 1986). Many of these deaths may be as a result of drinking biologically contaminated water.

The Puerto Rico Department of Health (PRDOH), in their monthly "Informe Epidemiológico" (Epidemiological Report), indicates that the number of gastroenteritis and hepatitis A cases is increasing. Cases of campylobacteriosis and giardiasis, possible waterborne diseases, have also been reported on the island. It is believed that Giardia could contribute as much as 40% of all cases of gastroenteritis in Puerto Rico (Román-Seda and Toranzos, 1988).

The number of gastroenteritis and hepatitis A cases in Puerto Rico seems to be caused by deteriorating water quality on the island. The following are several factors that may be exposing the population of Puerto Rico to possible waterborne epidemics of gastroenteritis and hepatitis (Román-Seda and Toranzos, 1988):

1. the phenomenal increase in population and the resulting extremely high population density
2. the aging sewage treatment plants
3. deficiencies in the upkeep and operation of the sanitary sewage collection and treatment infrastructure
4. deficiencies in the upkeep and operation of water treatment plants
5. the limitations of conventional water treatment plants for the removal of certain contaminants and very high bacterial densities, which are not supposed to be present in raw waters.
6. the extremely high bacterial densities found in Puerto Rico's natural fresh surface waters, which consistently exceed our water quality standards (Curtis, et al., 1990).

Realistic alternatives are needed in order to solve the problems of contamination not only in the cities, but in the small rural communities of the island as well.

The Puerto Rico Aqueduct and Sewer Authority (PRASA) operates 241 water supply systems (United States Environmental Protection Agency, 1987). These systems provide potable water (after treatment including disinfection) to 95% of the Puerto Rican population. Of the remaining population, living in the more rural areas, approximately 80,000 rely upon local systems for drinking water. These systems (294 in total) provide drinking water with little or no treatment or protection from contamination. Most of them rely on surface water sources which are highly vulnerable to contamination by parasites, bacteria, organic and inorganic pollutants. This means that the people served by the rural water supply and distribution systems in Puerto Rico are essentially ingesting fecally contaminated water which poses a serious threat to their health.

Many waterborne diseases such as giardiasis, amebiasis, cryptosporidiosis, yersiniosis, typhoid fever and cholera have in the past been attributed to similar unprotected systems. Waterborne epidemics of giardiasis occur most commonly in communities with surface water sources and where disinfection, without filtration, is the principal method of water purification (Craun, 1979).

The majority of the rural water supply systems in Puerto Rico do not provide any treatment, except chlorination at the most. Chlorination is being required by the PRDOH. This came as a result of some studies performed on these systems by the United States Environmental Protection Agency (EPA), in collaboration with the PRDOH itself (United States

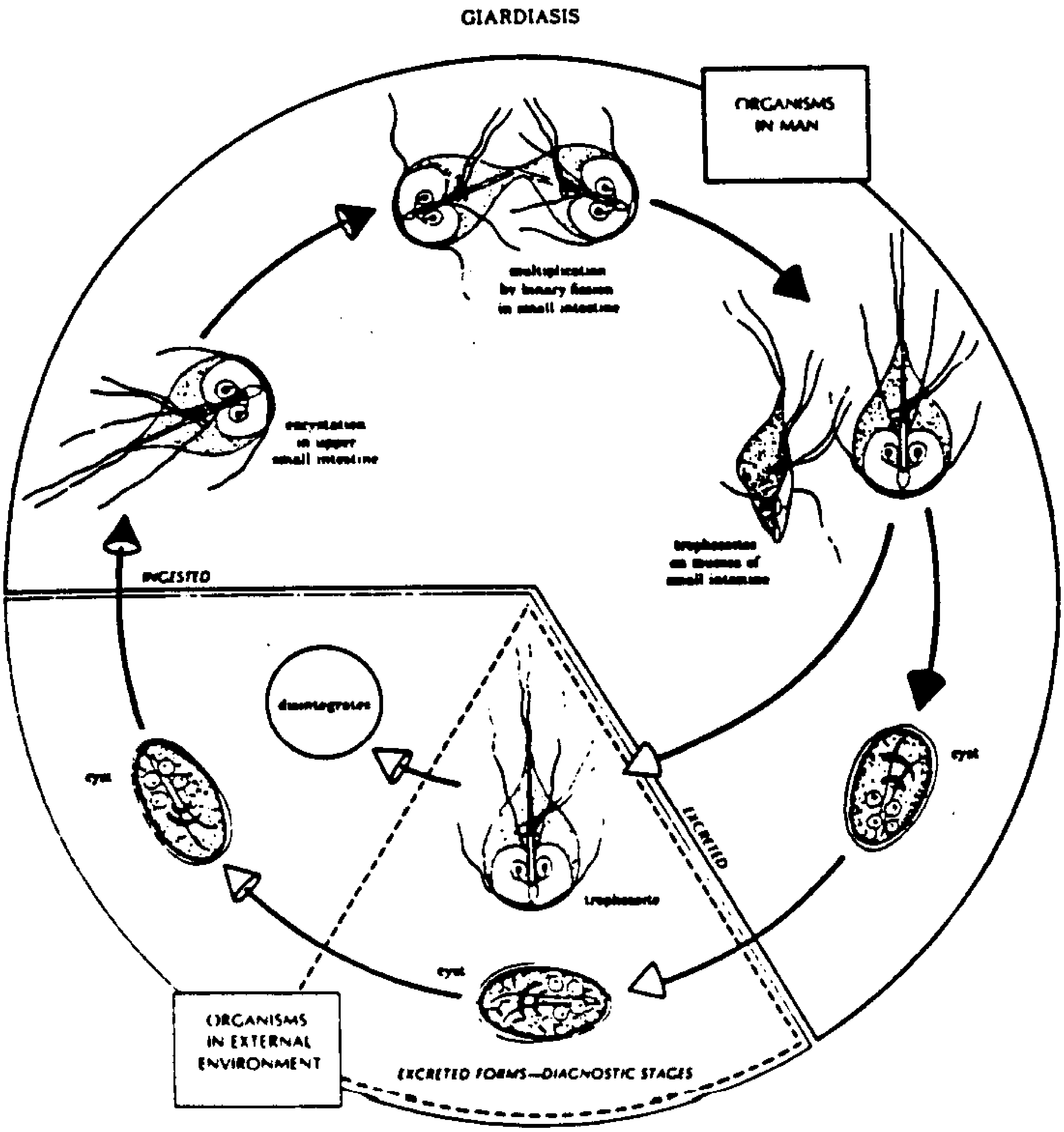


FIG. 1.1.- Life Cycle of <u>Giardia</u> in Humans

(Meyer and Jarroll, 1980)

by G. lamblia begins approximately 7 to 21 days (average = 9 days) after exposure (Rendtorff, 1954). When it occurs, the illness varies markedly among individuals from a mild case of "loose stools" for a day or two, to severe diarrhea, profound weight loss, and debilitation that may linger for months or require hospitalization.

1.3. Coliform Definition

Many pathogenic organisms can occur in water at very low densities (<1 per liter) and still be infective, so their actual presence may be undetectable or assessed only through very expensive and time consuming tests (Hazen, et al., 1987). Nearly all of these pathogens are transmitted to water by fecal contamination. For these reasons, bacteria that are found exclusively and universally in feces at very high densities are used as indicators of fecal contamination. Thus the presence of a certain group of bacteria in water is used to demonstrate the possibility of biological contamination.

The term "coliform" is used to indicate certain bacteria which resemble the bacterium Escherichia coli (coliform, or E. coli-like). The coliform group is further divided into two subgroups; total coliforms and fecal coliforms.

The total coliform group are Gram-negative, facultatively anaerobic, non-sporulating rods, which ferment lactose with the production of gas at 35°C. More than 50 species of bacteria have been shown to give a positive coliform reaction (Grabow, et al., 1981). The fecal coliform group (Escherichia coli, Citrobacter freundi, Klebsiella pneumoniae, and Enterobacter Cloacae may give positive fecal coliform reactions, even though E. coli is the target organism in this essay) has the same properties as mentioned above with the added property of thermotolerance, i.e. capability to ferment lactose at 44.5°C.

Escherichia coli was first described by Escherich in 1855 and is found in high densities in the feces of warm blooded animals. The presence of fecal coliforms in water, therefore, is generally interpreted to indicate recent fecal contamination.

On the other hand, the total coliform group is used to indicate the possible presence of E. coli in water. Even though total coliforms are found as part of the normal environmental microflora, they meet several criteria which make them desirable as indicators of bacterial pollution. Bonde (1977) enumerated these criteria as follows:

1. The indicator must be present whenever pathogens are present.
2. It must be present only when the presence of pathogenic organisms is an imminent danger.
3. It must occur in much greater number than the pathogens.

4. It must be more resistant to disinfectants and to aqueous environments than the pathogens.
5. It must grow readily on relatively simple media.
6. It must yield characteristic and simple reactions enabling as far as possible an unambiguous identification of the group or species.
7. It should preferably be randomly distributed in the sample to be tested.
8. Its growth on artificial media must be largely independent of any other organism present.

2. Literature Review

2.1. Principles of Slow Sand Filtration

2.1.1. Introduction

Slow sand filtration is a purification process in which the water to be treated is passed through a porous bed of sand filter medium. During this passage the water quality improves considerably by reduction of the number of micro-organisms (bacteria, viruses, cysts), by removal of suspended and colloidal material, and by changes in its chemical composition.

In a mature bed a thin layer called the schmutzdecke forms on the upper surface of the bed. This schmutzdecke consists of a great variety of biologically very active micro-organisms which break down organic matter, while a great deal of suspended inorganic matter is retained by straining and adsorption.

2.1.2. Basic Elements of a Slow Sand Filter

Basically, a slow sand filtration unit consists of a box, containing a supernatant raw water layer, a bed of filter medium, a system of underdrains and a set of filter regulation and control devices (see Fig. 2.1).

2.1.2.1. Supernatant Water Layer

The supernatant water layer serves two purposes: it provides a head of water that acts as the driving force to make the raw water pass through the bed of filter medium, and it creates a detention time of several hours for the raw water to be treated, during which period particles may settle and/or agglomerate or be subjected to other physical or (bio)chemical processes. If the raw water contains a relatively high content of suspended matter, a pre-treatment sediment removal unit should be installed to prevent rapid clogging of the slow sand filter.

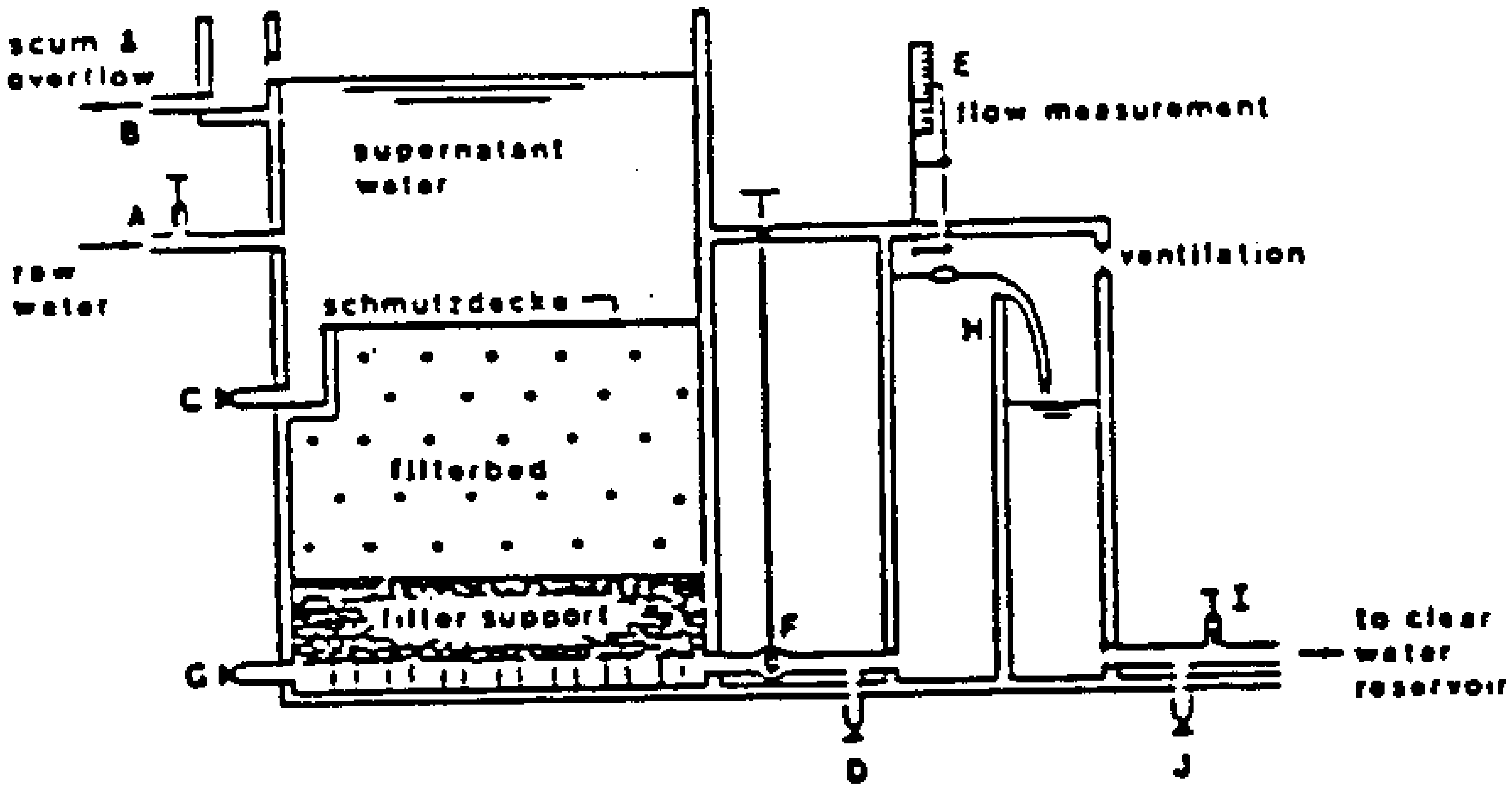


FIG. 2.1.- Basic Elements of a Slow Sand Filter (Thanh and Pescod, 1976)

2.1.2.2. Bed of Filter Medium

The filter medium is characterized by its effective size and uniformity coefficient. Normally an effective size in the range of 0.15-0.35 mm is selected (Thanh and Pescod, 1976). The uniformity coefficient should preferably be less than 2, although values up to 5 are acceptable. For a proper functioning of the purification process a minimum filter bed thickness of 0.6 meter should be provided. A suitable depth of the supernatant water layer is 1 meter.

Since the top layer (10-20 mm) of the filter bed will have to be removed regularly during cleaning operation of the clogged filter, a new filter should be provided with a filter bed 1 meter thick, so that the bed will not have to be refilled more than once every few years.

2.1.2.3. Underdrains System

A slow sand filter has a drainage system that serves two purposes: it provides an unobstructed passage for the collection of treated water and it supports the bed of filter medium. The drainage system may have various configurations such as a layer of coarse gravel or broken durable stones, or structures of main and lateral drains, built up from perforated or non-jointed pipes, concrete blocks or bricks. This system of underdrains is covered by layers of gravel which prevent filter bed grains from being carried into the drainage system. Including the gravel layers, the system of underdrains should have a thickness of 0.5 meter.

2.1.2.4. Filter Regulation and Control Devices

(The following letters correspond to those found in Fig. 2.1.)

A: Delivery of raw water into the supernatant water reservoir up to a constant level in the filter box

B: Drainage of surplus water and scum by means of an overflow weir

C: Drainage of the supernatant water prior to filter cleaning

D: Drainage of the water in the top layer of the filter bed

E: Measurement of the flow rate of effluent water by means of a calibrated flow rate measurement device

F: Regulation of the filtration rate

G: Backfilling of the filter bed with clean water after cleaning of the filter

H: Prevention of negative pressure in the filter bed by insuring through the height of an effluent weir control, that the filter bed will always be under water during the filtering cycle.

I: Delivery of treated water to the clear water storage reservoir

J: Delivery of treated water to waste.

2.1.3. Purification Process

The purification starts in the supernatant raw water layer where large particles will settle onto the filter bed and smaller particles may agglomerate to settleable flocks due to physical or (bio)chemical interactions.

The major part of the removal of impurities and the considerable improvement of the physical, chemical and bacteriological quality of the raw water takes place in the filter bed and especially in the schmutzdecke at the top of the filter bed. In this top layer micro-organisms abound, such as algae, plankton, diatoms and bacteria, which, through their biological activity, break down organic matter. A great deal of inorganic suspended matter is moreover retained by straining.

As the water passes through the bed it is constantly changing direction so that particles carried by the water come into contact with the filter grains by various transport mechanisms. The grains become covered with a sticky layer of mainly organic material which absorbs these particles by various attachment mechanisms. At the same time the active micro-organisms in the sticky layer around the grain feed on the impurities caught as well as on each other. In this way, degradable organic matter, including bacteria and viruses of fecal origin, is broken down and converted into water, carbon dioxide and inorganic salts.

The life-filled zone where these purification mechanisms take place extends to about 0.4-0.5 meter down from the surface of the filter bed, but it gradually decreases in activity downwards as the water is purified and contains less organic matter and nutrients (Thanh and Pescod, 1976). At greater depth in the filter bed the products of the biological process are further removed by physical processes (adsorption) and chemical action (oxidation) (Thanh and Pescod, 1976).

The transport, attachment and purification mechanisms described above will only function effectively if a sufficient detention time in the filter bed is allowed. The rate of filtration for slow sand filtration should be kept at a value of 0.1 to 0.2 meter/hour (Thanh and Pescod, 1976).

Another important parameter for the purification process is the oxygen content of the water. The activity of the bio-mass will decrease considerably if the oxygen content of the water in the filter medium falls below 0.5 mg/l. If anaerobic conditions occur, various obnoxious impurities may be added to the water by the bio-mass and evolution of gases within the bed will cause air binding and interruption of normal flow. An oxygen content of more than 3 mg/l in the filter effluent is the normal goal.

A simple overflow weir which suits a dual purpose with respect to aeration is installed in the effluent channel. The weir increases the oxygen content of the filtered water and simultaneously decreases the content of carbon dioxide and some other obnoxious dissolved gases which have been added to the water as by-products of the bio-chemical processes (Thanh and Pescod, 1976).

The effluent weir has two more important functions: it prevents negative pressure in the filter bed by ensuring a minimum overflow-level slightly above the top level of the filter bed, and it makes the operation of the filter bed independent of fluctuations of the water level in the clear water reservoir (Thanh and Pescod, 1976).

2.1.4. Operation and Maintenance of a Slow Sand Filter

2.1.4.1. Initial Commissioning of a Filter

When the construction of the filter has been completed, the filter bed is filled with clean water from the bottom of the filter up to drive out the air bubbles present in the interstices of the sand. When the level of the supernatant water reaches well above the sand bed (0.1 meter), raw water may be admitted through the raw water inlet. By the time the supernatant water has reached the design level, outlet valve D (see Fig. 2.1) is opened, and the effluent is run to waste (Thanh and Pescod, 1976).

The filter must now be run for a few weeks to enable the formation of the schmutzdecke and the sticky layers around the filter bed grains. This period is called the filter "ripening process". During this process the filtration rate is gradually increased until it reaches the design filtration rate. After comparative physical, chemical and bacteriological analyses of the raw water and the filtered water have shown that the filter is working properly, the drain valve D (see Fig. 2.1) may be closed and the effluent directed to the clear water tank by opening valve I (see Fig. 2.1). It is common to find that the filter will produce finished water of adequate quality within the first week of operation, when it relies on the sand media alone to perform the removal process.

2.1.4.2. Operation of the Filter Regulating Valve

After a proper ripening process the filter will operate successfully for several weeks with the regulating valve F (see Fig. 2.1) almost fully closed. Then, as the schmutzdecke becomes clogged, the valve is gradually opened, a little each day, to compensate for the head loss in the schmutzdecke and to maintain the flow rate at a constant value.

2.1.4.3. Cleaning of the filter

When, after an operation period of several weeks or months, the regulating valve is fully opened and the rate of flow starts to decrease, the resistance of the schmutzdecke has become too high and the filter must be cleaned. The raw water inlet valve A (see Fig. 2.1) is closed and the level of the supernatant water is allowed to drop by continuing the filtration process for some hours. The remaining supernatant water is drained by opening the drain valve C (see Fig. 2.1). Finally the water level in the filter bed is lowered to about 0.2 meter below the surface of the bed by opening the drain valve D (see Fig. 2.1). The schmutzdecke is then carefully removed by using flat-nosed shovels.

The procedures to be followed for the start-up of a cleaned filter ("re-ripening period") are similar to those applied for the initial commissioning of a new filter, although the periods required for both back-filling and re-ripening are much shorter than the initial commissioning period.

2.1.4.4. Resanding of a Filter

After several years of operation (approximately 3-4 years) and about 20-30 scrapings, the filter bed reaches its minimum permissible thickness and new or washed filter medium must be brought in to raise the bed to its original depth. The new filter medium should be placed under the top 0.3-0.5 meter of old filter medium. By doing so, the top layer which is richest in micro-biological life is replaced at the top of the filter bed which will enable the re-sanded filter to become operational with a minimum re-ripening period.

2.1.5. Pre-Treatment and Post-Treatment in Combination with Slow Sand Filters

2.1.5.1. Pre-Treatment

For slow sand filters pre-treatment is indispensable if raw water turbidity has an average value of more than 50 NTU for periods longer than a few weeks or values above 100 NTU for periods longer than a few days (Thanh and Pescod, 1976).

be applied for raw water turbidities up to 150 NTU (Thanh and Pescod, 1976). As filter media coarse gravel or crushed stones are applied; the filter box is comparable to the one used for plain sedimentation.

Aeration of the raw water, or re-cycling of oxygen enriched effluent water to the supernatant water reservoir, will be necessary if the oxygen consumption in the filter bed leads to anaerobic conditions.

2.1.5.2. Post Treatment

The only post-treatment which may be required for the effluent of a slow sand filter is safety chlorination, which is mainly aimed at the prevention of aftergrowth of bacteria in storage tanks or the distribution system. It should also be applied as a precaution if the raw water source is heavily polluted with organic matter of fecal origin, for instance for raw water with an E. Coli content of 10000/100 ml or more (Thanh and Pescod, 1976).

2.1.6. Advantages of Slow Sand Filters

Slow sand filtration is the only known unit-operation which accomplishes such a high degree of simultaneous improvement of the physical, chemical and bacteriological quality of raw water. For developing countries, the use of this technology represents a number of special advantages, such as:

1. The simplicity of design, construction

and operation enables the application of locally available materials and skills with limited technical supervision.

2. With the exception of disinfection or safety chlorination of the effluent, no chemicals are required.
3. Operation and maintenance can be carried out by semi-skilled labor.
4. Power may only be required to pump raw water to the supernatant water "reservoir"; the filtration process is carried out by gravity; no other power driven mechanical parts are present. In addition, if the topography is mountainous, it is possible to feed the filter influent by gravity, in which case even pumps are not necessary.

2.2. *Giardia* Removal Studies With Various Water Filtration Techniques

2.2.1. Slow Sand Filtration

Pyper (1985a) conducted a study to evaluate the slow sand filtration process for small water systems. The study addressed the concerns of small water systems with regard to *Giardia* cysts, bacteria, trihalomethanes (THM's) and operating costs.

This study was conducted at McIndoe Falls, Vermont, at the site of a slow sand filtration plant. The average temperature was 9.7°C. The rate of filtration was maintained at a constant value of 0.08 m/hr.

Reductions averaged 80% for total coliforms and 90% for standard plate count bacteria. Giardia cysts removals tended to be best (99.9%) during warm water conditions and less effective (99.5%) during cold water conditions.

Some other results were the following:

1. Slow sand filtration provided dependable water treatment with a minimum of attention, but capital cost was high.
2. Turbidity was below 1 NTU 99.19% of the time. After the first 100 days of operation, the effluent turbidity values were below 1 NTU 99.68% of the time. Turbidity values were 0.2 NTU, or less, 72% of the time.
3. Slow sand filtration reduced total coliforms to 10/100 ml, or fewer, 86% of the time under ambient load conditions.
4. The standard plate count bacteria were reduced to 10/ml or fewer, 94% of the time under ambient load conditions.
5. Massive spikes of total coliform and

standard plate count bacteria were removed from raw water at temperature conditions above 5° to 10°C.

6. Slow sand filtration was not as efficient in removing bacteria at temperatures below 5°C, particularly around 0° to 1°C.
7. _Giardia_ cysts were removed very dependably; 99.98% removals or better were achieved under warm temperature conditions.
8. _Giardia_ cysts removal was not as efficient at low temperatures below 7°C, where removals were of the order of between 99.36 to 99.91%.
9. Slow sand filtration did not produce any significant reduction of THM precursors.
10. The mature filter recovered from cleaning within 2 weeks to provide dependable bacteria and turbidity removal.

Between November 15, 1985 and November 15,1986 a research was conducted at 100 Mile House, British Columbia (B.C.), Canada, in the village's new water treatment plant (Bryck, et al., 1988). The research was conducted to ascertain removal efficiencies of Giardia cysts, of coliform bacteria and of any other measurable indicator particles by the operating and pilot scale slow sand filters.

From November, 1985, to February 28, 1986, the water temperature in the raw water was between 1°C and 3°C. From March 1, 1986, to October 31, 1986, the water temperature in the raw water ranged from 3°C to a peak of 19°C in August and decreased to a minimum of 3°C.

The maximum raw water turbidity value was 1.8 NTU in March, 1986, while the minimum value was 0.5 NTU in December, 1985. The filtered water turbidity ranged between 0.15 NTU and 0.8 NTU. The reduction in turbidity was about 20-50% between November, 1985 and April, 1986 while it was 40-80% in the period of May, 1986 to November, 1986. The filtered water, with one exception, was less than the British Columbia Ministry of Health objective of 1 NTU. The increased efficiency in the summer and fall of 1986 was likely due to the effectiveness of the schmutzdecke in trapping and holding the particles (Bryck, et al., 1988).

The removal of Giardia cysts through the slow sand filter was essentially complete even in the absence of schmutzdecke. When the pilot filter was spiked with 500,000 cysts/100 l., an extremely high concentration compared to cysts detected in the raw water, the removal efficiency was 99.99% (Bryck, et al., 1988).

The total coliform count was typically below the detectable limits in the filtered water except in November, 1985 and January, 1986 samples. In the latter cases biological activity in the media was minimal due to low water temperatures and low organic matter content in the water. The coliform reduction on March 20, 1986, was in the order of 99.5% (Bryck, et al., 1988).

The total coliform and standard plate count reduction increased with the increase in the heterotrophic activity and invertebrate population. The trend to higher removal efficiency with increasing filter age and biological activity was noted with the spiked pilot filters (Bryck, et al., 1988).

2.2.2. Diatomaceous Earth Filtration

Giardia cyst removals exceeding 99%, and often 99.9%, were reported by Lange et al. (1986) in diatomaceous earth (DE) filtration studies, for filtration rates of 2.4 to 9.6 m/h, for temperatures from 3.5 to 15°C, and for four different grades of diatomaceous earth (Celite 545^{TM}, Celite 535^{TM}, Celite 503^{TM}, and Hyflo Super-Cel^{TM}).

Pyper (1985a) reported 99.97% for one DE filter run in which Giardia cysts were added in a study conducted at McIndoe Falls, Vermont, at the site of the slow sand filtration plant.

Removal of total coliform bacteria by DE filtration was studied extensively at Colorado State University by Lange et al. (1986). Coliform removals were strongly influenced by the grade of diatomaceous earth used. Coarser grades attained removals ranging from 30% to 50% for Celite 545™ and from 50% to 70% with Celite 503™. The fine grades, with smaller pores, were considerably more effective. Removal with Celite 512™ was from 92% to 96%, and total coliform removal with Super-Cel™ was from 99.92% to more than 99.98%.

Pyper (1985a) reported total coliform reductions of 86% or more in 70% of the samples, and standard plate count bacteria reductions of 80% or more in 70% of the samples.

Turbidity removal when treating Horsetooth Reservoir water, as reported by Lange et al. (1986), was less than 20% for the grades of diatomaceous earth commonly used for water treatment (Celite 545™, Celite 535™, Celite 503™, and Hyflo Super-Cel™). Turbidity of the Horsetooth Reservoir raw water ranged from 4.5 to 5.4 NTU. The finest grade tested, Filter-Cel™, could reduce the turbidity by over 95%.

In contrast to these results, Logsdon et al. (1981) reported that turbidity reductions of 56% to 78% were attained with Celite 535™ when raw water turbidity ranged from 0.95 to 2.5 NTU, but little change was observed when raw water turbidity ranged from 0.24 to 0.45 NTU.

Pyper (1985a) reported an average turbidity reduction of 71%, with an effluent quality of 0.5 NTU.

2.2.3. Coagulation-Filtration (Rapid Sand Filtration)

This category includes conventional filtration (coagulant feed and rapid mix, flocculation, sedimentation and filtration), direct filtration (coagulant feed and rapid mix, flocculation, and filtration), and in-line filtration (coagulant feed and rapid mix, followed by filtration).

Most coagulation-filtration research for Giardia cyst removal in the United States has focused on the in-line or direct filtration variations of the process, because waterborne giardiasis outbreaks tended to be observed in regions of the country that had low turbidity waters which were thought to be suitable for such treatment. Results of three direct filtration studies indicate that Giardia cyst removal can exceed 99.0% or even 99.9% when the raw water is coagulated properly and filtered (Logsdon, 1988).

McCormick and King (1982) stated that coliform removal by direct filtration was practically 100% when filtered water turbidity was 0.10 NTU or less. Cleasby et al. (1984) reported that in-line filtration removed more than 86% of the total coliform bacteria in raw water, after the first hour of the filter run had passed, in 10 test runs.

2.2.4. Pressure Slow Sand Filtration

Pyper (1985b) conducted a study at the Champlain Water District plant in South Burlington, Vermont, to determine the feasibility of developing a small, compact treatment system and still maintain the advantages of the slow sand filtration process.

The objectives of this study were developed to address the concerns of the very small water system with particular emphasis on bacterial and Giardia cyst removal.

This study utilized the biologic treatment capacity of slow sand filtration in combination with new materials. The schmutzdecke was grown on a covering which consisted of an unwoven geotextile material resting on the surface of the sand with a modified underdrain support system. The sand used in this study had an effective size of 0.28 mm and a uniformity coefficient of 2.46. This arrangement was installed in a container which operated at a filtration head comparable to normal slow sand filter operation (2 psi). This combination provided for easy cleaning.

Filter rates were evaluated between half of normal to three times normal filtration in order to determine the feasibility of using this revolutionary concept to meet drinking water quality requirements.

A summary of the results obtained follows:

1. The selected material used in the underdrain sand support system (unwoven geotextile), provided excellent support and performed well as a major component of the modified filter.

2. The selected sand surface covering material (unwoven geotextile) functioned satisfactorily as a covering and supporting surface for retaining the surface biological (schmutzdecke) growth.
3. The combination of the artificially supported biologic growth surface, modified underdrain system, modified sand and filtration head configuration in three short duration studies appeared to remove bacteria, turbidity, and *Giardia* cysts satisfactorily after filter maturity was reached.
4. The selected sand surface covering material provided a means for quick cleaning and thus the filter could be placed back in operation in less than an hour after cleaning.
5. Filtration rates in the range 0.03-0.04 m/hr for these short duration studies did not demonstrate that there was any significant deterioration in treatment as the rate of filtration was increased.
6. For most filtration rates and sand

configurations, turbidity reduction was about 50% with the effluent containing about 0.2-0.3 NTU.

7. Total coliform bacterial reductions could not be easily evaluated because of low numbers in the raw water. When the raw water numbers were reasonably high, coliform removal was in the order of 70-100%.
8. Standard plate count bacteria reduction (after adequate biological maturing of the filter) was in the order of 85-95% for most filtration rates and operating configurations. Giardia cyst removal was in the range of 91-100%.
9. The modified slow sand filter system provided a meaningful reduction in Giardia cysts and thus improved protection to water users.

The prefabricated, pressure driven slow sand filter which was used throughout Dr. Pyper's research (which is the one selected to be used for this project) is considered to have a lot of potential as a treatment alternative for very small, isolated communities in Puerto Rico with no safe drinking water supply. However, this technology has not been tested for waters under tropical environmental conditions. Research is needed in this area to produce a scientific basis with which to judge the effectiveness of this technology in producing potable, or nearly potable water under tropical conditions with raw waters of much higher turbidities than those tested in the United States.

3. Objectives and Scope

3.1. Objectives

The main objectives of this research are the following:

1. To determine the variation with time of various water quality parameters measured at the influent and the effluent of a compact, prefabricated, pressure driven, slow sand filter. These parameters include:
    a. *Giardia* cysts
    b. Fecal and Total Coliforms
    c. Temperature
    d. pH
    e. Alkalinity
    f. Conductivity
    g. Turbidity
    h. Suspended Solids
    i. Chemical Oxygen Demand.
2. To assess the applicability of this technology as an appropriate treatment to provide safe drinking water for isolated homes or small groups (4-5) of homes in rural communities in Puerto Rico, not served by PRASA.

conditions by means of a compact, prefabricated, pressure driven, slow sand filter designed and developed by Dr. Gordon R. Pyper, former Managing Director of Research and Special Projects of Dufresne-Henry, Inc., in Vermont, U.S.A.

2. To evaluate the capability of said filter to produce potable or nearly potable water under tropical conditions. Relatively cheap and simple filter assemblies as represented by this filter could prove to be very useful for producing potable water in rural and isolated areas of Puerto Rico for single or small groups (from 2 to 5) of dwellings.

The water sources for the study consisted of streams located in the western area of Puerto Rico, near Mayagüez. These streams were known to be contaminated with Giardia. Table 3.1 shows the results of the preliminary sampling performed in order to find sources of natural waters containing Giardia cysts. These sources had to be located near Mayagüez because the water was going to be transported to the Environmental Engineering Laboratory, located at the

TABLE 3.1.- RESULTS OF GIARDIA CYST SAMPLING IN STREAMS LOCATED ON THE WESTERN AREA OF PUERTO RICO

LOCATION	DATE	FILTERED WATER VOLUME (gal.)	FILTERED WATER VOLUME (l.)	NUMBER OF CYSTS/100 l.
QUEBRADA DE ORO ENGINEERING COMPLEX MAYAGÜEZ CAMPUS, U.P.R. MAYAGÜEZ, P.R.	8/8/89	202	765	N.D.
	12/1/89	270	1022	N.D.
RIO PIEDRAS COMMUNITY CHLORINATED TANK SAN GERMAN, P.R.	8/8/89	201	761	N.D.
QUEBRADA RIO PIEDRAS (NEAR BRIDGE) SAN GERMAN, P.R.	11/28/89	740	2801	5.4
	1/10/90	1000	3785	2
RIO GUANAJIBO (DOWNSTREAM FROM WASTEWATER TREATMENT PLANT) SAN GERMAN, P.R.	11/28/89	200	757	7.9
	4/2/90	900	3407	0.87
QUEBRADA MONDONGO (UPSTREAM FROM WASTEWATER TREATMENT PLANT) LAJAS, P.R.	12/22/89	308	1166	N.D.
QUEBRADA MONDONGO (DOWNSTREAM FROM WASTEWATER TREATMENT PLANT) LAJAS, P.R.	12/22/89	747	2827	0.4
	5/25/90	1000	3785	8.42
RIO PIEDRAS COMMUNITY TANK WITHOUT CHLORINE SAN GERMAN, P.R.	1/10/90	1000	3785	298
	2/26/90	1000	3785	N.D.
RIO CULEBRINAS (DOWNSTREAM FROM DAM) AGUADA, P.R.	3/19/90	456	1726	N.D.
	5/25/90	1000	3785	N.D.
QUEBRADA EL CAÑO ROAD P.R.301 km. 2 CABO ROJO, P.R.	5/14/90	1000	3785	2.1

N.D. = NONE DETECTED

Civil Engineering Building at the Mayagüez Campus of the University of Puerto Rico, where the filter was installed and operated for security reasons.

The evaluation of Giardia cyst removal from natural waters depended on the cyst concentration of these waters. If such concentrations were too low, Giardia cysts would be injected to produce greater concentrations to the raw waters, in order to simulate cyst concentrations of greater magnitude that are known to be present in certain natural streams of Puerto Rico.

There were other water quality parameters, besides Giardia, whose variation with time were determined in this study. These parameters were:

1. Temperature
2. pH
3. Alkalinity
4. Conductivity
5. Turbidity
6. Suspended Solids (SS)
7. Chemical Oxygen Demand (COD).

Microbiological analyses were limited to fecal and total coliforms, and Giardia.

Four rates of filtration were studied to determine if there was a significant deterioration in the water quality of the filter effluent as the filtration rate changed. The rates of filtration used in the study were: 0.02, 0.04, 0.06, and 0.08 gal/min-ft^2 because these are rates commonly found in the slow sand filtration literature. Four filtration runs were performed at these rates, using a piece of unwoven geotextile over the 22-in. sand bed in the filter. Four runs were performed at the same filtration rates without the geotextiles.

4. Methodologies and Procedures

4.1. Preliminary Giardia Sampling

Several samplings were performed from August, 1989, to May, 1990, on streams located in the western area of Puerto Rico to find a source of water contaminated with Giardia cysts. Table 3.1 shows the results obtained. A stream that consistently showed the large concentrations of Giardia cysts needed for the research was not found. For this reason, the raw water that was used for the filtration runs was spiked with Giardia cysts at the laboratory using a commercially available cyst suspension.

Sampling for the Giardia detection analysis was performed according to Standard Methods for the Examination of Water and Wastewater (1985). Water was taken from the given stream using a Homelite Model P100 fuel pump and passed through a 1-μm polypropylene filter. A water meter connected after the filter housing gives the volume of filtered water in gallons. After the required volume of water was filtered, the filter was removed from its housing, placed in a plastic bag and transported on ice to the laboratory for analysis.

4.2. Equipment Description and Operation

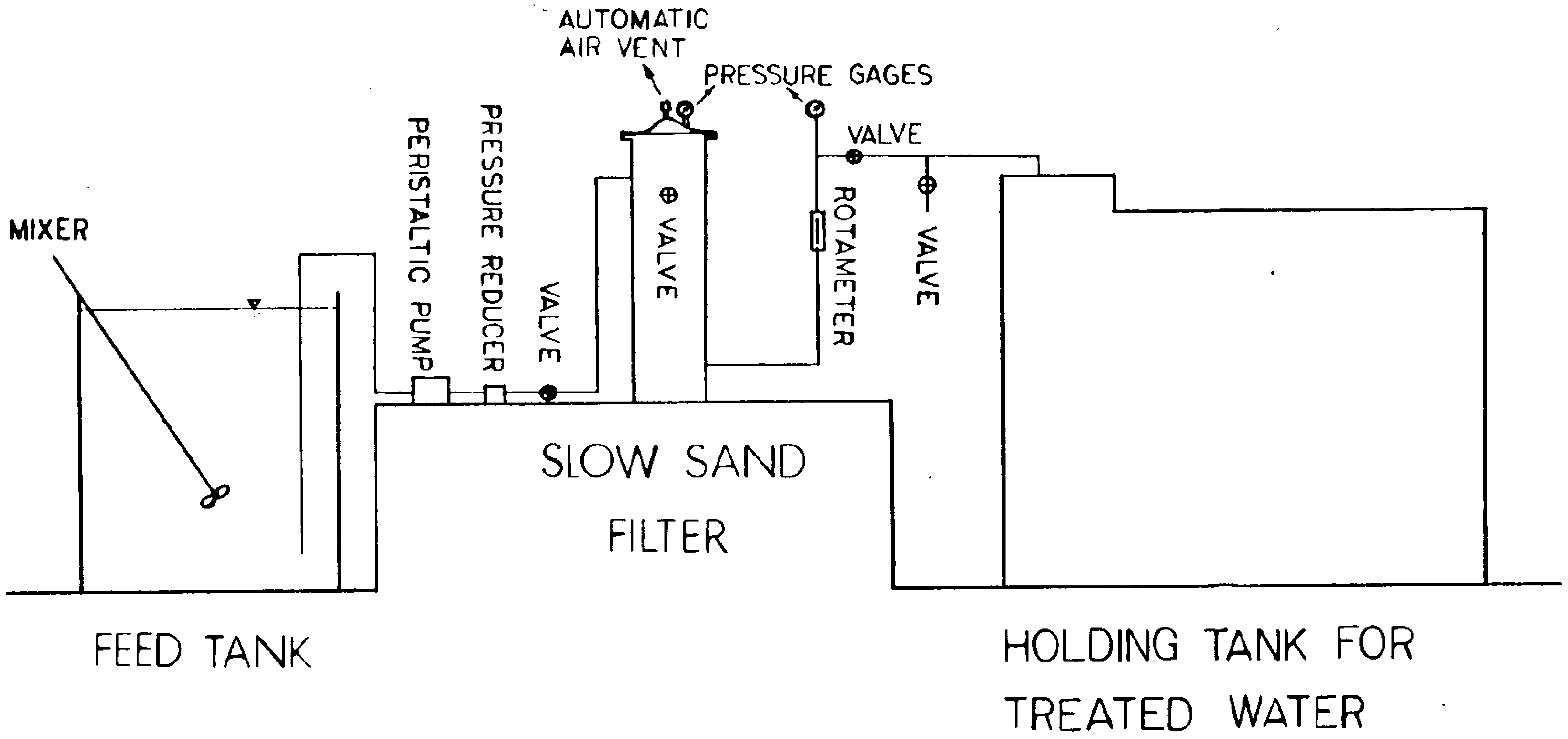
Raw water was taken from a stream and was transported to the laboratory. Sampling of this stream for the Giardia detection analysis was performed on site in order to determine the cyst concentration of the raw water. At the laboratory, the raw water was held in a 200 gal. capacity tank, keeping its contents mixed so that there was no sedimentation of suspended solids. Fig. 4.1 shows a schematic diagram of the experimental equipment setup.

Raw waters were spiked with <u>Giardia</u> cysts since the beginning of the filtration runs for two reasons:

1. there was no way of knowing immediately the natural cyst concentration of that water (the <u>Giardia</u> analysis takes several hours to be completed),
2. low cyst concentrations were expected in the sources, namely Río Caín in San Germán and Río Guanajibo in Hormigueros, as can be noticed from Table 3.1 (Quebrada Río Piedras is a tributary of Río Caín).

The process of spiking was continued throughout the filtration runs because the samples taken in both rivers every time the volume of 200 gal. was taken had no <u>Giardia</u> cysts.

Water was pumped from the feed tank at the given rates to the filter with a peristaltic pump. A pressure reducer kept the influent water pressure below 2 psi, which is equivalent to a head of 4.62 ft of water. This head approximates that of conventional slow sand filters which



NOT TO SCALE

FIG. 4.1.- EXPERIMENTAL EQUIPMENT SETUP

varies from 3 to 5 ft. Influent and effluent pressures were read using pressure gages. Filtration rates were read by means of a rotameter at the effluent side of the filter.

The filtered water was collected in a 1000 gal. capacity tank for Giardia analysis at the end of each filtration run. The filter runs ended whenever a volume of 1000 gal. of filtered water was collected or when there was a difference between influent and effluent pressures of 1 psi (Pyper, pers. com., 1990). This difference in pressure indicated that there was terminal pressure loss and that therefore the filter needed cleaning.

Another objective in every filtration run was to have a treated water volume of 1000 gal. for Giardia analyses. This was necessary because the capacity of the raw water tank was 200 gal., it was necessary to bring a water volume of 200 gal. six times to have a treated water volume of 1000 gal. at the end of the run. As soon as the first 200 gal. of water were consumed (treated) by the filter, a new volume of 200 gal. was brought before the first volume was finished, and so on. In this way, there was a continuous flow throughout the filter for each filtration run. The variation in water quality that may have been introduced by each successive 200 gal. batch helped to simulate the random variation of water quality that exists in natural streams due to hydrologic events and anthropogenic sources.

4.3. Filter Description and Operation

The filter unit consists of a PVC pipe with a 12-in. interior diameter and a height of 3 ft. 1.5 in., sealed at the bottom. It has a removable top cover with an automatic air release valve and a pressure gage to read influent water pressure. At the bottom, the unit has an underdrain system. Fig. 4.2 shows a cross-section of the filter unit.

The filter uses a 22-inch sand layer, which is considerably less than the 3.28 ft used in conventional slow sand filters, then making the unit more economical and easier to handle. At the bottom, on top of the underdrain system, two geotextiles are placed to retain the sand in the filter. A sheet of a woven geotextile is placed first, and over it a 1/4-in. thick unwoven geotextile is placed. This functions as a sand support. The sand is placed on top of this support.

On top of the sand bed, another unwoven geotextile is placed. Then a 1/2-in. sand layer is placed, and over it, another unwoven geotextile. It is over this last geotextile that the biological growth known as schmutzdecke, or filter skin, takes place.

When terminal pressure loss occurs, cleaning of the filter is needed. Filter cleaning (when geotextiles are being used over the sand bed) involves opening the filter, removing the top geotextile, the 1/2-in. sand layer and the second geotextile. A new geotextile is placed over the 22-in. sand

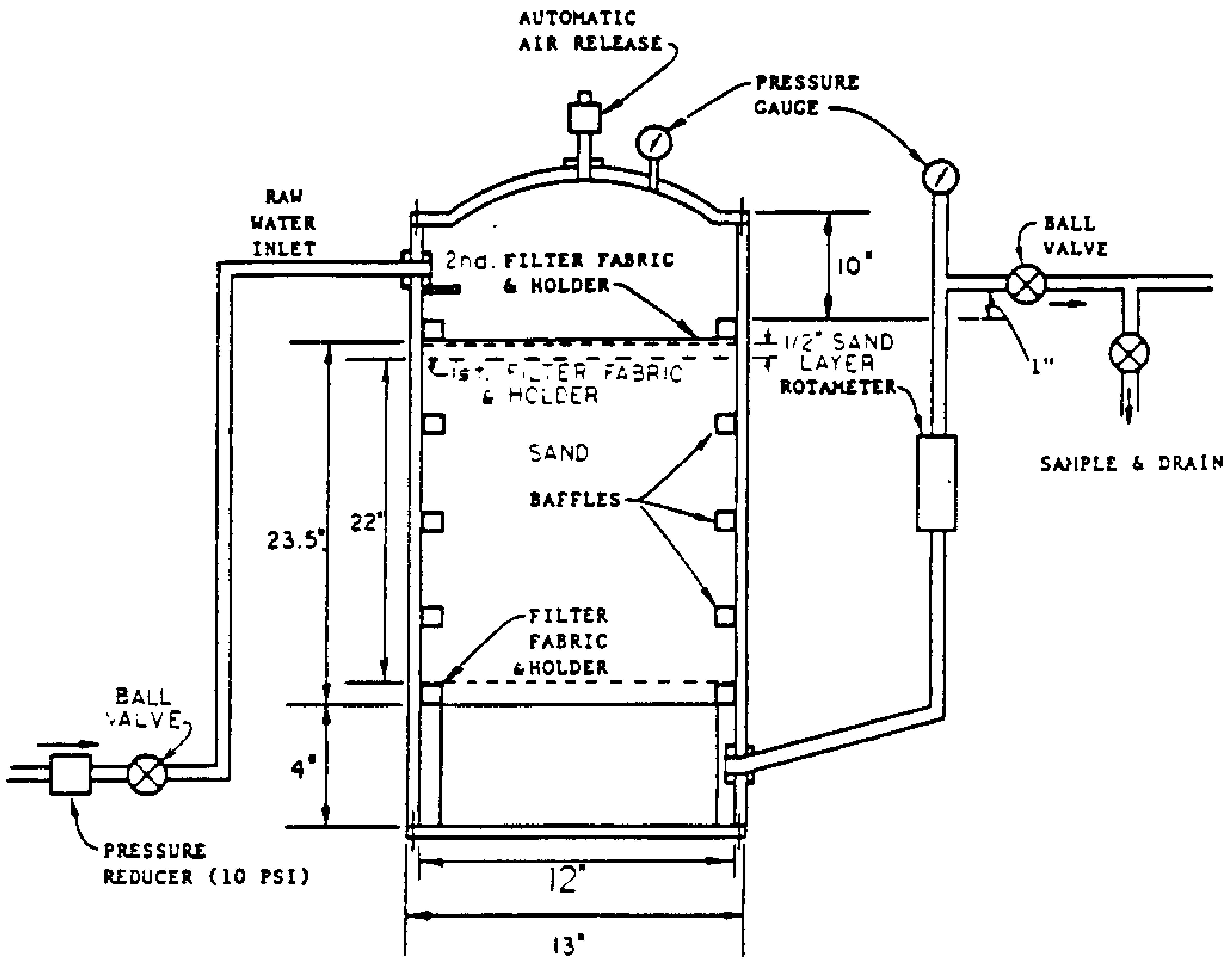


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FIG. 4.2.- Cross Section of Filtration Unit as Modified From Pyper (1985b)

bed, the same sand removed before is placed over it, and the geotextile formerly located below the 1/2-in. sand layer before cleaning is now placed at the top. This procedure is done because the 1/2-in. sand layer and the geotextile below it contain a biological seed that passes through the original top geotextile. This geotextile with the biological seed is placed at the top to accelerate the growth of the schmutzdecke in the next filtration run.

Filter cleaning when no geotextiles are being used over the sand bed involves scraping and removing the top 1/2-in. layer of the 22-in. sand bed.

4.4. Sand Characteristics

The sand used in the filter was from Rincón, Puerto Rico. It was washed at the laboratory to remove the very fine particles and dried at 105°C for one day. This dry sand was sieved, removing the portion that was retained in the No. 10 U.S. Standard Sieve and the portion that passed through the No. 100 sieve. This was done in order to meet the requirements of a sand for slow rate filtration and according to Dr. Gordon Pyper's recommendations (Pyper, Written pers. com., 1990). The sand has an effective size (ES) of 0.2 mm and uniformity coefficient (U) of 1.8. The uniformity coefficient is the ratio of the 60 percentile size to the 10 percentile size in the media grain size distribution logarithmic probability curve. In conventional slow sand filters the recommended effective size is in the range of 0.15 to 0.35 mm, and the uniformity coefficient should be less than 5 and preferably below 3 (Thanh, 1978). Therefore, the sand used for this investigation meets the recommended design values for conventional slow sand filters.

4.5. Collection and Analysis of Samples

The reasons for measuring the water quality parameters selected for this project are the following:

1. Fecal and total coliforms were determined in the samples because these are indicator organisms of fecal contamination in water, and are regulated by EPA.
2. Water temperature was measured in order to determine if there was any effect of this parameter on <u>Giardia</u> cyst removal.
3. Alkalinity was measured in order to observe its relationship with the biological activity in the schmutzdecke.
4. Chemical oxygen demand was determined in order to see if there was removal of organic matter in the water by the biological activity in the schmutzdecke.

5. pH, electrical conductivity and turbidity were measured because these are parameters regulated by EPA.
6. Suspended solids were sampled (although this parameter is not regulated by EPA) because they interfere with water treatment processes such as chlorination.

The following procedure was followed for collection and analysis of samples:

1. Sampling for pH, alkalinity, conductivity, turbidity, suspended solids, and COD analyses were taken every two days throughout the project. Temperature was read on site every two days. Samples for total and fecal coliforms were taken and analyzed twice a week for the longer runs (hydraulic loading rates of 0.02 and 0.04 gpm/ft^2). For the shorter runs (hydraulic loading rates of 0.06 and 0.08 gpm/ft^2) samples for coliform analyses were taken once for each kind of water (each volume of 200 gal.). <u>Giardia</u> analyses of the treated water (filter effluent) were

performed at the end of each filtration run.

2. Flow and pressure readings were recorded daily whenever possible, but at least every two days. Dissolved oxygen was measured on site every two days in the last four runs (on which geotextiles were used on top of the sand bed).
3. pH readings were taken by using a Horizon Model 5998-10 Digital Readout pH Meter. Temperature and dissolved oxygen were measured with a YSI Model 57 Oxygen Meter. Conductivity was measured with a YSI Model 31 Conductivity Bridge. Turbidity was measured with a Hach Model 2100 A Turbidimeter.
4. The suspended solids, volatile suspended solids, total solids, volatile total solids, alkalinity and biochemical oxygen demand analyses were performed according to Standard Methods for the Examination of Water and Wastewater (1985).
5. Chemical oxygen demand analyses were performed by using a Hach Model 16500-10

COD Reactor and Hach Reagent Vials, and according to Standard Methods for the Examination of Water and Wastewater (1985).

6. Total and fecal coliform analyses were performed according to Standard Methods for the Examination of Water and Wastewater (1985), using the membrane filtration technique.
7. An immunofluorescence method (LeChevallier and Lee, 1988) was employed to detect Giardia cysts both in the filter influent and effluent , and sampling was performed according to Standard Methods for the Examination of Water and Wastewater (1985).

4.6. Schmutzdecke Analysis

In the last day of a filtration run, a normal sampling of effluent and influent water was performed. Then the filter was drained, opened and the schmutzdecke removed. In the first four filtration runs (without geotextiles over the sand bed), the schmutzdecke was removed by scraping the top 1/2-in. layer from the sand bed. In the last four runs (with geotextiles over the sand bed), the schmutzdecke was removed by taking out the top geotextile.

After the schmutzdecke was removed, it was suspended in a determined volume of distilled water and thoroughly mixed. The distilled water volume used for the first run was 1800 ml. For run 2 the distilled water volume was 2000 ml. For runs 3 and 4 the volume was 3000 ml, for runs 5 and 6 it was 4000 ml, and for runs 7 and 8 the volume was 5000 ml. The distilled water volumes used to make the suspensions were different for the filtration runs because the schmutzdecke in some runs was thicker than in others.

Some parameters were measured and several analyses were performed on the schmutzdecke solution, which included:

1. pH
2. Alkalinity
3. Conductivity
4. Turbidity
5. Suspended Solids and Volatile Suspended Solids
6. Total Solids and Volatile Total Solids
7. Biochemical Oxygen Demand (BOD)
8. Chemical Oxygen Demand (COD)
9. Fecal and Total Coliforms.

The biochemical oxygen demand test with the successive dilutions technique was performed on the schmutzdecke solution to determine if there was toxicity present.

5. Results and Discussion

5.1. Filtration Run 1 (0.02 gpm/ft^2 without geotextile at the top of the sand bed)

Water for this filtration run was taken from Río Caín in San Germán. The graphs and tables for this run are presented in Appendix A.

5.1.1. Temperature

Minimum and maximum temperatures for the influent in this run were 23.8 and 28.0°C, respectively. The difference between these two values was 4.2°C. This filtration run extended from October 27 to December 10, 1991.

5.1.2. Pressure Loss

In this filtration run, the terminal pressure head loss of 1 psi was not reached. Maximum pressure loss was 0.6 psi. The run was ended at day 44 when the volume of approximately 1000 gal. of effluent was collected.

5.1.3. Turbidity

There was turbidity removal up to day 26. From day 28 on, there was not a significant difference between influent and effluent values. Effluent turbidity was less than 1.0 NTU all through the run, meeting the water quality standard for this parameter (1.0 NTU). Furthermore, effluent turbidity was greater than 0.5 NTU only between days 6 and 16 (presently, EPA is considering to lower the standard to 0.5 NTU).

5.1.4. Suspended Solids

There was suspended solids (SS) removal up to day 38. Beyond day 40 we can not say that there was removal because both influent and effluent concentrations were almost equal. Although looking at the graph it seems that there was not a significant removal from day 18 on, there were removals of 64% to 86% between days 22 and 32. Effluent concentrations were less than 1.15 mg/l.

5.1.5. Electrical Conductivity (and Total Dissolved Solids)

There was a low conductivity removal. There was a maximum removal of 30 μmho/cm (6.78%) on day 16.

Total dissolved solids (TDS) values were approximated by multiplying electrical conductivity (EC) values by the constant 0.67 ($TDS \approx 0.67 * EC$). Both effluent and influent values throughout the run were less than 330 mg/l, meeting the water quality standard for this parameter (500 mg/l).

5.1.6. pH

There was pH reduction all through the filtration run. Minimum pH of the effluent was 8.16 and maximum pH was 8.53. The effluent exceeded the value of 8.5 only for one day, basically meeting the water quality standard for this parameter (from 6.5 to 8.5).

5.1.7. Alkalinity

There was removal of alkalinity basically throughout the run. Alkalinity consumption is defined as the difference between influent and effluent concentrations. At the beginning of the run (day 0), there was a maximum alkalinity consumption (16.61% removal), then consumption decreased and stayed stable (there was not a tendency to increase or decrease with time throughout the run).

5.1.8. Chemical Oxygen Demand

Since the graphic shows an erratic pattern, a moving average analysis was performed to see the smoothed tendency of the curves. The resulting graph after the moving average analysis was performed shows us that there was removal throughout the run, except for three points (days 22, 24 and 26).

Chemical oxygen demand (COD) consumption is defined as the difference between influent and effluent concentrations. At the end of the run (after day 26) COD consumption increased, thus suggesting an increase of biological activity with time, as it is expected.

5.1.9. Total Coliforms

Effluent concentrations for days 2 and 4 were 2.5 and 1.5 org/100ml, respectively. Such concentrations are very low considering that at the start of a filtration run low removals are expected, since the biological layer known as schmutzdecke has not developed yet. From day 9 on, removal was total (effluent concentrations were 0).

5.1.10. Fecal Coliforms

Effluent concentration at day 2 was 1.5 org/100ml, a very low concentration considering that it occurred at the beginning of a filtration run. From day 4 on, removal was total (effluent concentrations were 0), meeting the water quality standard for this parameter (1 org/100ml).

5.1.11. Filter Maturity

The time required for the filter to reach biological maturity was determined by considering the parameters that are currently regulated by the United States Environmental Protection Agency from those that were measured. These parameters are : turbidity, total dissolved solids, pH and fecal coliforms.

From the discussion of the parameters for this filtration run we know that turbidity was removed and met the standard since the beginning (day 0). There was no significant difference between influent and effluent total dissolved solids throughout the run; however effluent TDS met the standard since the beginning. pH was reduced and met the standard since day 0. Fecal coliforms in the effluent met the standard since day 4. The time required for the filter to reach biological maturity in this filtration run is therefore 4 days.

5.2. Filtration Run 2 (0.04 gpm/ft^2 without geotextile at the top of the sand bed)

Water for this filtration run was taken from Río Caín in San Germán. From day 16 on, there was no flow in Río Caín due to a drought characteristic of the time of the year, and water was taken from a pond at the same sampling site. The graphs and tables for this run are presented in Appendix B.

5.2.1. Temperature

Maximum and minimum influent temperatures for this run were 27.5 and 24.0°C, respectively (a difference of 3.5°C). This run extended from February 4 to February 28, 1992.

5.2.2. Pressure Loss

This filtration run was finished at day 24 because the 1000-gal. effluent volume was collected. Approximately at day 23 terminal pressure head loss was reached, so both criteria to end a run were met. Maximum pressure loss was 1.2 psi.

5.2.3. Turbidity

Turbidity was removed throughout the run. Influent turbidities were less than 1.0 NTU. Effluent turbidity values were less than 0.32 NTU (meeting the standard of 1.0 NTU) and the curve tended to decrease with time.

5.2.4. Suspended Solids

There was effective removal of suspended solids all through the run. Effluent concentrations were less than 0.16 mg/l.

5.2.5. Electrical Conductivity (and Total Dissolved Solids)

Removal was observed all through the run, except for days 14, 22, 24 on which there was no removal (influent and effluent values were equal). A maximum removal of 25 μmho/cm was observed (4.81%) on day 8. From day 14 on there was not a significant difference between influent and effluent values. This could be due to an increase in biological activity. Biological activity generates dissolved matter like non-biodegradable organic residues and nutrients as products of the degradation of organic matter. As time passes in a filtration run, and biological activity increases, the production of dissolved matter increases and could exceed the ion reduction caused by bacteria.

Both influent and effluent TDS concentrations were less than 390 mg/l, meeting the standard (500 mg/l).

5.2.6. pH

There was reduction throughout the run. Minimum and maximum pH values in the effluent were 8.16 and 8.48, respectively, meeting the standard (from 6.5-8.5).

5.2.7. Alkalinity

There was removal throughout the run. Generally, alkalinity consumption was stable (no tendency to increase or decrease with time).

5.2.8. Chemical Oxygen Demand

A moving average analysis was performed to see the smoothed tendencies. After this was done, it can be observed that there was a tendency for removal all through the run. COD consumption increased at the beginning, but from day 7 on, it tended to decrease. A decrease in COD consumption with time is possible due to biological activity, which generates non-biodegradable products which in turn increases effluent COD, making the difference in effluent and influent COD less and thus decreasing consumption.

5.2.9. Total Coliforms

There was removal all through the sampling period. Effluent concentration of day 14 was 25.5 org/100ml in response to the peak (TNTC) in the influent on day 9.

5.2.10. Fecal Coliforms

There was removal throughout the sampling period. Effluent concentration on day 14 was 5 org/100ml in response to the peak of 400 org/100ml in the influent of day 9. On the other days, removal was total (effluent concentration was zero), thus meeting the standard (1 org/100ml).

5.2.12. Filter Maturity

For this filtration run, turbidity and total dissolved solids were removed, and pH was reduced and met the standard since the beginning of the run. Fecal coliforms were removed and met the standard since day 9, although there was an increase on day 14; but the graph was stabilized since day 9. The time required for the filter to reach biological maturity is 9 days, according to the considerations mentioned.

5.3. Filtration Run 3 (0.08 gpm/ft^2 without geotextile at the top of the sand bed)

Water for this filtration run was taken from Río Guanajibo in Hormigueros. The graphs and tables for this run are presented in Appendix C.

5.3.1. Temperature

Minimum and maximum influent temperatures for this run were 25.2 and 28.0°C, respectively, with a difference between these two values of 2.8°C. This filtration run extended from March 10 to March 22, 1992.

5.3.2. Pressure Loss

This filtration run was ended at day 12 because the 1000-gal. volume of effluent was collected. Terminal pressure head loss was not reached. Maximum pressure loss was 0.7 psi.

5.3.3. Turbidity

There was effective removal throughout the filtration run. In this run removals were better observed since influent turbidities were higher than those of the first runs (this is a characteristic of Río Guanajibo). Effluent turbidities were less than 0.5 NTU all through the run, meeting the standard (1.0 NTU).

5.3.4. Suspended Solids

As with turbidity, removal of suspended solids was effective throughout the run and was observed in a better way than in the first runs because of the higher influent concentrations found in Río Guanajibo. Effluent concentrations were less than 0.08 mg/l.

5.3.5. Electrical Conductivity (and Total Dissolved Solids)

Influent and effluent values were basically the same throughout the run. There was a maximum removal of 5 μmho/cm (1.56%) which occurred on day 7. The fact that there was no considerable removal during this run could be due to the fact that bacteria had not enough time to trap ions, since this was the fastest filtration run (0.08 gpm/ft^2).

Both effluent and influent TDS concentrations were less than 245 mg/l, meeting the standard (500 mg/l).

5.3.6. pH

Reduction was observed throughout the run, except for day 0. Minimum and maximum pH values were 8.04 and 8.28, respectively, meeting the standard (from 6.5 to 8.5).

5.3.7. Alkalinity

There was alkalinity removal except at the beginning of the run (day 0). Alkalinity consumption increased at the end of the run (day 12), suggesting an increase in biological activity.

5.3.8. Chemical Oxygen Demand

A moving average analysis was performed to see in a better way the tendencies. After this was done, removal was observed throughout the run. COD consumption tended to decrease with time, possible due to the same reason given on filtration run 2 for this parameter (section 5.2.8).

5.3.9. Total Coliforms

There was removal all through the sampling period. On days 5 and 8, effluent concentrations were 0.5 and 0 org/100ml, respectively. The peak of 200 org/100ml in the effluent (day 10) and the concentration of 50.5 org/100ml on day 12 were a response to the peak of TNTC in the influent for day 10.

5.3.10. Fecal Coliforms

Removal was total (effluent concentration of 0) all through the sampling period, thus meeting the standard (1 org/100ml).

5.3.11. Filter Maturity

In this run, turbidity was removed and met the standard since day 0. Although there was no significant difference between influent and effluent TDS values throughout the run, effluent concentrations met the standard since day 0. Effluent pH met the standard all through the run, but there was reduction since day 2. Fecal coliforms were removed and met the standard since day 5. The time required for the filter to reach biological maturity is therefore 5 days.

5.4. Filtration Run 4 (0.06 gpm/ft^2 without geotextile at the top of the sand bed)

Water for this filtration run was taken from Río Guanajibo in Hormigueros with one exception. The last 200-gal. volume of influent for the run was taken from Río Caín because there was a flood at the sampling site at Río Guanajibo the day it was taken. The graphs and tables for this run are presented in Appendix D.

5.4.1. Temperature

Minimum and maximum influent temperatures for this run were 27.0 and 31.0°C, respectively (a difference of 4.0°C). This filtration run extended from April 1 to April 18, 1992.

5.4.2. Pressure Loss

This run was finished at day 17 because the 1000-gal. effluent volume was collected. Terminal pressure head loss was not reached. Maximum pressure loss was 0.70 psi.

5.4.3. Turbidity

There was effective removal all through the run, including removals of up to 98.46% (on day 6). Effluent turbidities were less than 0.5 NTU, meeting the standard (1.0 NTU).

5.4.4. Suspended Solids

Removal was effective, with effluent concentrations less than 0.4 mg/l all through the run. There were removals of 100%.

5.4.5. Electrical Conductivity (and Total Dissolved Solids)

There was not a significant difference in effluent and influent values throughout the run. This occurs probably due to the fact that this is the second fastest filtration run, and bacteria do not have time enough time to trap ions. There was a maximum difference of 10 μmho/cm (3.08% removal).

An explanation to the increase in both influent and effluent conductivities at day 17 could be the fact that the last influent of the run was taken from Río Caín. Río Caín is a smaller river than Río Guanajibo and thus the contribution of the groundwater (with a high concentration of dissolved solids) to the base flow is greater than that in Río Guanajibo.

Both effluent and influent TDS concentrations were less than 340 mg/l, meeting the standard (500 mg/l).

5.4.6. pH

There was pH reduction basically throughout the run. Minimum and maximum pH values in the effluent were 8.07 and 8.40, respectively, meeting the standard (from 6.5 to 8.5).

5.4.7. Alkalinity

There was not a considerable alkalinity removal throughout this run. A maximum removal of 8.76 mg$CaCO_3$/l (5.93%) was observed at day 8.

5.4.8. Chemical Oxygen Demand

COD removal was observed starting from day 4. However, a moving average analysis was performed to see more clearly the tendencies. From the moving average graph we can see that there was removal throughout the run except at the beginning (day 3). COD consumption tended to increase with time, suggesting an increase in biological activity with time.

5.4.9. Total Coliforms

Effluent concentrations were 0 since day 1.

5.4.10. Fecal Coliforms

As with total coliforms, fecal coliform concentrations in the effluent were 0 since day 1, meeting the standard (1 org/100ml).

5.4.11. Filter Maturity

For this filtration run, turbidity was removed and met the standard since day 0. Although there was not a significant difference between influent and effluent TDS concentrations, effluent values met the standard since day 0. pH was reduced and met the standard since day 0. Fecal coliforms were removed and met the standard since day 1. The time required for the filter to reach biological maturity is 1 day for this filtration run.

5.5. Filtration Run 5 (0.02 gpm/ft^2 with geotextile at the top of the sand bed)

Water for this run was taken from Río Guanajibo in

Hormigueros. The graphs and tables for this run are presented in Appendix E.

5.5.1. Temperature

Minimum and maximum influent temperatures for this run were 27.2 and 31.5°C respectively (a difference of 4.3°C). This run extended from June 16 to July 30, 1992.

5.5.2. Pressure Loss

This run was finished at day 44 because the 1000-gal. effluent volume was collected. Terminal pressure head loss did not occur. Maximum pressure loss was 0.7 psi.

5.5.3. Turbidity

There was turbidity removal all through the run. Effluent turbidity tended to increase at the second half of the run in response to the peaks of the influent at days 26, 34 and 42. However, effluent turbidities were less than 0.55 NTU throughout the run, thus meeting the standard (1.0 NTU). Moreover, the only point at which effluent turbidity was greater than 0.5 was day 28.

5.5.4. Suspended Solids

Suspended solids removal was observed throughout the run. Effluent concentrations were less than 1.6 mg/l.

5.5.5. Electrical Conductivity (and Total Dissolved Solids)

There was not a significant difference between influent and effluent values throughout the run. A maximum removal of 12.5 μmho/cm (3.70%) was observed at day 6. Basically, at the first half of the filtration run removal occurred, while at the second half of the filtration run effluent values were greater than influent values. A possible explanation to this behavior is given in section 5.2.5.

TDS values in the effluent and in the influent were less than 250 mg/l, thus meeting the standard (500 mg/l).

5.5.6. pH

pH was reduced all through the run. Minimum and maximum pH values in the effluent were 7.93 and 8.50 respectively, meeting the standard (from 6.5 to 8.5).

5.5.7. Alkalinity

There was alkalinity removal up to day 22. From day 24 on, there was not a significant difference between influent and effluent concentrations. Alkalinity consumption tended to decrease with time. A possible explanation to this is that within the filter, organic nitrogen is being hydrolyzed by bacterial decomposition and transformed to ammonia nitrogen. This process generates alkalinity, so effluent concentration increases and the difference between influent and effluent values decreases (consumption decreases).

5.5.8. Dissolved Oxygen

Dissolved oxygen (DO) consumption is defined as the difference between influent and effluent concentrations. DO consumption tended to increase with time, suggesting an increase of biological activity with time.

5.5.9. Chemical Oxygen Demand

Due to the erratic form of the graph, a moving average was performed. As a result, the removal tendency was observed throughout the run. COD consumption tended to increase at the beginning of the filtration run (up to day 18). After day 18 there was a tendency to decrease with time, possibly for the same reason given in section 5.2.8.

5.5.10. Total Coliforms

There was total coliform removal all through the run. From day 9 on, effluent concentrations were basically stabilized (considering the high influent concentrations).

5.5.11. Fecal Coliforms

From day 9 on, effluent concentrations were 0, meeting the standard (1 org/100ml). However, on days 14,16 and 21, both effluent and influent concentrations were 0.

5.5.12. Biochemical Oxygen Demand

Biochemical Oxygen Demand (BOD) was measured at the beginning, midpoint and at the end of the run to determine if there was toxicity present. An increase in BOD with increasing dilution is a sign of toxicity in the sample.

For day 1, the influent showed the toxicity pattern, but the effluent did not (apparently toxicity was being removed by the filter). On day 23, the influent did not seem to show the toxicity pattern. For day 44 (last), the influent showed again the toxicity pattern, but the effluent did not (apparently toxicity was being removed again by the filter).

5.5.13. Filter Maturity

Turbidity in this run was removed and met the standard since day 0. Although there was not a significant difference in influent and effluent TDS, effluent concentrations met the standard since day 0. pH was reduced and met the standard since day 0. Effluent fecal coliforms met the standard since day 9. The time that the filter required to reach biological maturity was 9 days, according to the above discussion.

5.6. Filtration Run 6 (0.04 gpm/ft^2 with geotextile at the top of the sand bed)

Water for this run was taken from Río Guanajibo in Hormigueros. The graphs and tables for this run are presented in Appendix F.

5.6.1. Temperature

Minimum and maximum influent temperatures were 27.4 and 32.8°C (a difference of 5.4°C). This run extended from August 18 to August 31, 1992.

5.6.2. Pressure Loss

This filtration run was ended at day 13 because terminal pressure head loss occurred, as a result of the SS concentration and turbidity overloads to which the filter was subjected during this run. Maximum pressure loss was 4.5 psi.

The run should have lasted 22 days, based on the criterion of the 1000-gal. volume of effluent.

5.6.3. Turbidity

Removal occurred all through the run. Effluent turbidities were greater than 1.0 NTU from day 0 to day 8, because of the high influent turbidities (from 73 to 14 NTU). However, effluent turbidities were less than 2.0 NTU through this period. There was a drastic increase in effluent turbidity at days 10 and 12 (11 and 12 NTU respectively) because of the extremely high turbidities of the influent (385 and 380 NTU respectively). However, removals for these days (days 10 and 12) were 97.14% and 96.84% respectively. The standard (1.0 NTU) was not met on this run.

5.6.4. Suspended Solids

There was removal throughout the run. Effluent concentration increased at day 12 in response to the influent SS overload to which the filter was subjected on days 10 and 12. Effluent concentrations were less than 2.5 mg/l throughout the run. Moreover, effluent concentrations were less than 0.6 mg/l except for days 12 and 13, on which the values were 2.45 and 1.13 mg/l respectively. However, removal for day 12, on which the peak in effluent concentration occurred, was 99.46%. The smallest removal throughout the run was 99.21% at day 13.

The relatively low effluent SS concentrations compared to the high effluent turbidities suggests that the majority of the solids in the effluent contributing to those high turbidities were colloidal solids.

5.6.5. Electrical Conductivity (and Total Dissolved Solids)

Through the first half of the filtration run there was removal, but through the second half effluent were greater than influent values. A possible explanation to this behavior could be the one given in section 5.2.5. However, there was not a significant difference between effluent and influent values throughout the run. A maximum removal of 5 μmho/cm (1.75%) is observed at day 0.

Both TDS curves were below 220 mg/l, meeting the standard (500 mg/l).

5.6.6. pH

There was pH reduction all through the run. Minimum and maximum pH values were 8.07 and 8.47 respectively, meeting the standard (from 6.5 to 8.5).

5.6.7. Alkalinity

There was removal up to day 8. On days 10 and 13, effluent was greater than influent alkalinity, but these differences were not significant. On day 12, both influent and effluent concentrations were equal. Alkalinity consumption tended to decrease with time. A possible explanation to this behavior is given in section 5.5.7.

5.6.8. Dissolved Oxygen

DO consumption tended to increase with time, suggesting an increase of biological activity with time.

5.6.9. Chemical Oxygen Demand

Due to the erratic pattern observed in this graphic, a moving average analysis was performed. As a result, a removal tendency was observed throughout the run except at the beginning (day 4). A general tendency to increase or decrease with time of COD consumption was not observed.

5.6.10. Total Coliforms

There was removal of this parameter throughout the run. The high effluent concentrations were a response to the high concentrations of the influent throughout the run. The peak in the effluent curve (1650 org/100ml) at day 9 responds to the peak in the influent curve (47000 org/100ml) at the same day. The high effluent concentration at day 0 (1408 org/100ml) responds to the high influent concentration (7000 org/100ml) at the same day, as well as to the fact that the schmutzdecke had not developed yet.

5.6.11. Fecal Coliforms

There was removal all through the run. As in total coliforms, the high effluent concentrations were a response to the high influent concentrations throughout the run. The effluent peak at day 9 (250 org/100ml) responds to the influent peak at the same day (4000 org/100ml). The high effluent concentration at day 0 (400 org/100ml) responds to the high influent concentration (1100 org/100ml), as well as to the fact that the schmutzdecke had not developed yet. The standard (1 org/100ml) was met only at day 7.

5.6.12. Biochemical Oxygen Demand

At day 0, the influent showed the toxicity pattern, while the effluent did not (apparently toxicity was being removed by the filter). At day 13 (last) the influent also showed the toxicity pattern. Effluent BOD results for day 13 were negative values for almost all of the dilutions. A possible explanation for this behavior follows: there could be a high toxicity in the sample that is inhibiting bacteria in such a way that there is more activity in the controls of the test than in the samples, thus making BOD values negative.

5.6.13. Filter Maturity

There was turbidity removal all through the run, but the standard was not met. Effluent TDS met the standard since day 0, although there was not a significant difference between influent and effluent values throughout the run. pH was reduced and met the standard since day 0. Fecal coliforms were removed all through the run, but met the standard only at day 7. After this day, effluent fecal coliforms did not met the standard because of the high influent concentrations to which the filter was subjected. The time required for the filter to reach biological maturity in this run is therefore 7 days.

5.7. Filtration Run 7 (0.06 gpm/ft^2 with geotextile at the top of the sand bed)

Water for this run was taken from Río Guanajibo in Hormigueros. The graphs and tables for this run are presented in Appendix G.

5.7.1. Temperature

Minimum and maximum influent temperatures were 27.3 and 30.6°C respectively (a difference of 3.3°C). This filtration run extended from September 9 to September 20, 1992.

5.7.2. Pressure Loss

This filtration run was finished at day 11 because terminal pressure head loss occurred, as a result of the high SS concentrations and turbidities to which the filter was subjected during this run and the overloads to which it was subjected during the previous run. Maximum pressure loss was 1.7 psi. This filtration run should have lasted 15 days, according to the criterion of the 1000-gal. effluent volume.

5.7.3. Turbidity

There was turbidity removal throughout the run. However, effluent turbidities were greater than 4 NTU (not meeting the standard of 1 NTU). The increase in effluent turbidities on days 4 and 6 (14 NTU at both days) respond to the increase in influent turbidities at the same days (85.5 NTU and 79.5 NTU respectively). However, removals for these days were 83.63% and 82.39% respectively. The generally high effluent turbidity responds to the turbidity overloads to which the filter was subjected in the previous run, and the high influent turbidities in this run.

A decision was taken to dilute the water taken from the river (in the case its turbidity was very high), to have a maximum influent turbidity of approximately 25 NTU, which is the highest influent turbidity accepted for a conventional slow sand filter. This decision was taken in order to avoid subjecting the filter to such SS concentration and turbidity overloads furthermore. This was done starting from day 6. However, because of errors in calculation, the dilution of the raw water on day 6 was not correctly done and thus influent turbidity was 79.5 NTU.

5.7.4. Suspended Solids

There was SS removal throughout the run. Effluent concentrations were less than 1.4 mg/l. The relatively low effluent SS concentrations compared to the high effluent turbidities suggests that the majority of the solids contributing to such high turbidities are colloidal solids. However, minimum removal in the run was 97.58% at day 2.

5.7.5. Electrical Conductivity (and Total Dissolved Solids)

There was not a significant difference between influent and effluent values throughout the run. There was a maximum difference of 10 μmho/cm at day 4, effluent EC being greater than influent EC.

Both effluent and influent TDS concentrations were less than 195 mg/l throughout the run, meeting the standard (500 mg/l).

5.7.6. pH

There was pH reduction all through the run. Minimum and maximum effluent pH values were 8.16 and 8.49 respectively, meeting the standard (from 6.5 to 8.5).

5.7.7. Alkalinity

Low alkalinity removal was observed throughout this run. Maximum removal was 5.06 $mgCaCO_3/l$ (3.86%) at day 2. Alkalinity consumption tended to decrease with time. A possible explanation to this behavior is given in section 5.5.7.

5.7.8. Dissolved Oxygen

DO consumption tended to increase with time, suggesting an increase in biological activity with time.

5.7.9. Chemical Oxygen Demand

Due to the erratic behavior of the graph, a moving average analysis was performed. The moving average graph shows removal tendency all the time. Generally, COD consumption tended to decrease with time. This behavior could be possible for the reason given in section 5.2.8.

5.7.10. Total Coliforms

Total coliform removal was observed all through the run. Effluent concentrations tended to decrease with time. The high concentrations in the effluent are a response to the high influent concentrations. The initial high concentration (day 0) in the effluent of 4250 org/100ml is a result of the extremely high influent concentration (14000 org/100ml), and due to the fact that the schmutzdecke had not developed yet.

5.7.11. Fecal Coliforms

There was fecal coliform removal all through the sampling period. Effluent concentrations tended to decrease with time. The water quality standard for fecal coliforms (1 org/100ml) was met only at the end of the run (day 11).

5.7.12. Biochemical Oxygen Demand

BOD results for day 0 on both effluent and influent were negative on most of the dilutions. A possible explanation is given in section 5.6.12. BOD results for day 8 show the toxicity pattern in the effluent. Influent BOD values were negative in most of the dilutions, possibly to the reason explained in section 5.6.12. For day 11 (last) effluent BOD results do not show the toxicity pattern. BOD values for the influent were negative in most of the dilutions, possibly due to the reason explained in section 5.6.12.

5.7.13. Filter Maturity

Turbidity was removed since day 0, but did not met the standard. Although there was no TDS removal throughout the run, effluent TDS met the standard since day 0. pH was reduced and met the standard since day 0. Although fecal coliforms did not meet the standard until day 11, effluent concentrations dramatically decreased and tended to stabilize since day 3. The time required for the filter to reach biological maturity is therefore 3 days.

5.8. Filtration Run 8 (0.08 gpm/ft^2 with geotextile at the top of the sand bed)

Water for this filtration run was taken from Río Caín in San Germán (with lower turbidity and SS concentration than that from Río Guanajibo), because it was suspected that the sand bed of the filter was clogged, as a result of the overloads in SS and turbidity to which it was subjected during the two previous runs. The graphs and tables for this run are presented in Appendix H.

5.8.1. Temperature

Minimum and maximum influent temperatures for this run were 25.3 and 31.6°C (a difference of 6.3°C). This was the only run in which temperature tended to increase with time. This run extended from September 23 to October 4,1992.

5.8.2. Pressure Loss

This filtration run was finished at day 11 because the 1000-gal. effluent volume was collected. Terminal pressure head loss was not reached in this run. Maximum pressure loss was 0.7 psi.

5.8.3. Turbidity

From day 0 to day 5, there was an export of turbidity from the filter sand bed to the effluent, because effluent was greater than influent turbidity. After day 5 a low removal occurred, being 44.24% the maximum (day 7). Effluent turbidities were greater than 3 NTU throughout the run, although influent values were less than 11 NTU. Influent turbidities were not high enough to cause such high turbidities in the effluent (this can be observed in previous runs). These facts confirm the belief that the sand bed of the filter was clogged. Effluent turbidities did not met the standard (1 NTU).

5.8.4. Suspended Solids

There was removal throughout the run. Effluent SS concentrations were less than 3 mg/l all the time. Effluent concentrations were not so low considering that influent concentrations were not as high as those of previous runs, which yielded lower effluent concentrations than the ones obtained in this run. This seems to confirm the belief that the sand bed of the filter was clogged.

5.8.5. Electrical Conductivity (and Total Dissolved Solids)

There were small differences between influent and effluent values at days 5 and 9; for the rest of the run influent and effluent values were the same. A possible explanation to this behavior could be the fact that since this is the fastest filtration run, bacteria had not enough time to trap ions.

Both effluent and influent TDS concentrations were less than 230 mg/l, meeting the standard (500 mg/l).

5.8.6. pH

There was pH reduction throughout the run. Minimum and maximum pH values were 8.28 and 8.60 respectively. pH was greater than 8.5 at three days, exceeding the standard (from 6.5 to 8.5). pH values at days 2, 4 and 9 were 8.60, 8.56, and 8.51 respectively.

5.8.7. Alkalinity

There was not a significant difference between influent and effluent concentrations throughout the run. A maximum removal of 4.93 mgCaCO$_3$/l (3.94%) at day 0. Alkalinity consumption tended to decrease with time, possibly for the reason given in section 5.5.7.

5.8.8. Dissolved Oxygen

DO consumption tended to increase with time, suggesting an increase of biological activity with time.

5.8.9. Chemical Oxygen Demand

There was COD removal basically all through the run. However, after a moving average analysis was performed, removal tendency was better observed throughout the run. COD consumption tended to decrease with time, possibly due to the reason given in section 5.2.8.

5.8.10. Total Coliforms

There was removal all through the run. Effluent concentrations at the beginning of the run were high due to the high influent concentrations and due to the fact that the schmutzdecke had not developed. Then effluent decreased until there were 0 org/100ml at day 7. After that point, the effluent curve increased in response to the high influent concentrations of 8500 and 5577 org/100ml at days 7 and 9 respectively.

5.8.11. Fecal Coliforms

There was fecal coliform removal throughout the run. The high effluent turbidities at the start of the run were in response to the high influent concentrations and to the fact that the schmutzdecke had not developed. Effluent concentrations decreased until the standard (1 org/100ml) was met at day 7, with a concentration of 0 org/100ml. After this point, effluent concentrations increased because of the high influent concentrations at days 7 and 9.

5.8.12. Biochemical Oxygen Demand

At day 0, most of the dilutions of the BOD test were negative. A possible explanation to this behavior is given in section 5.6.12. At days 6 and 11, influent BOD results did not show the toxicity pattern. Effluent BOD values for most of the dilutions were negative probably for the reason given in section 5.6.12.

5.8.13. Filter Maturity

In this filtration run, there was a low turbidity removal and effluent turbidities did not meet the standard. Furthermore, there was not a tendency in effluent turbidities to stabilize with time. Effluent TDS concentrations met the standard since day 0, although there was not a significant difference between influent and effluent values. pH was reduced since day 0, but met the standard basically since day 5. Fecal coliforms were removed since day 0, but the standard was met at day 7. The time required for the filter to reach biological maturity is 7 days for this run, according to the above discussion.

5.9. Schmutzdecke Characterization Analyses

The BOD test for the schmutzdecke in filtration runs 1 to 5 showed the toxicity pattern, while for runs 6, 7 and 8 it did not. Apparently the filter removed toxicity in the first 5 runs, but did not remove it in runs 6, 7 and 8.

The BOD test of the effluent of the last day for filtration runs 2 and 3 showed the toxicity pattern (apparently toxicity was escaping, although part of it was being removed by the filter). The BOD values for all the dilutions were negative in the effluent of the last day for run 4 . An explanation to this behavior could be a high toxicity, as explained in section 5.6.12.

Generally, for all the parameters measured, it was observed that for runs 6 and 7 (on which the turbidity and SS overloads occurred) the concentrations and values of the parameters in the schmutzdecke were the greatest of all. In the same way, it was observed that for runs 1 and 2 (the runs with generally lowest influent turbidities) the concentrations and values of the parameters in the schmutzdecke were the smallest of all.

5.10. Flow and Hydraulic Loading Rates

Real flows in gal/hr varied from theoretical values in the first decimal place at most, as can be seen in Table I-1 (Appendix I). However, these differences were not significant because real hydraulic loading rates, when rounded up to the second decimal place, met theoretical values. This can be observed in Table I-2.

5.11. *Giardia lamblia* Removal

It was not possible to evaluate *Giardia* cyst removal using surface waters with their natural cyst concentrations. Throughout the investigation, all *Giardia* samples taken in both rivers (Río Caín and Río Guanajibo) showed no presence of cysts. This is true for all the investigation period, even though in the preliminary sampling performed before starting the filtration runs, samples taken in a tributary of Río Caín and upstream from the sampling site during the filtration runs in Río Guanajibo showed the presence of cysts. However, these concentrations were low, being 5 cysts/100l the maximum for Quebrada Río Piedras (tributary of Río Caín) and 8 cysts/100l the maximum for Río Guanajibo upstream from the sampling site during the investigation. As a result, Giardia cysts were added to the influent in the filtration runs simulating concentrations found in natural superficial waters in Puerto Rico, and higher concentrations.

Giardia lamblia cysts were completely removed in all eight filtration runs, as can be seen in Table J-1 (Appendix J). Of special interest is the fact that cysts were completely removed in the last three runs. In these runs, cysts were added in greater numbers, and suspended solid concentrations and turbidities in the effluent were high in response to the overloads of this parameters to which the filter was subjected during runs 6 and 7. The excellent cyst removals in these runs are possibly a result of the additional removal capacity of the geotextiles, as well as biological activity in the schmutzdecke.

The filter completely removed Giardia lamblia cysts in concentrations of up to 43 cysts/100l without the need of the unwoven geotextile. The filter also removed completely Giardia cysts in concentrations of up to 18,576 cysts/100l using geotextiles on top of the sand bed. The highest concentration found so far in natural superficial waters in Puerto Rico has been approximately 195 cysts/100l (Toranzos, pers. com., 1990).

Giardia cyst removal apparently was not affected by changes in water temperature.

6. Conclusions

1. The compact, prefabricated, pressure driven slow sand filter completely removed <u>Giardia lamblia</u> cysts in concentrations of up to 43 cysts/100l without the need of the unwoven geotextile. The filter also removed completely <u>Giardia</u> cysts in concentrations of up to 18,576 cysts/100l using geotextiles on top of the sand bed.
2. The filter was effective providing near potable water in terms of the water quality standards of the U.S. Environmental Protection Agency, provided that influent turbidity was less than 23 NTU without using geotextiles on top of the sand bed and 37 NTU using them. The value of 37 NTU, which is greater than the maximum used in conventional slow sand filters (25 NTU) demonstrates the additional removal capacity of the geotextiles.
3. The quality of the effluent did not seem to deteriorate with increasing hydraulic

loading rate; rather, it seemed to deteriorate with increasing influent turbidity.

4. Fecal coliforms were removed to a level that could be eliminated by adding the final step of disinfection. As a matter of fact, they were removed completely in some runs.
5. Electrical conductivity (and thus Total Dissolved Solids) is a parameter that was not changed by the filter (its removal was not significant).
6. The time required for the filter to reach biological maturity was from as low as 1 day to 9 days.

7. Recommendations

1. An investigation should be carried out in order to study the inactivation of Giardia lamblia cysts using chlorine under tropical conditions.
2. Research should be carried out involving rapid sand filtration of Giardia lamblia cysts in Puerto Rico, since it is the treatment process used by the Puerto Rico Aqueduct and Sewer Authority (PRASA) water treatment plants.
3. Further research should be carried out in order to study the removal of viruses from surface waters in Puerto Rico using slow sand filtration, since our surface waters are highly contaminated with fecal matter (as was demonstrated in this investigation).

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Appendix A: Illustrations for Filtration Run 1

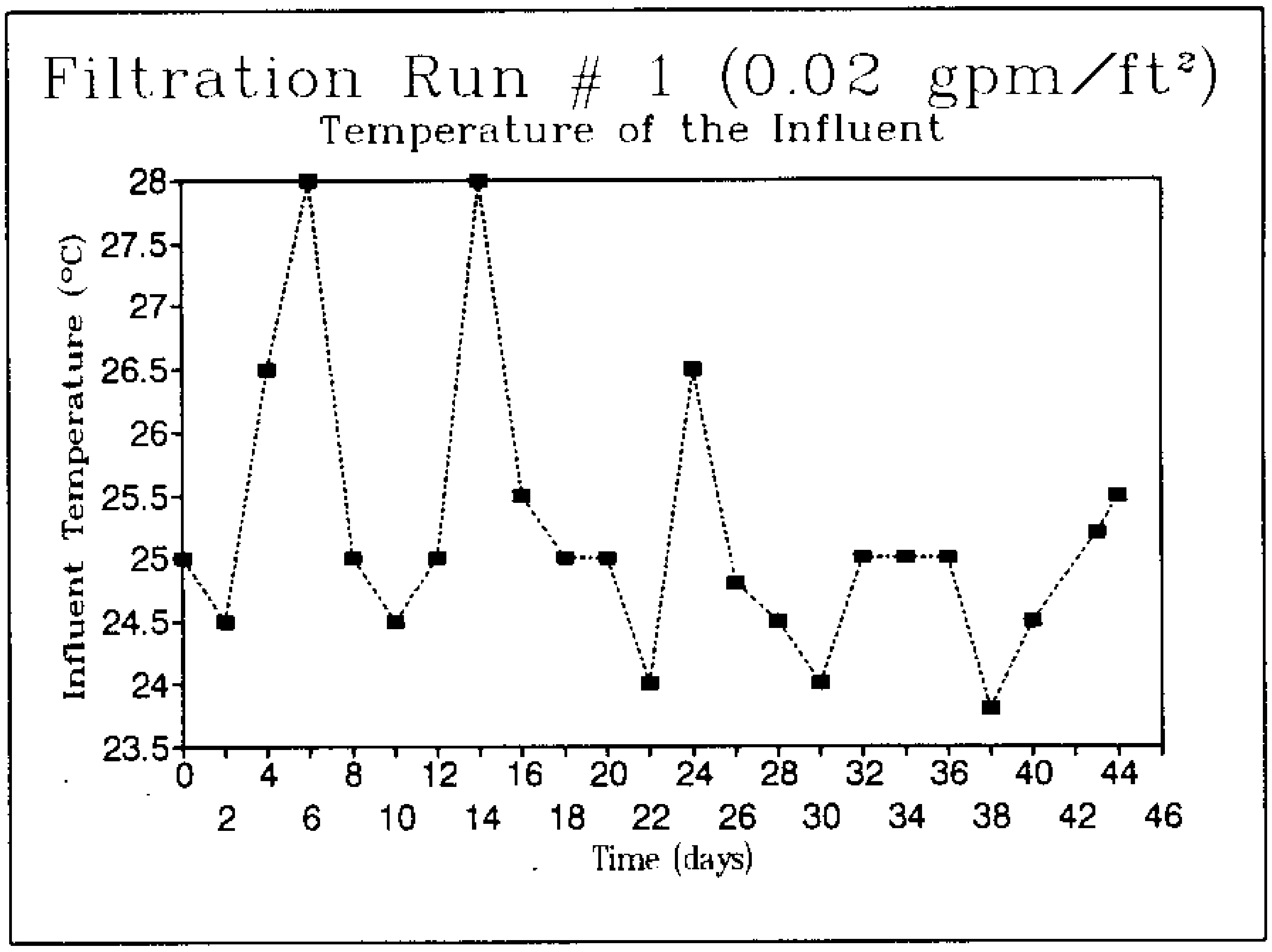

FIG. A-1.- Influent Temperature for Filtration Run 1

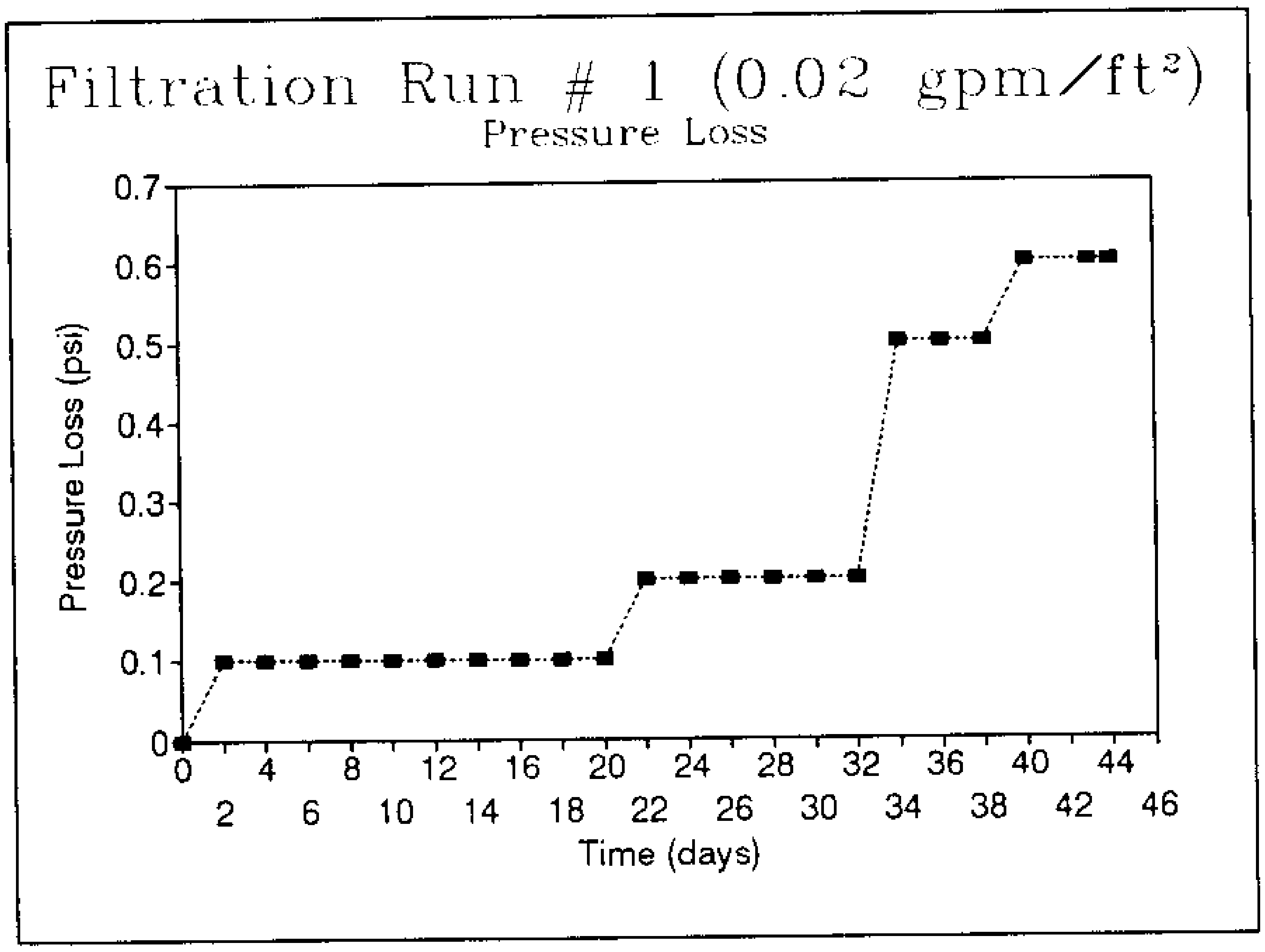

FIG. A-2.- Pressure Loss for Filtration Run 1

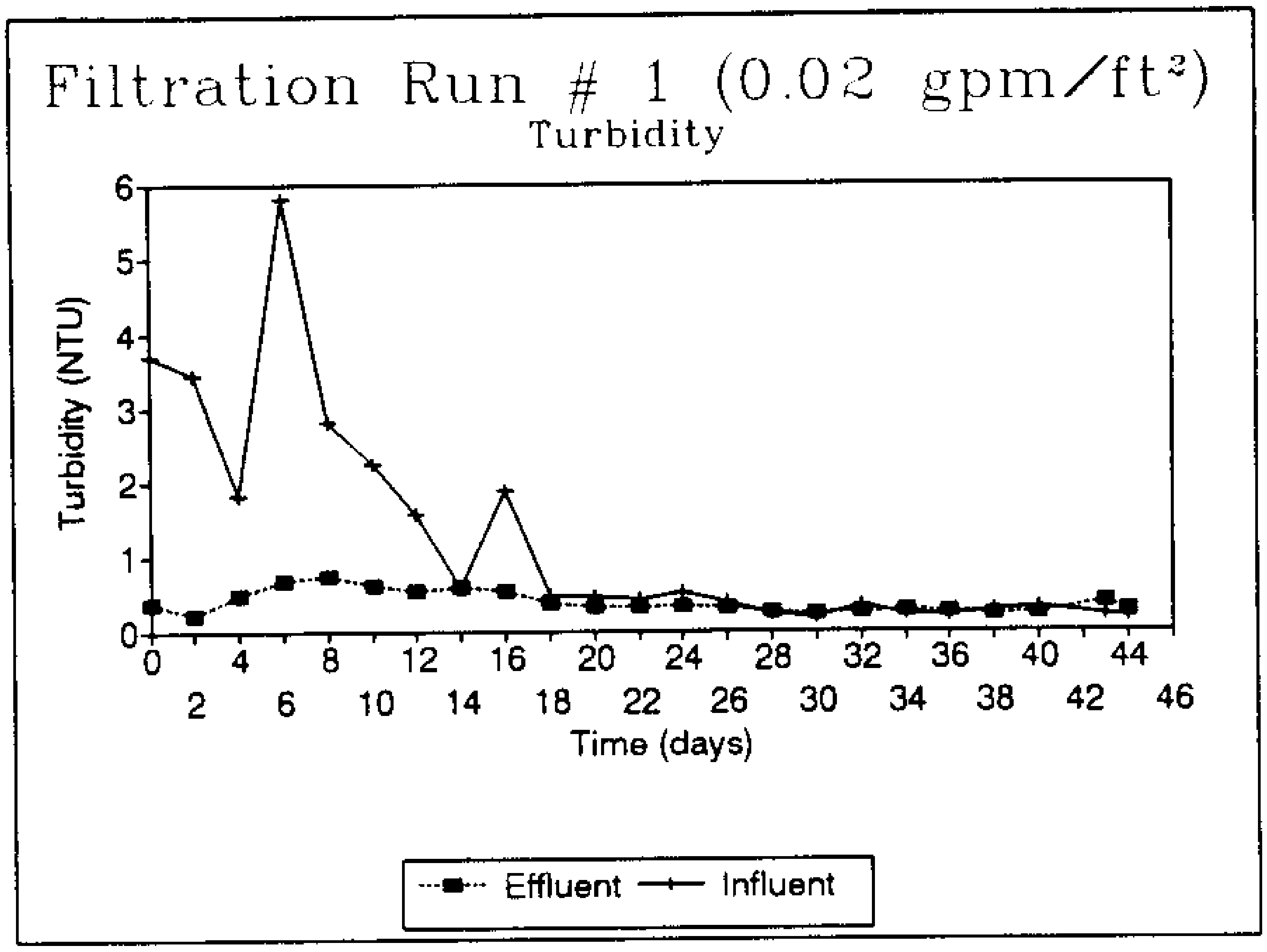

FIG. A-3.- Turbidity for Filtration Run 1

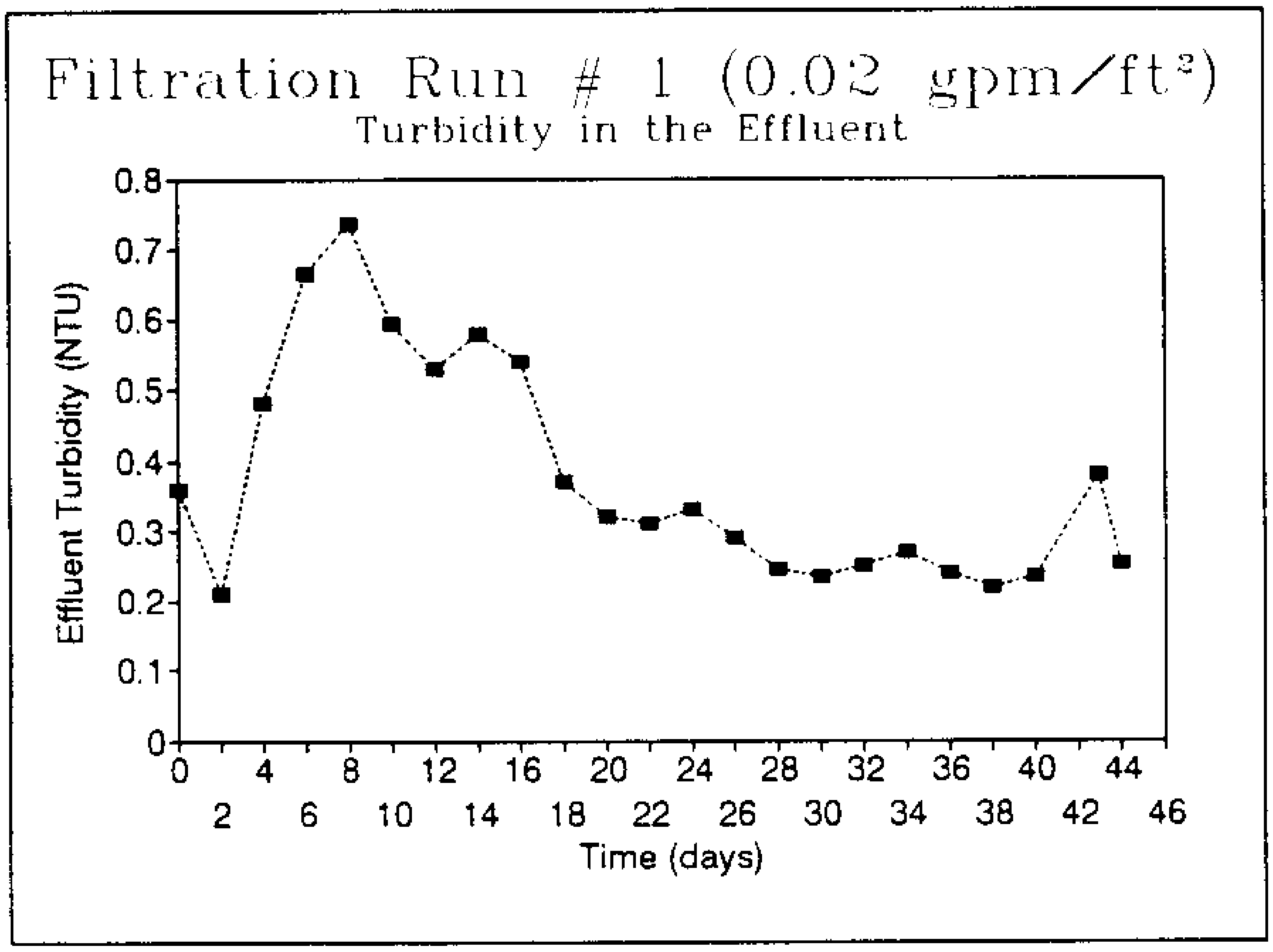

FIG. A-4.- Effluent Turbidity for Filtration Run 1

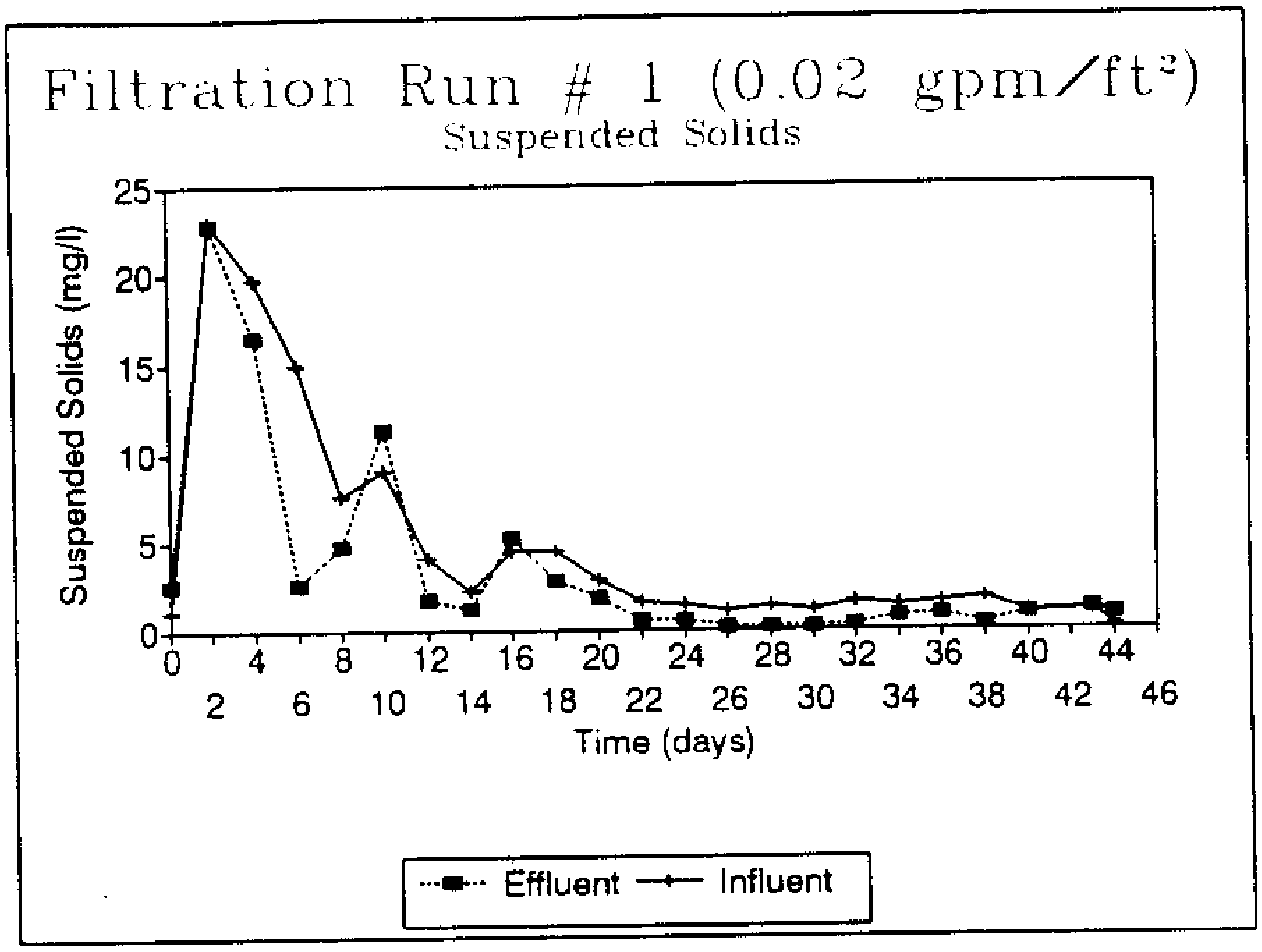

FIG. A-5.- Suspended Solids for Filtration Run 1

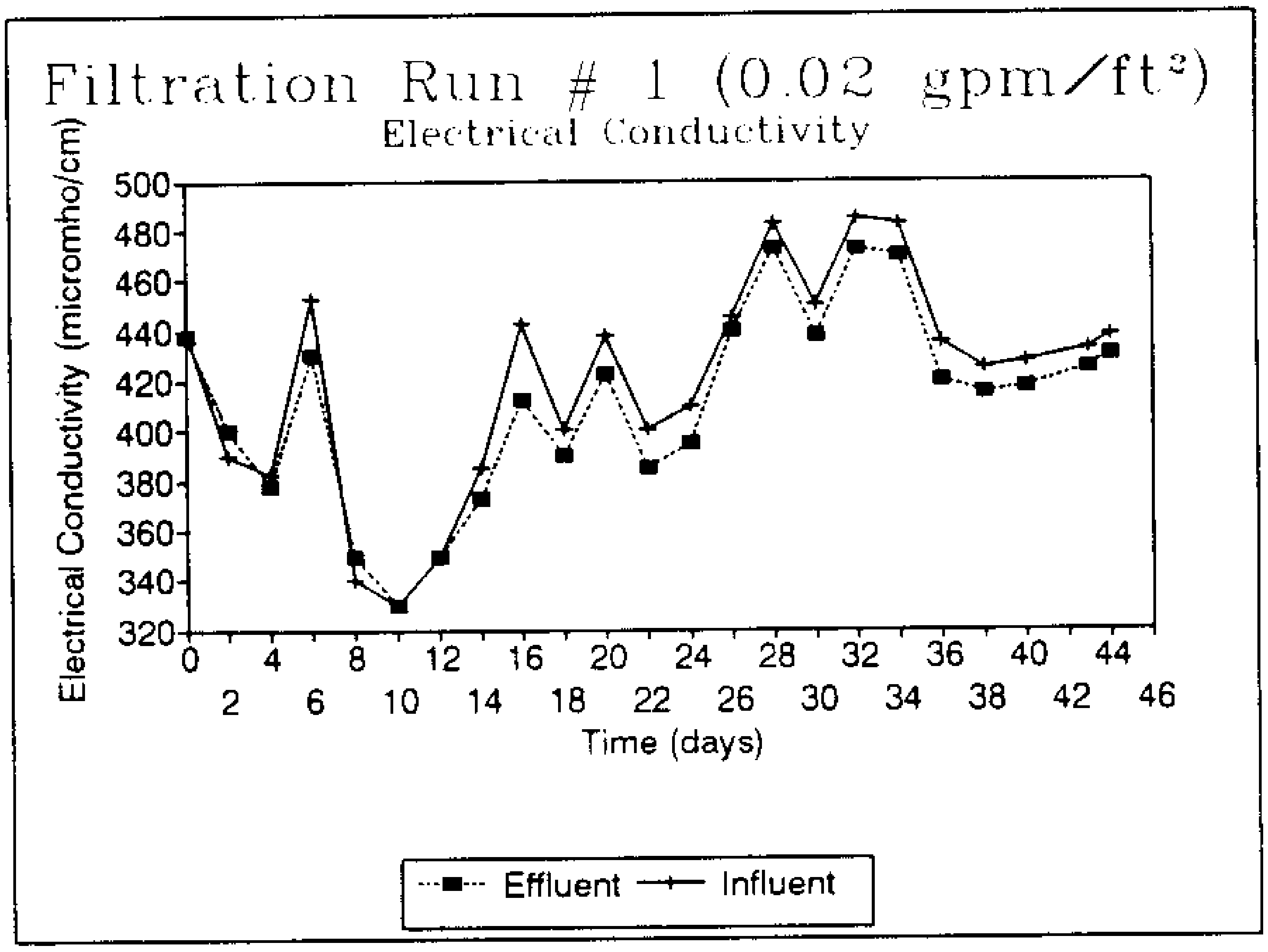

FIG. A-6.- Electrical Conductivity for Filtration Run 1

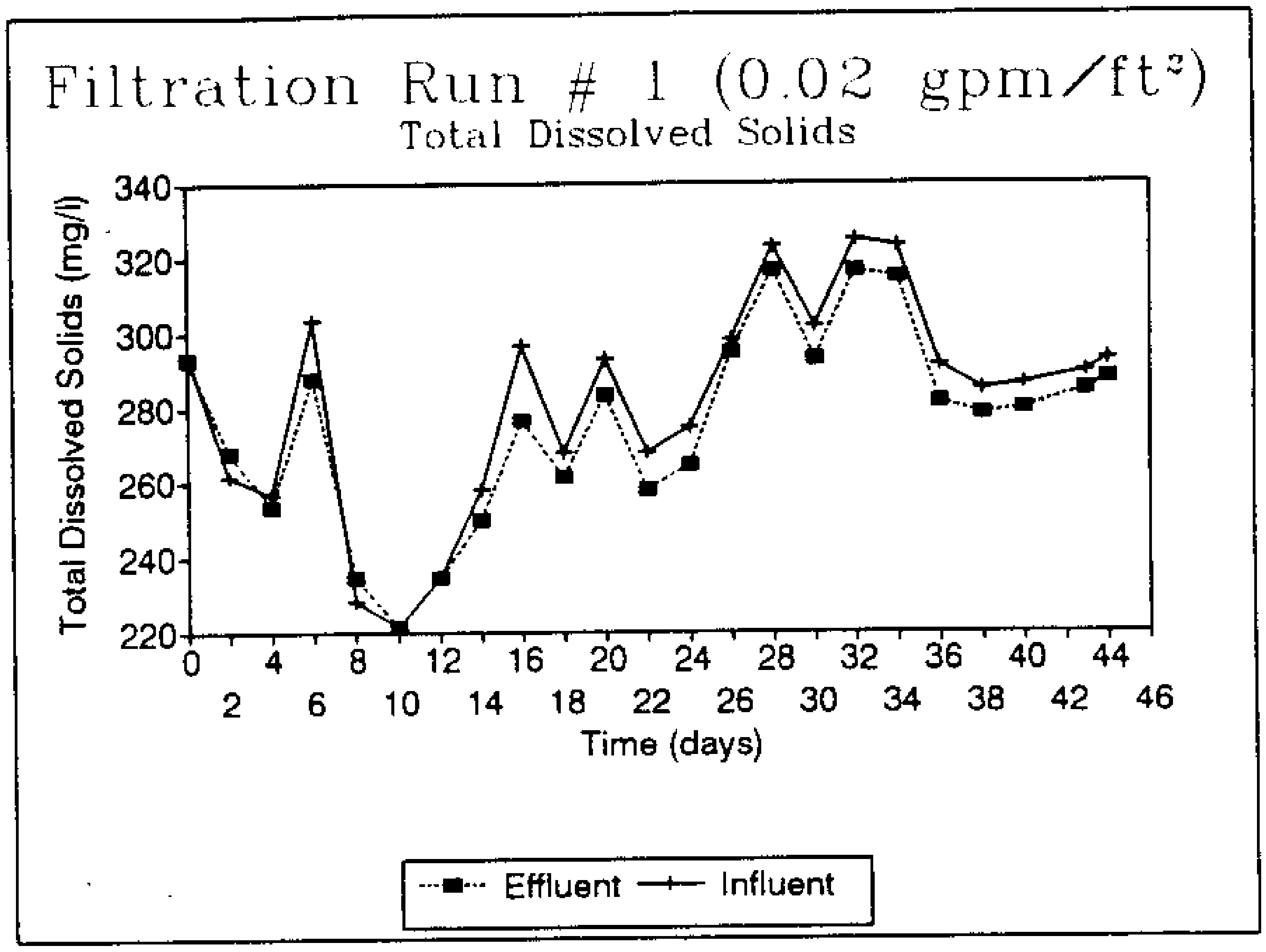

FIG. A-7.- Total Dissolved Solids for Filtration Run 1

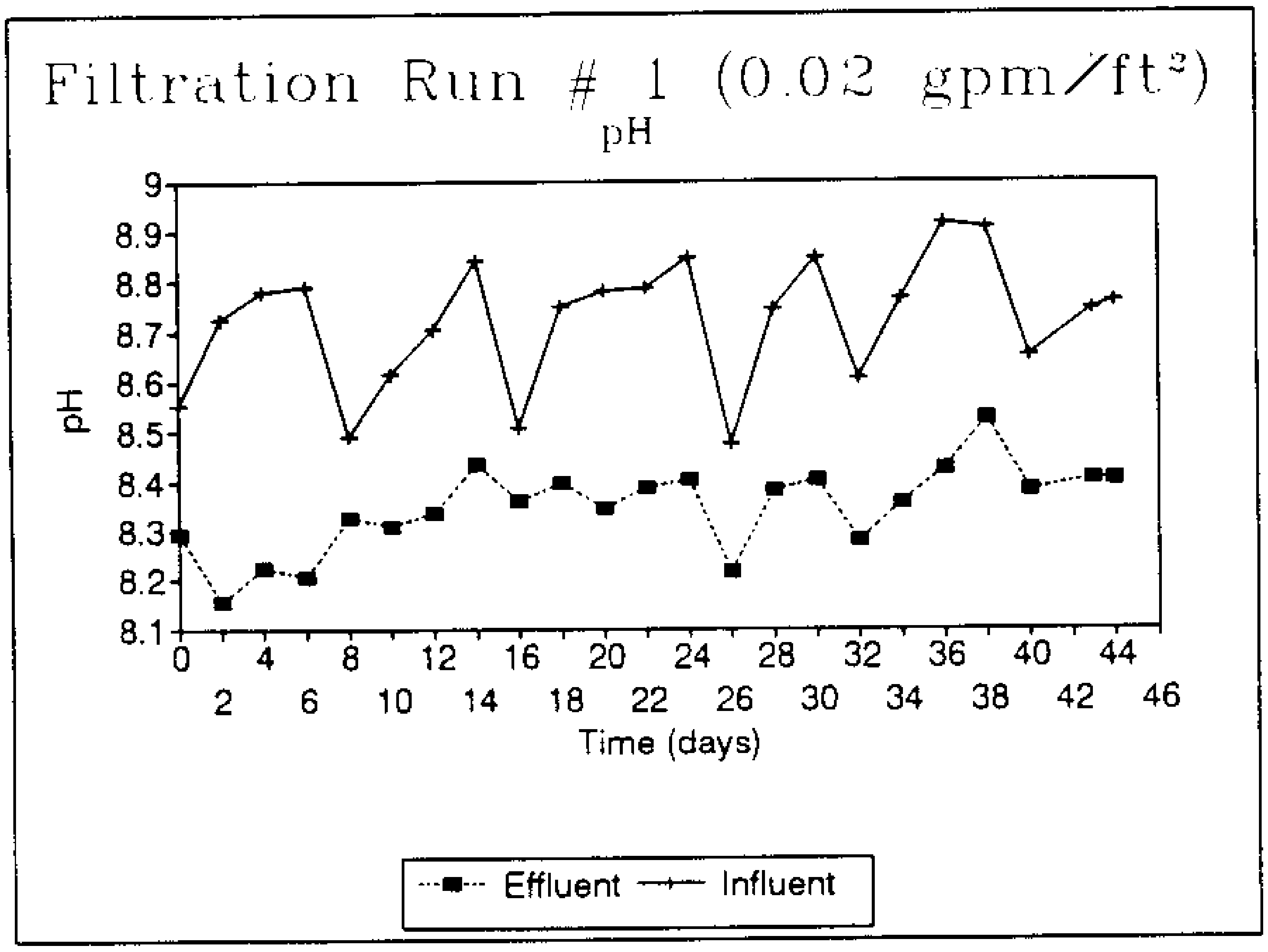

FIG. A-8.- pH for Filtration Run 1

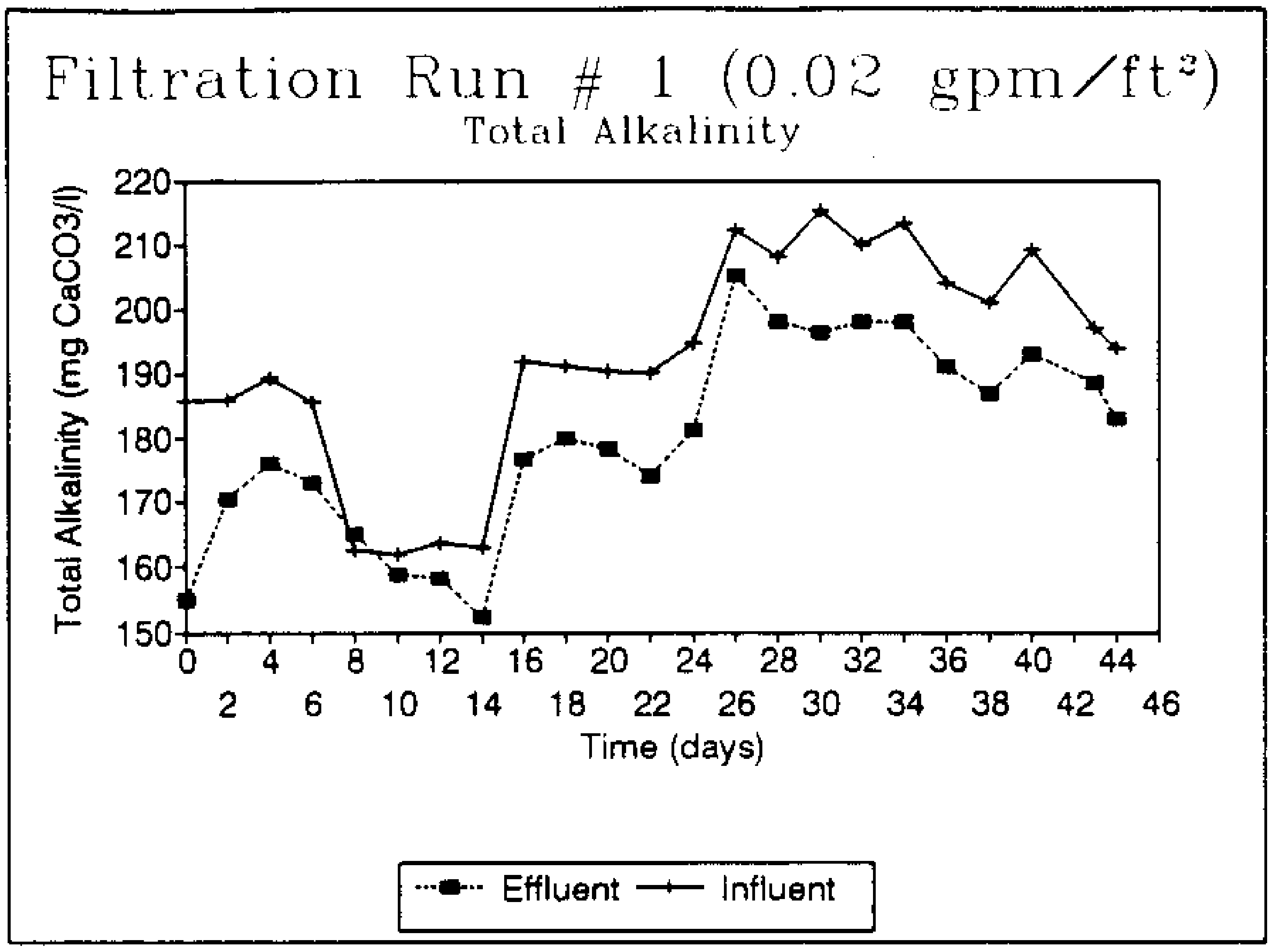

FIG. A-9.- Total Alkalinity for Filtration Run 1

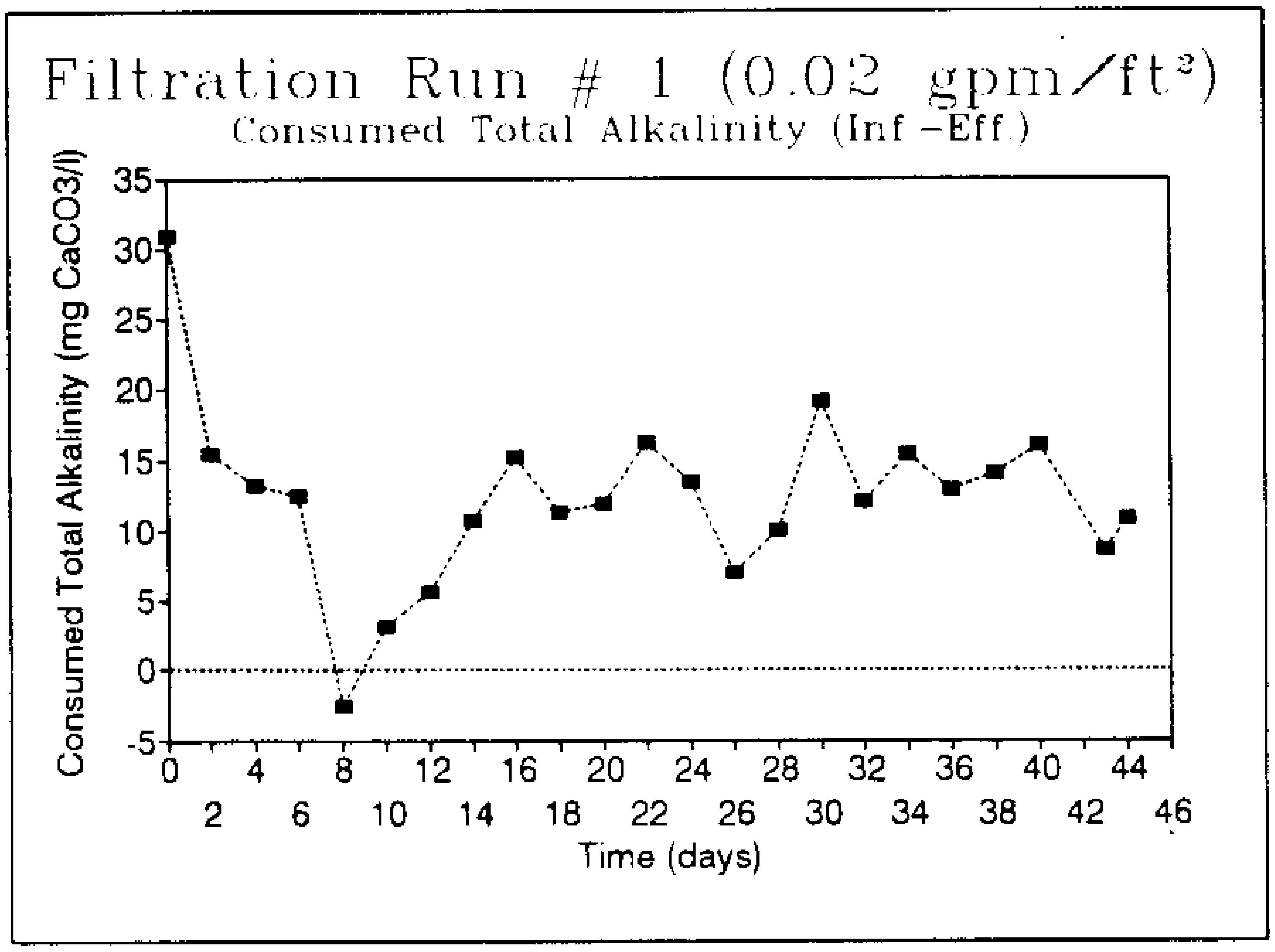

FIG. A-10.- Consumed Total Alkalinity for Filtration Run 1

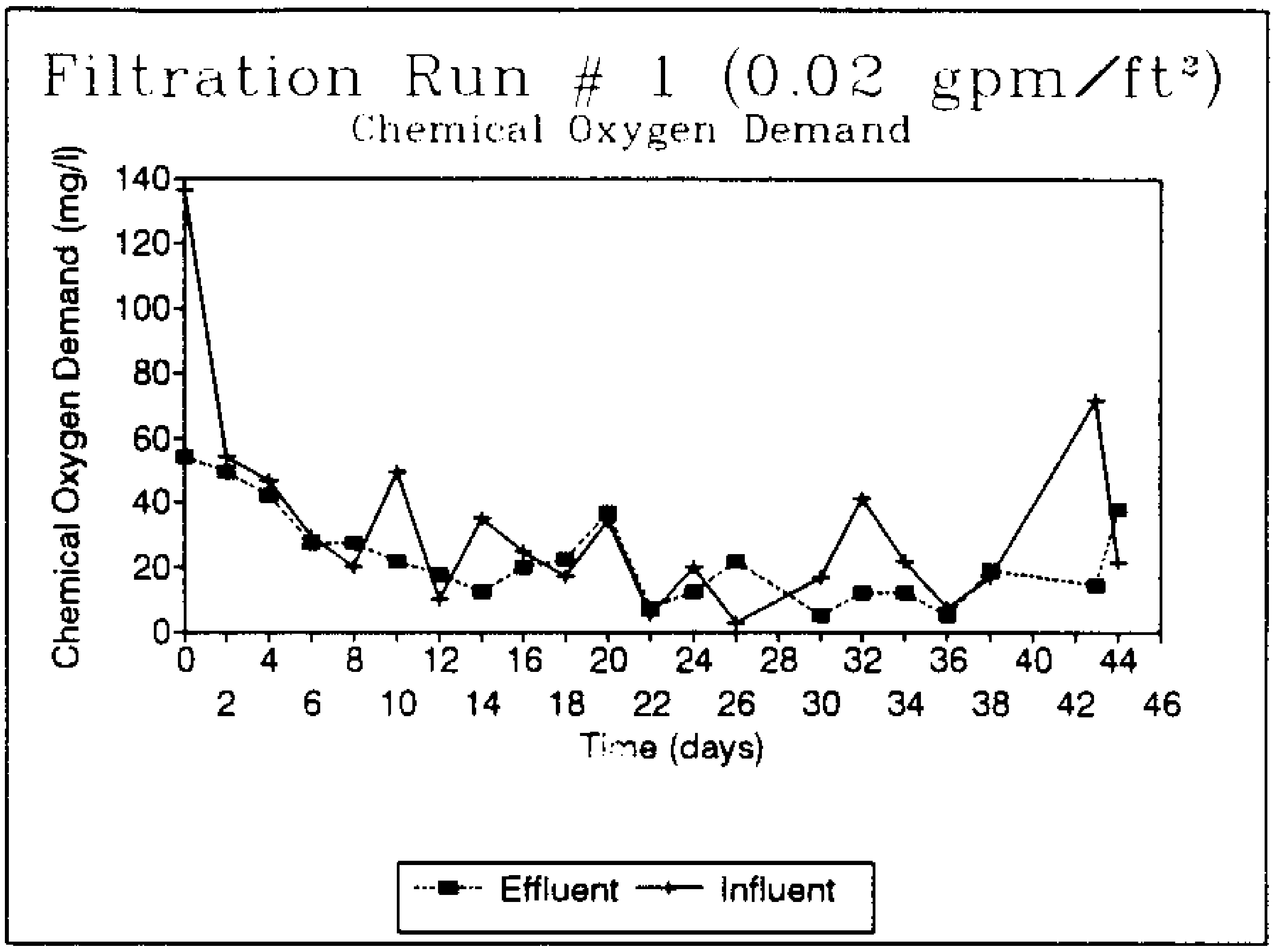

FIG. A-11.- Chemical Oxygen Demand (COD) for Filtration Run 1

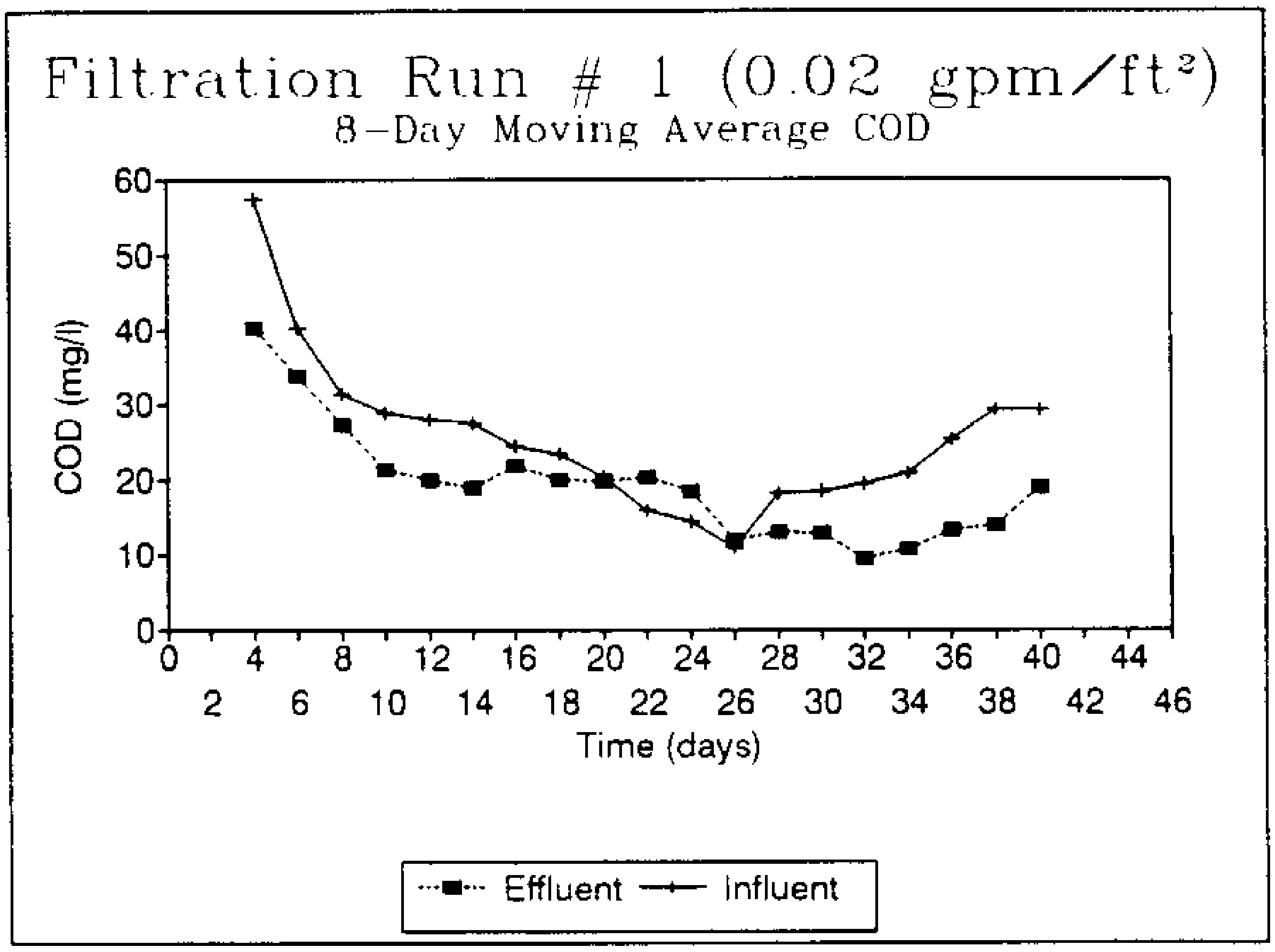

FIG. A-12.- 8-Day Moving Average COD for Filtration Run 1

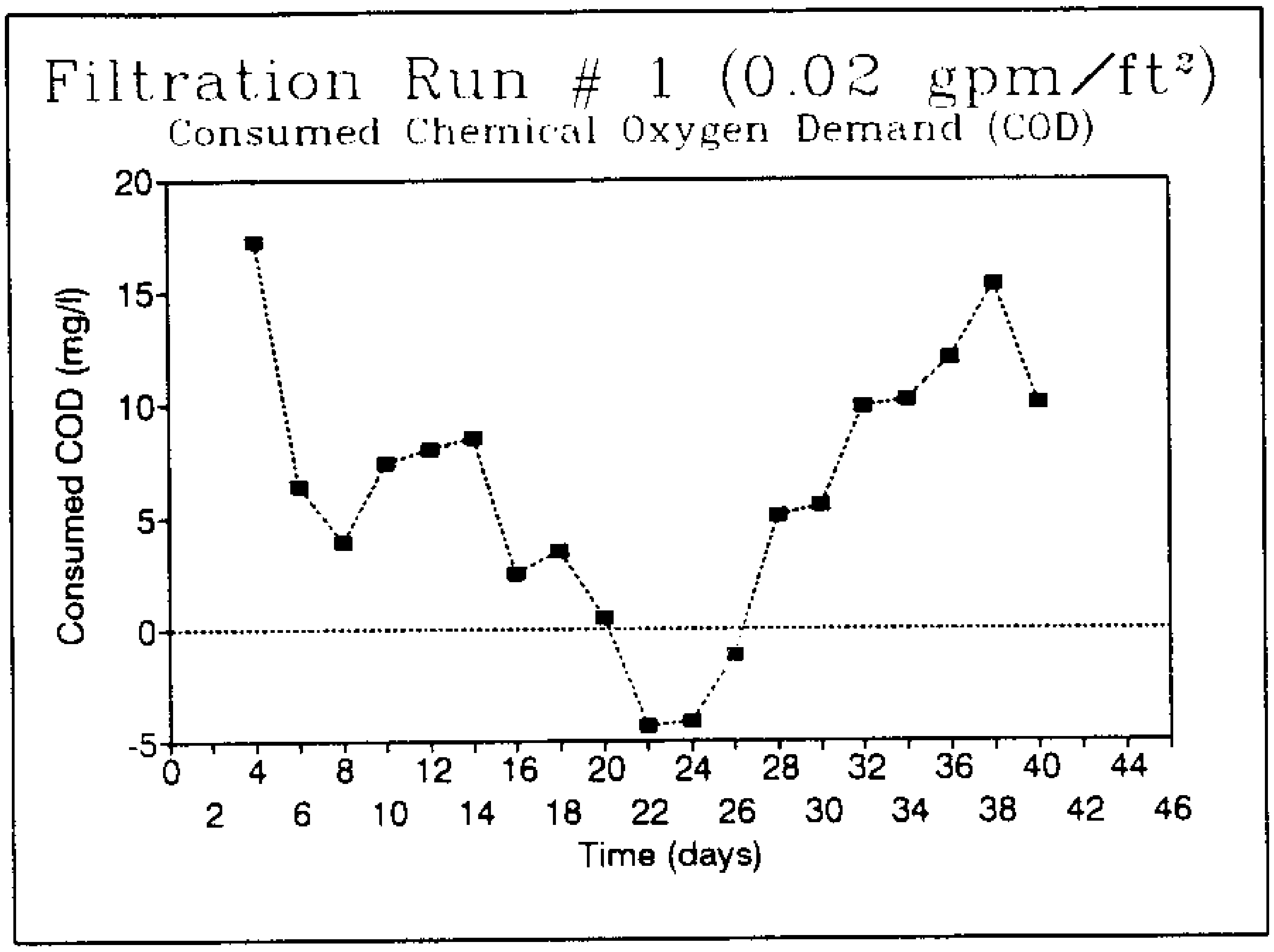

FIG. A-13.- Consumed COD for Filtration Run 1

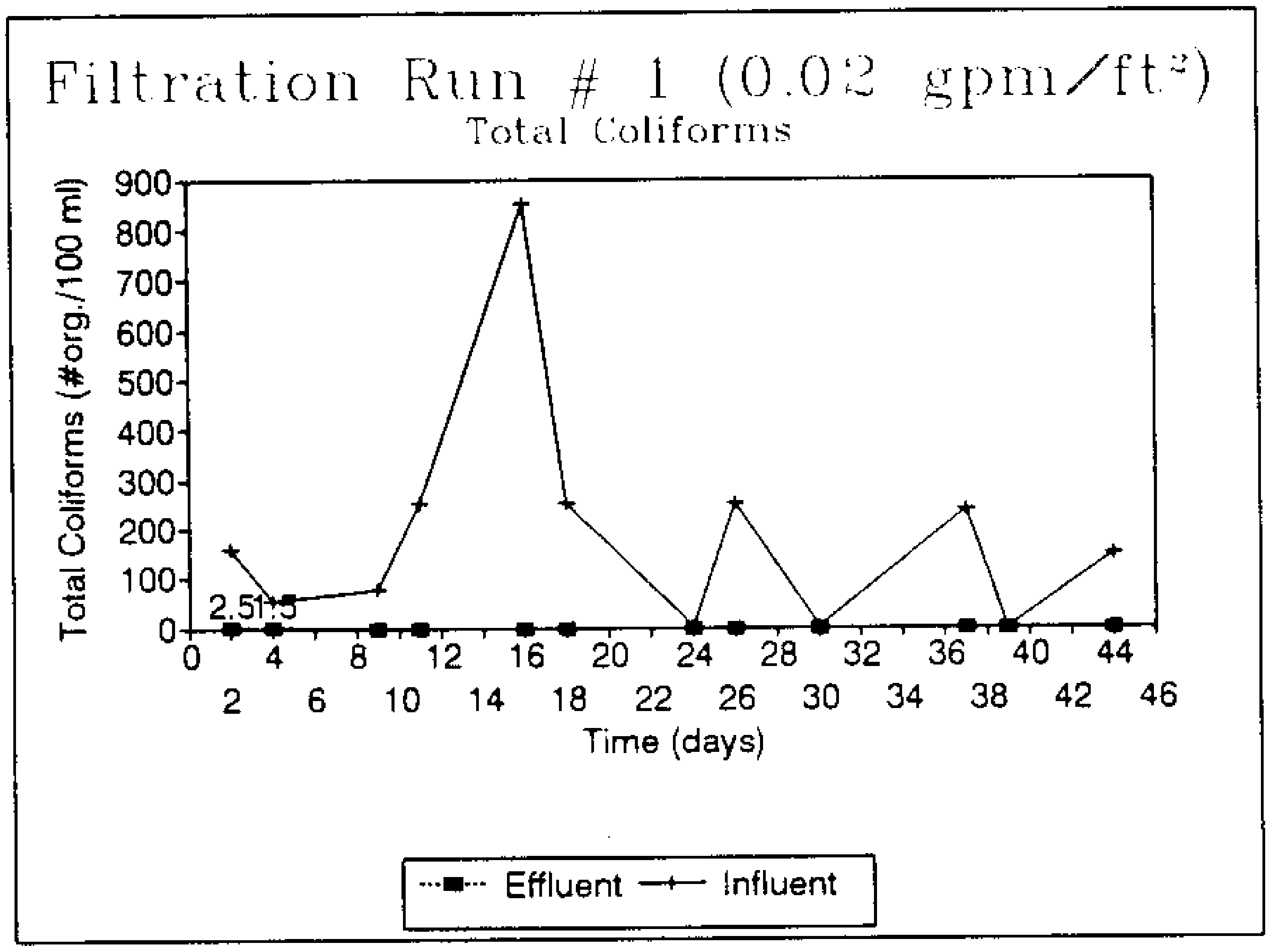

FIG. A-14.- Total Coliforms for Filtration Run 1

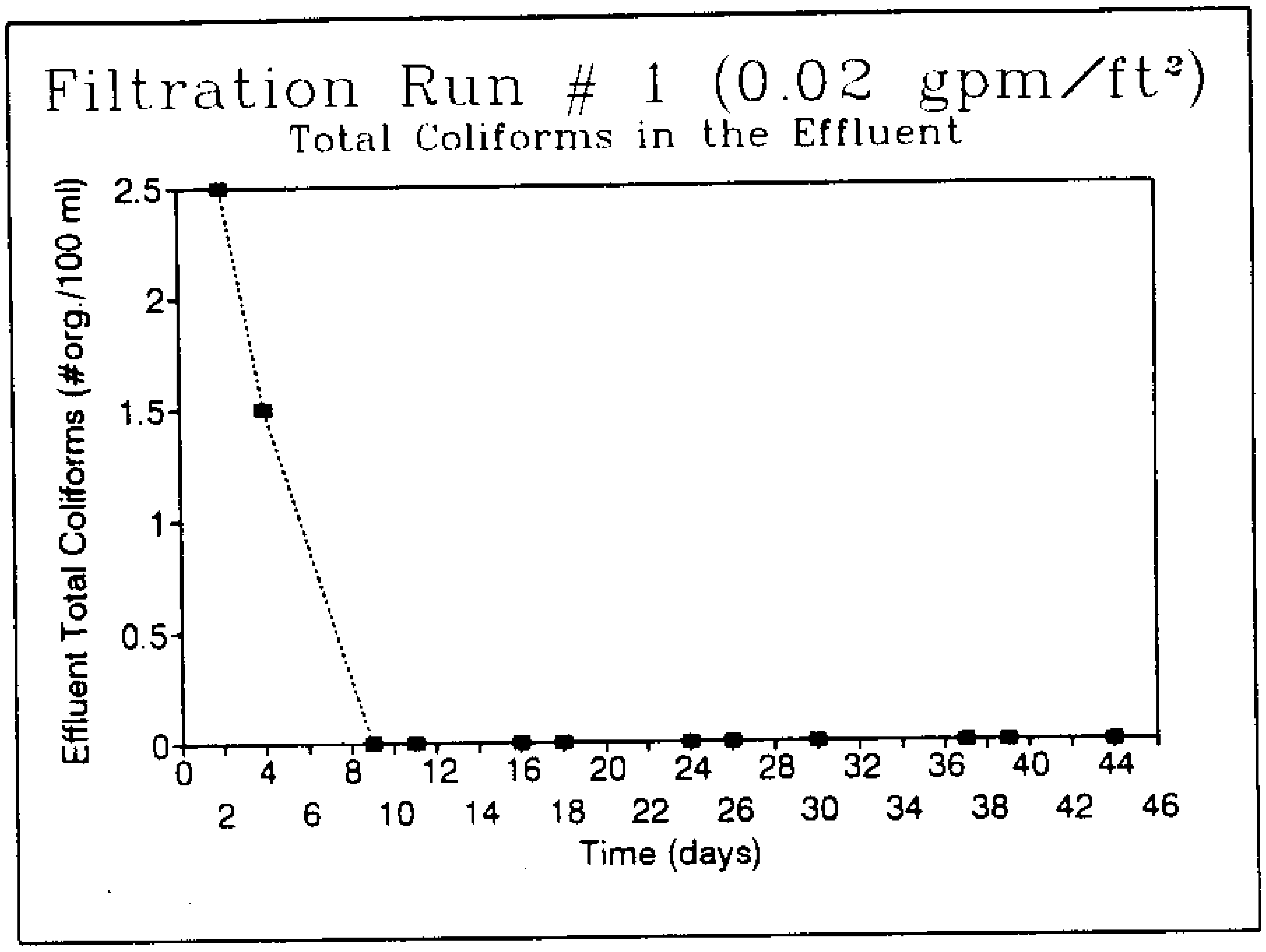

FIG. A-15.- Effluent Total Coliforms for Filtration Run 1

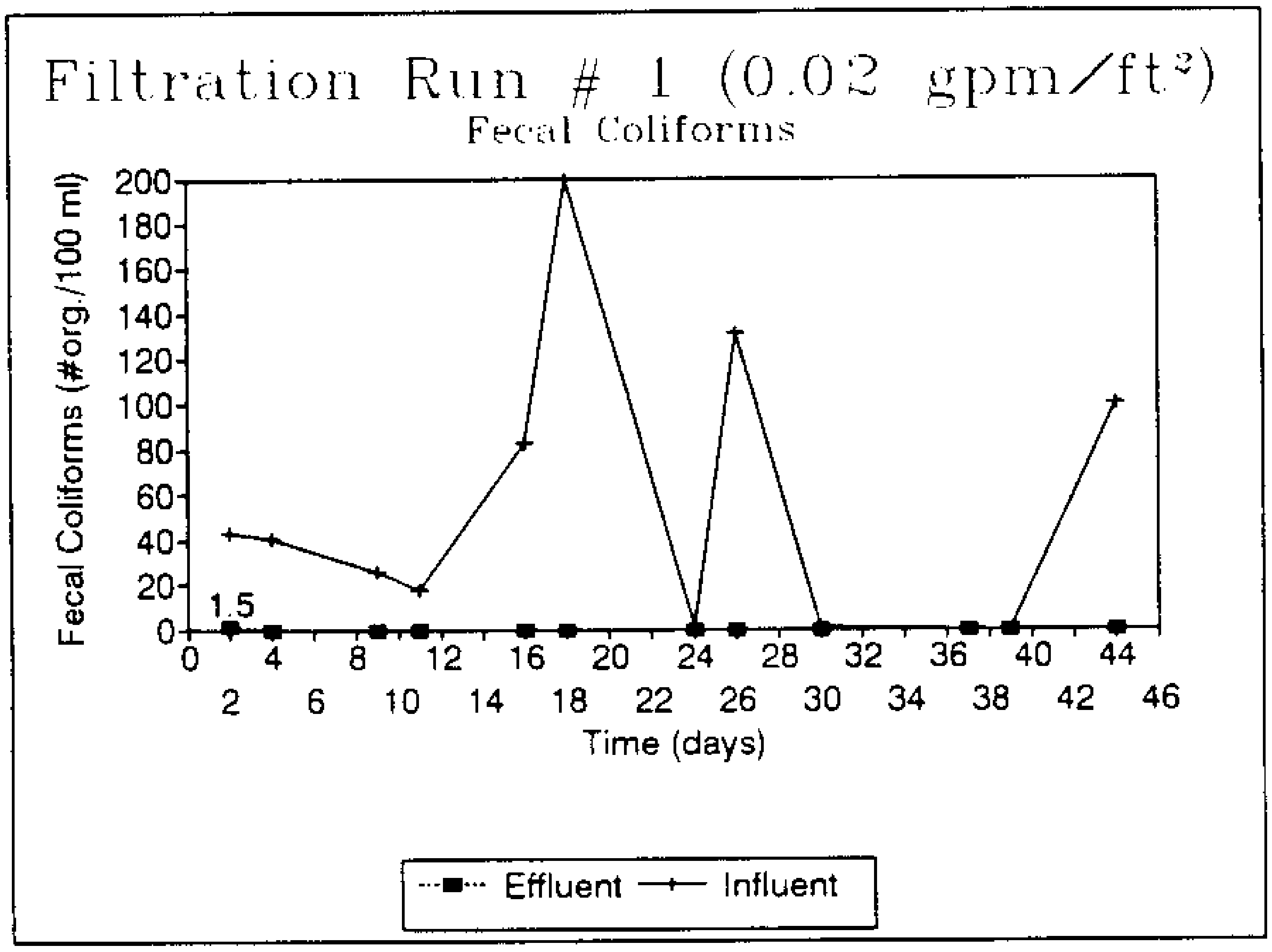

FIG. A-16.- Fecal Coliforms for Filtration Run 1

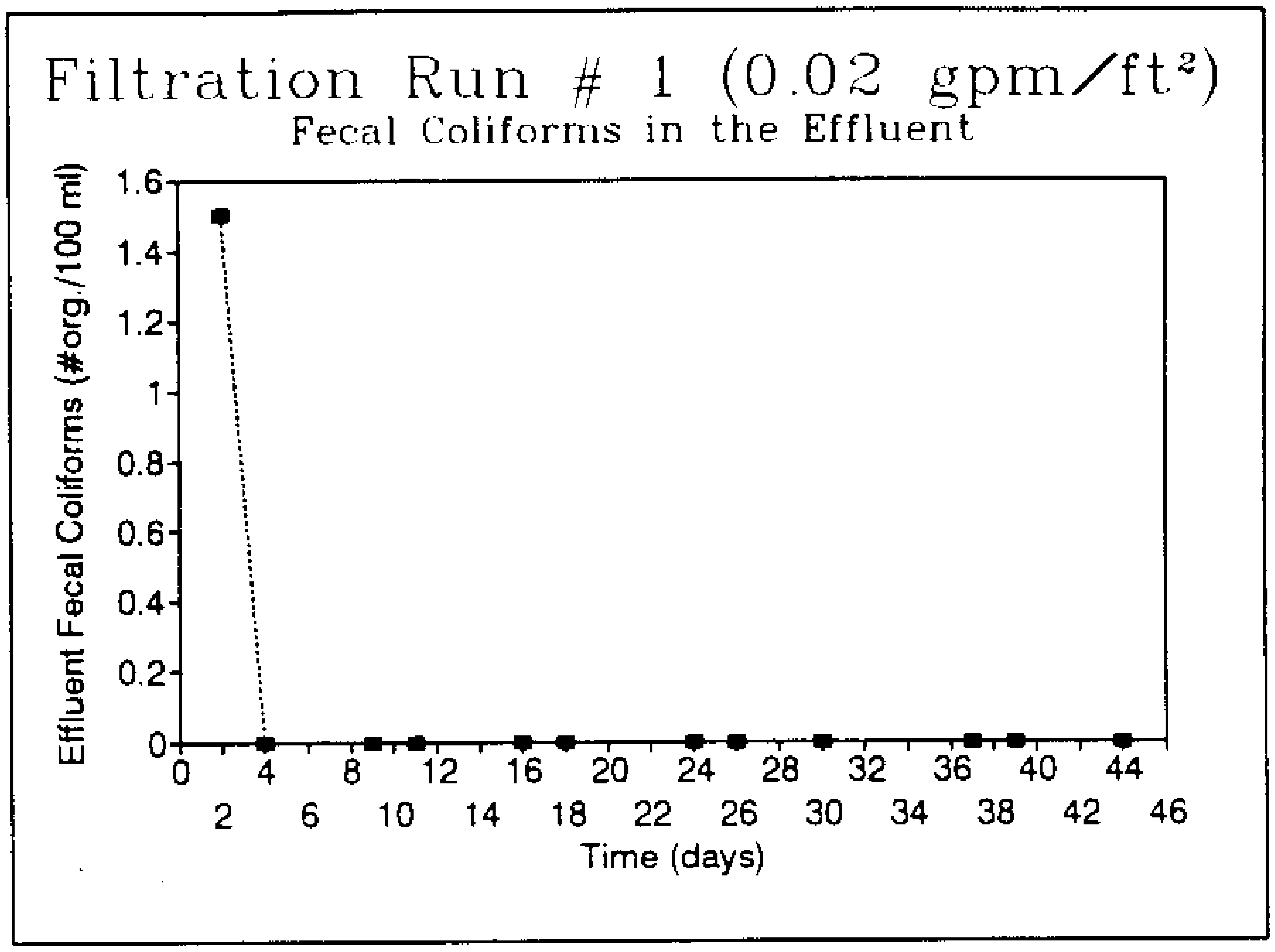

FIG. A-17.- Effluent Fecal Coliforms for Filtration Run 1

Table A-1.- Schmutzdecke Biochemical Oxygen Demand

$\mathrm{BOD}(\mathrm{mg/l}) = ((D1-D2) - (B1-B2)*f)/P$

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	8.38	7.53	8.48	7.95	1	0.0001	3250
0.05%	8.28	7.58	8.48	7.95	1	0.0005	350
0.1%	8.30	7.73	8.48	7.95	1	0.0010	50
0.5%	8.30	7.73	8.48	7.95	1	0.0050	10
Glucose	8.38	5.45	8.48	7.95	1	0.0200	120

Table A-2.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.03	4.03	-	
S.A.+P.D.	4.03	8.07	4.04	-	-
Blank	0.00	4.10	4.10	-	
Blank	4.10	8.20	4.10	-	-
Standard	0.00	3.00	3.00	545.23	
Standard	3.00	6.04	3.04	525.40	535.32
Sch.	0.00	4.03	4.03	3469.64	
Sch.	4.03	8.05	4.02	3965.30	3717.47

Table A-3.- Schmutzdecke Turbidity

Sample	Turbidity (NTU)	Average Turbidity (NTU)
1	215.00	
2	220.00	217.50

Table A-4.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	54.00	36.18		
2	56.00	37.52	55.00	36.85

Table A-5.- Schmutzdecke pH

Sample	pH	Average pH
1	8.42	
2	8.43	8.43

Table A-6.- Schmutzdecke Alkalinity

A = 2.50
B = 40.00
C = 19.15

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	18.75	21.25	2.5	0.09852702	61.58	
2	21.25	23.75	2.5	0.09852702	61.58	61.58

Table A-7.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	TNTC	TNTC
2	TNTC	TNTC

TNTC = Too Numerous To Count

Table A-8.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
4	16.39075	10	16.39867	792		16.39678	189	
2	16.62815	10	16.63631	816	804	16.63426	205	197

Table A-9.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
21	38.55001	20	38.56711	855		38.56266	222.50		632.50	
4E	37.87253	20	37.88995	871	863	37.88553	221.00	221.75	650.00	641.25

Appendix B: Illustrations for Filtration Run 2

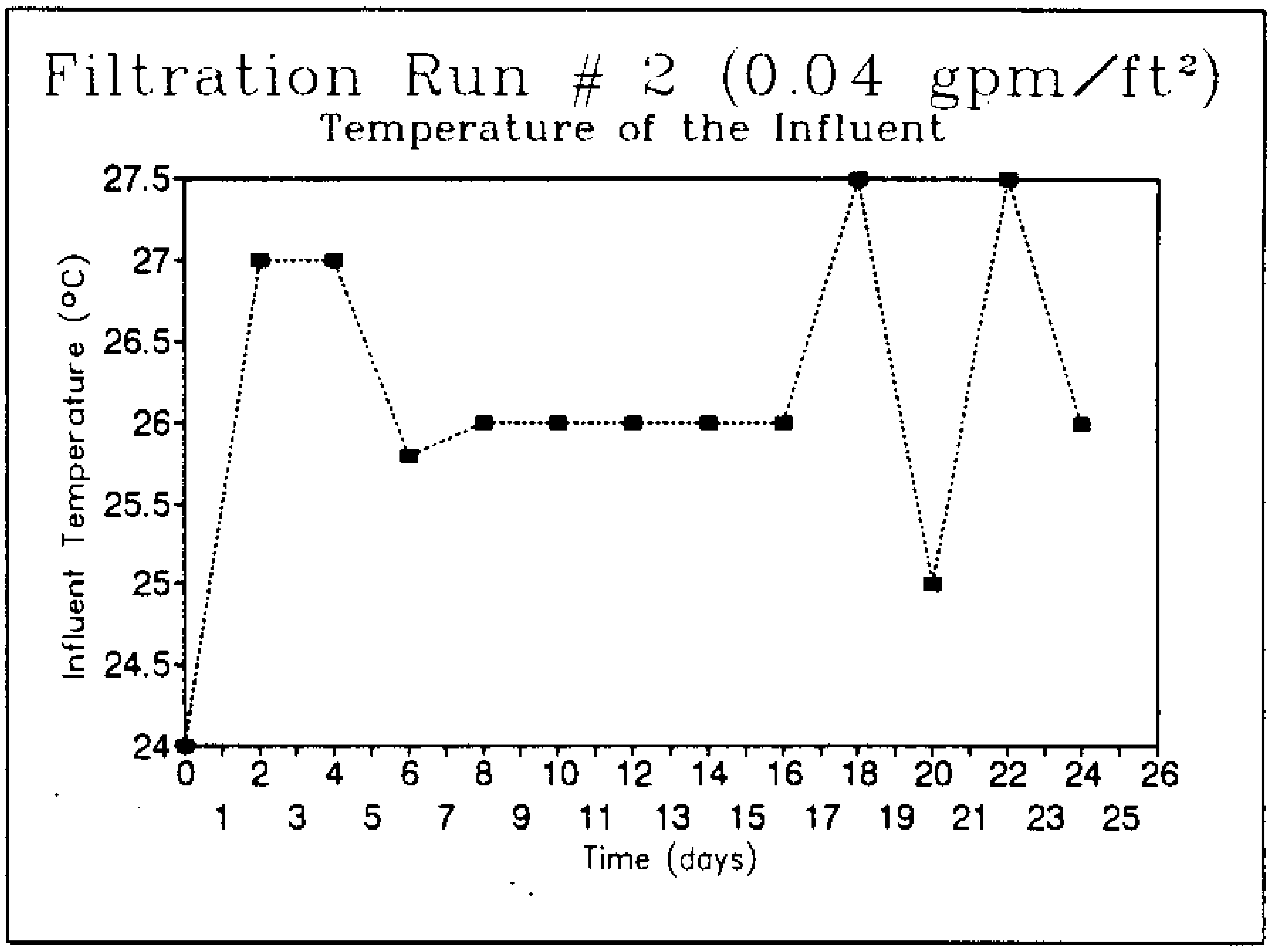

FIG. B-1.- Influent Temperature for Filtration Run 2

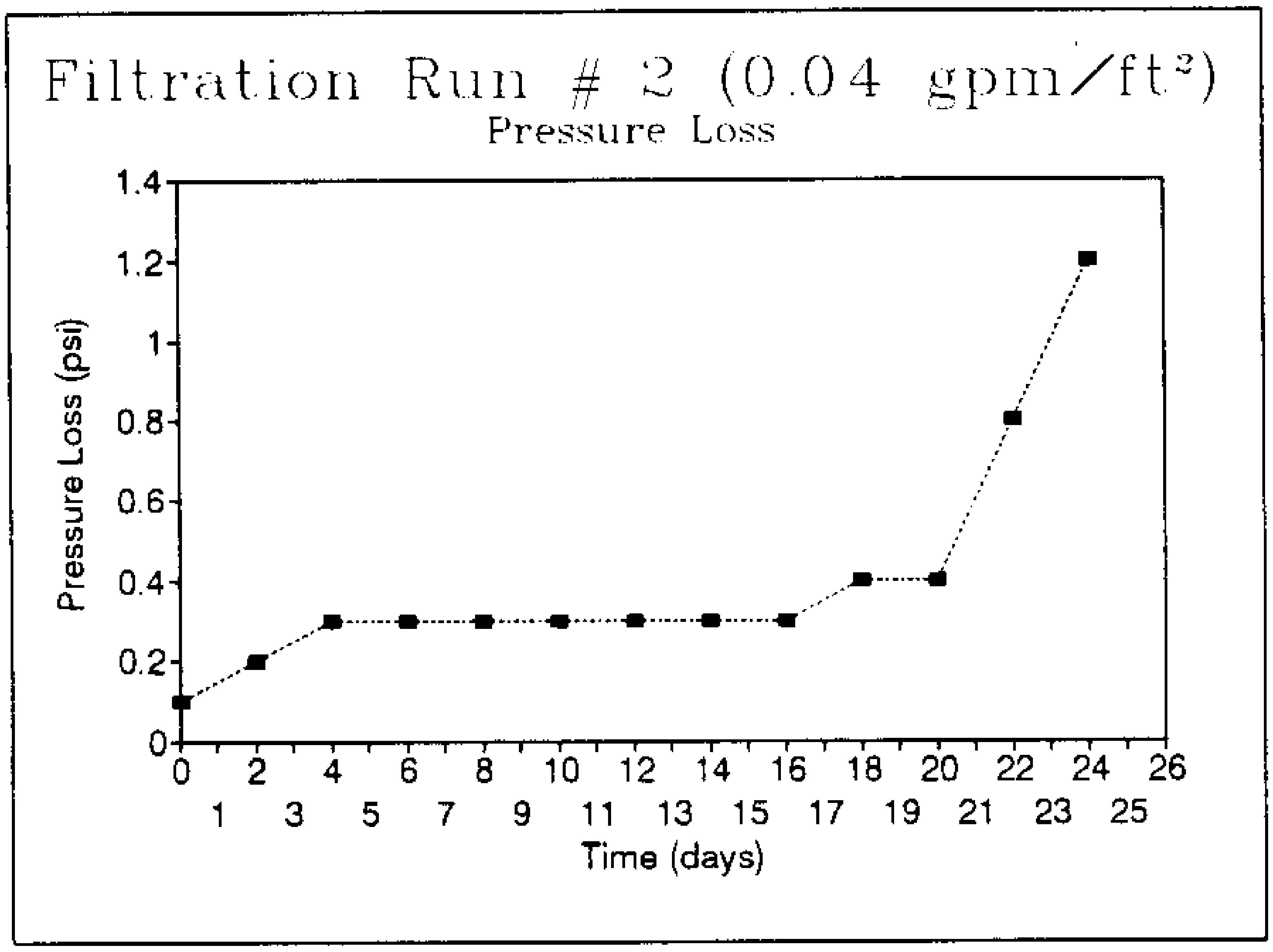

FIG. B-2.- Pressure Loss for Filtration Run 2

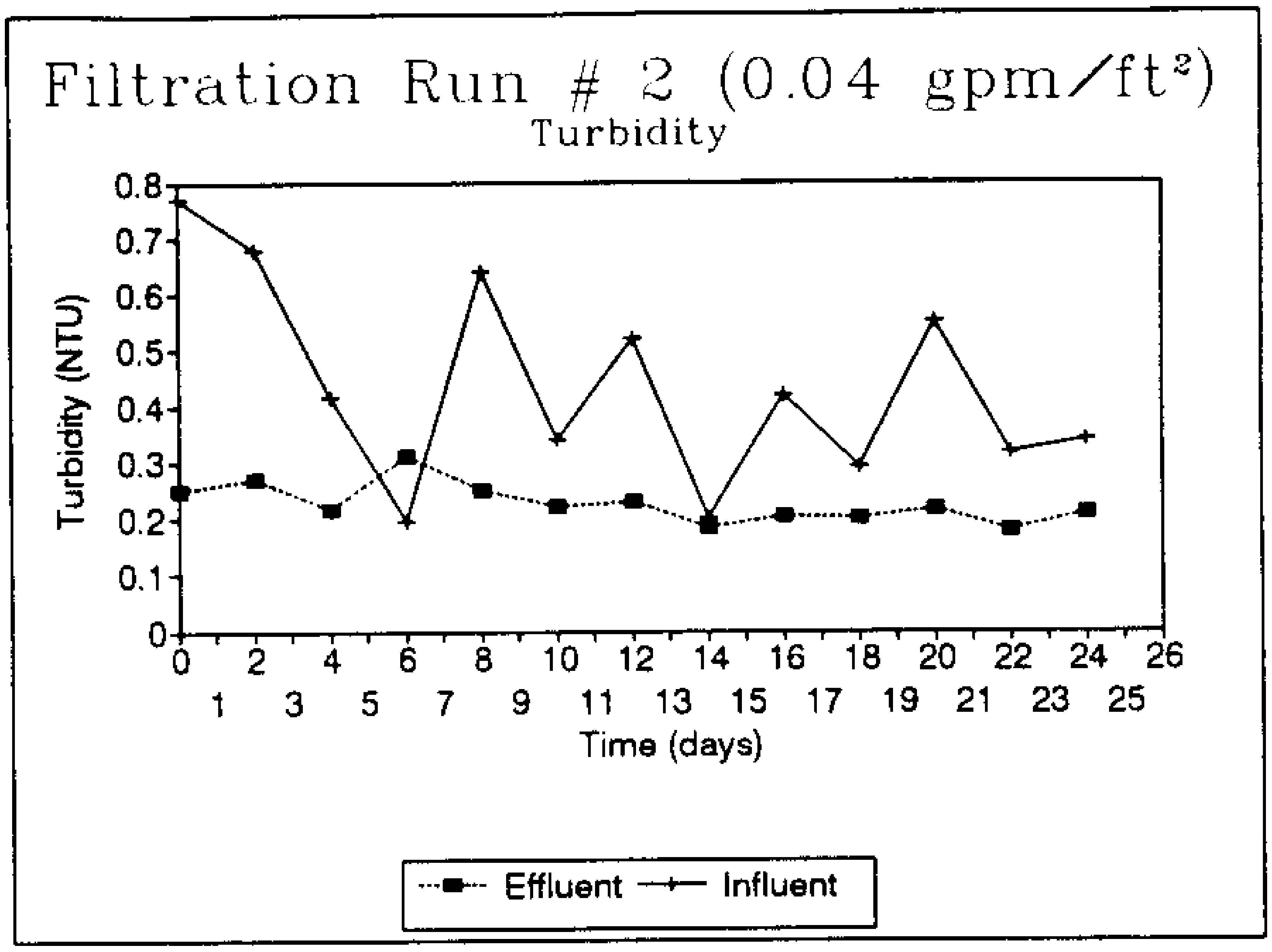

FIG. B-3.- Turbidity for Filtration Run 2

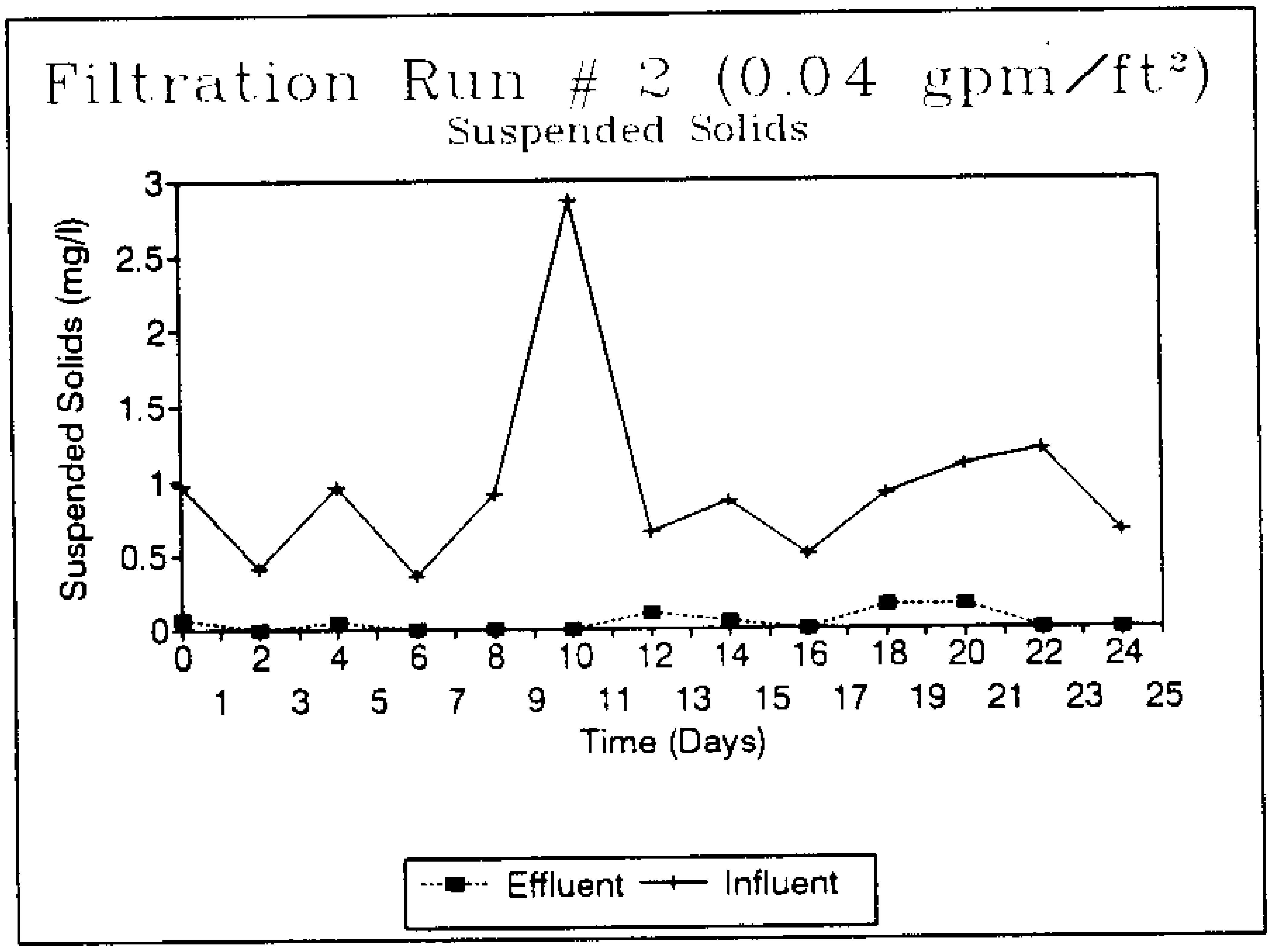

FIG. B-4.- Suspended Solids for Filtration Run 2

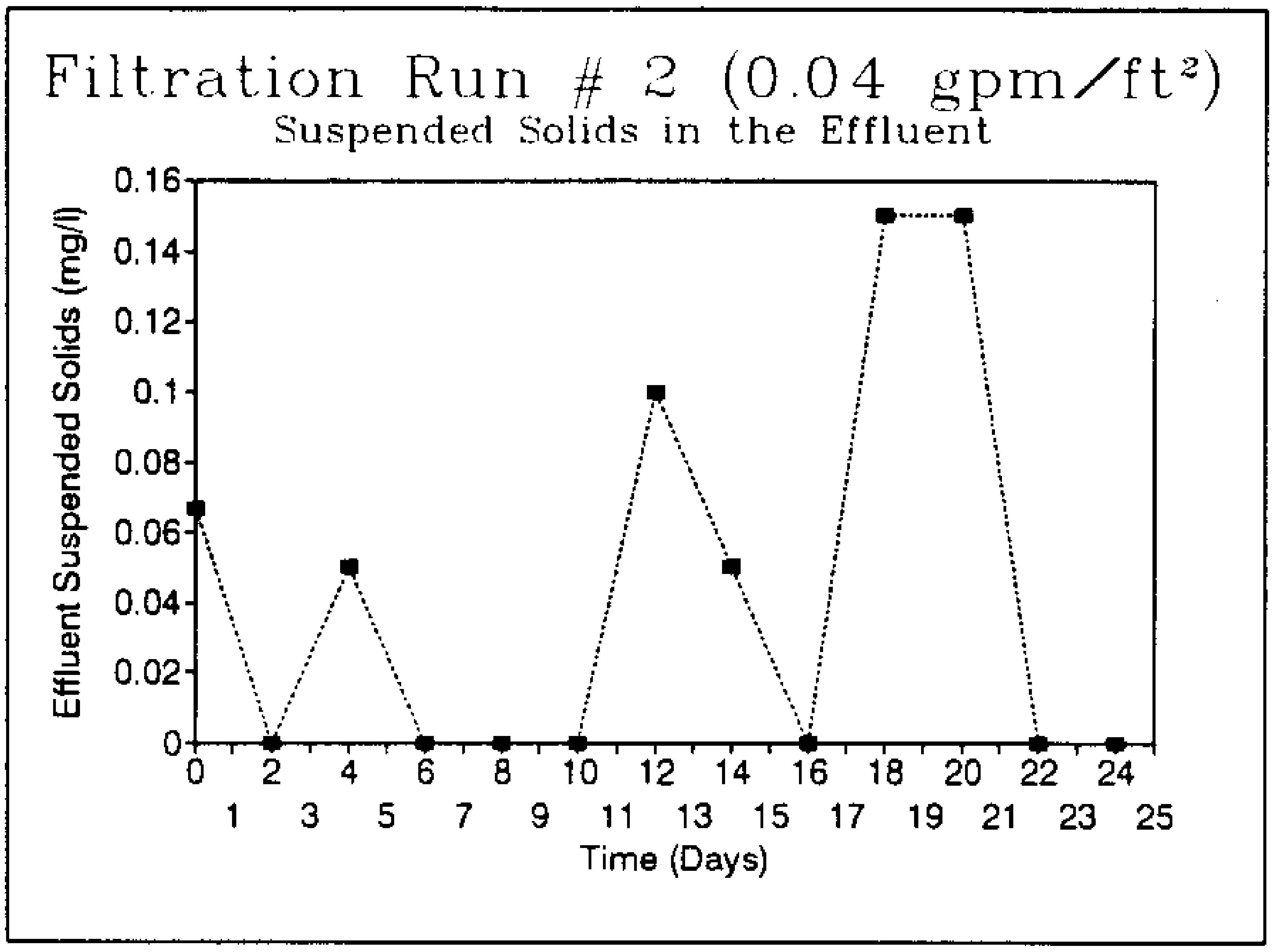

FIG. B-5.- Effluent Suspended Solids for Filtration Run 2

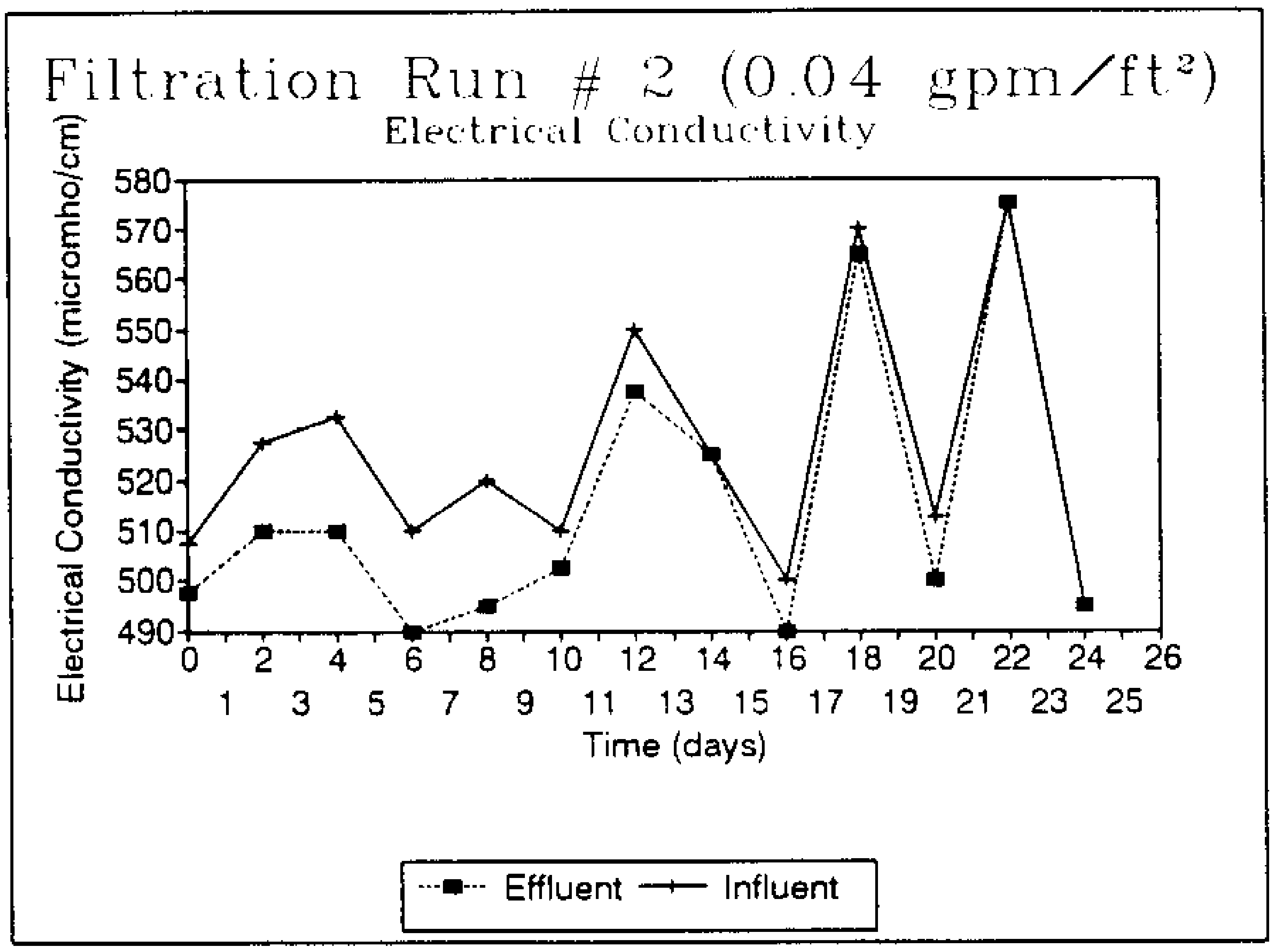

FIG. B-6.- Electrical Conductivity for Filtration Run 2

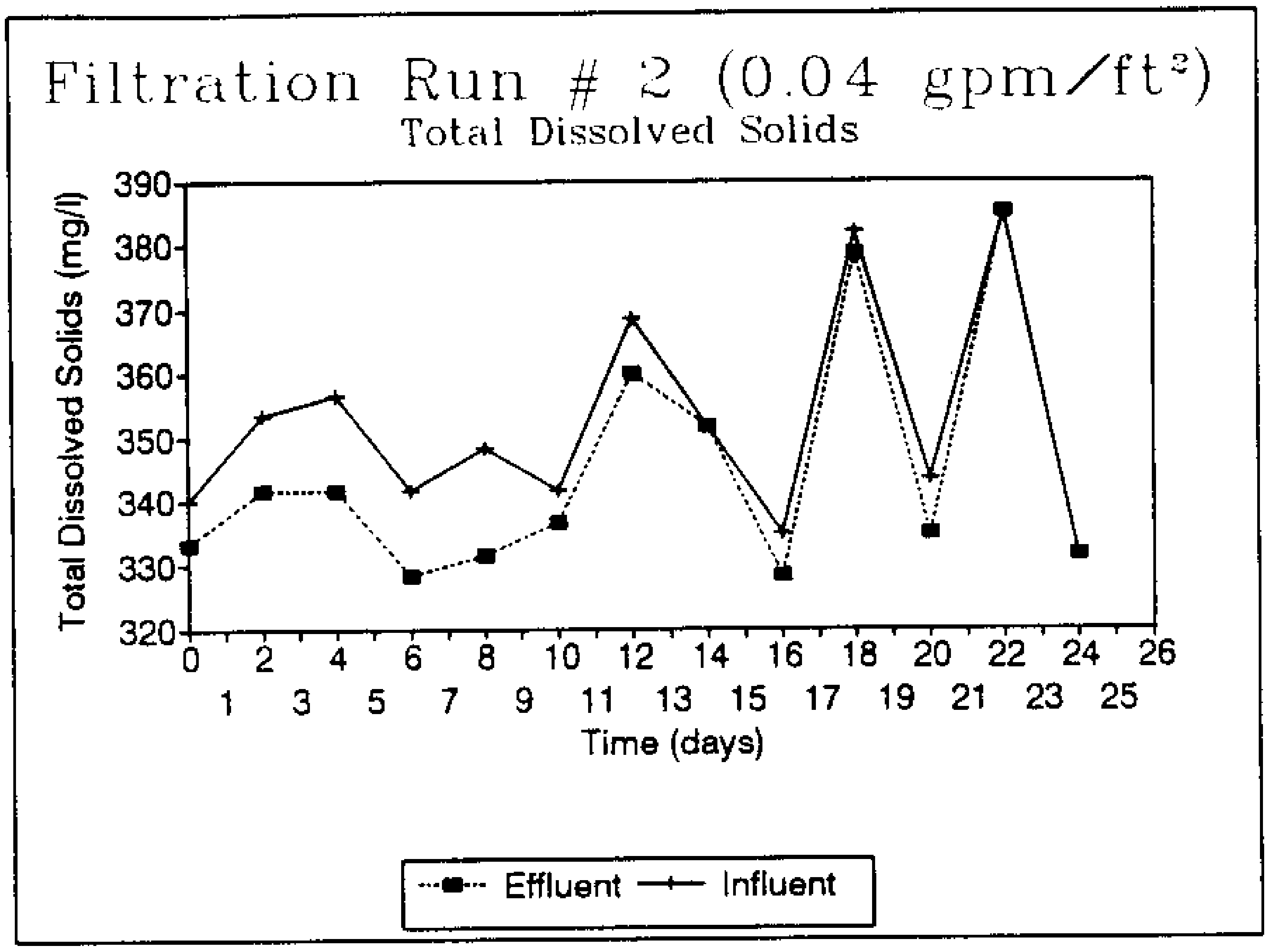

FIG. B-7.- Total Dissolved Solids for Filtration Run 2

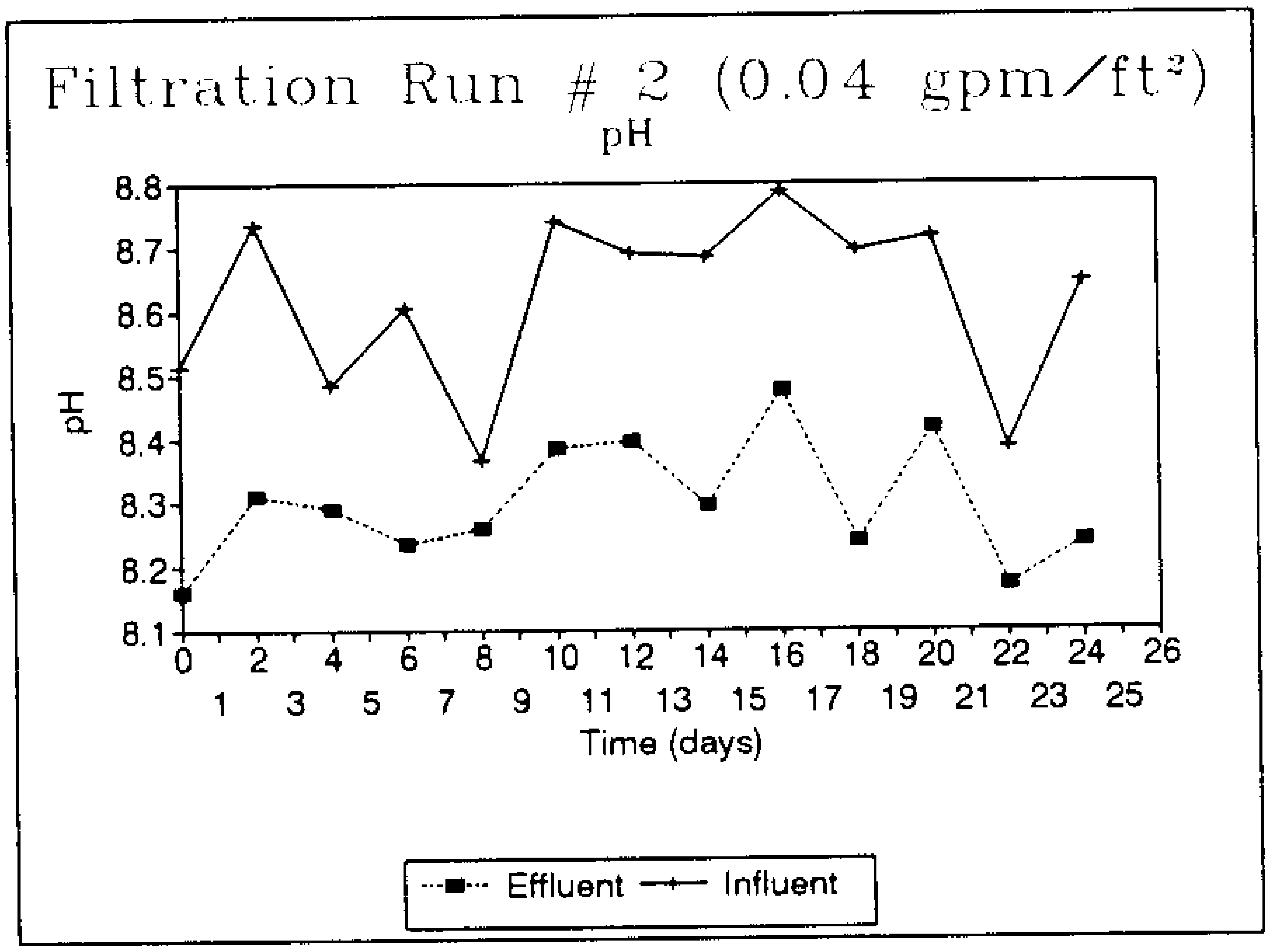

FIG. B-8.- pH for Filtration Run 2

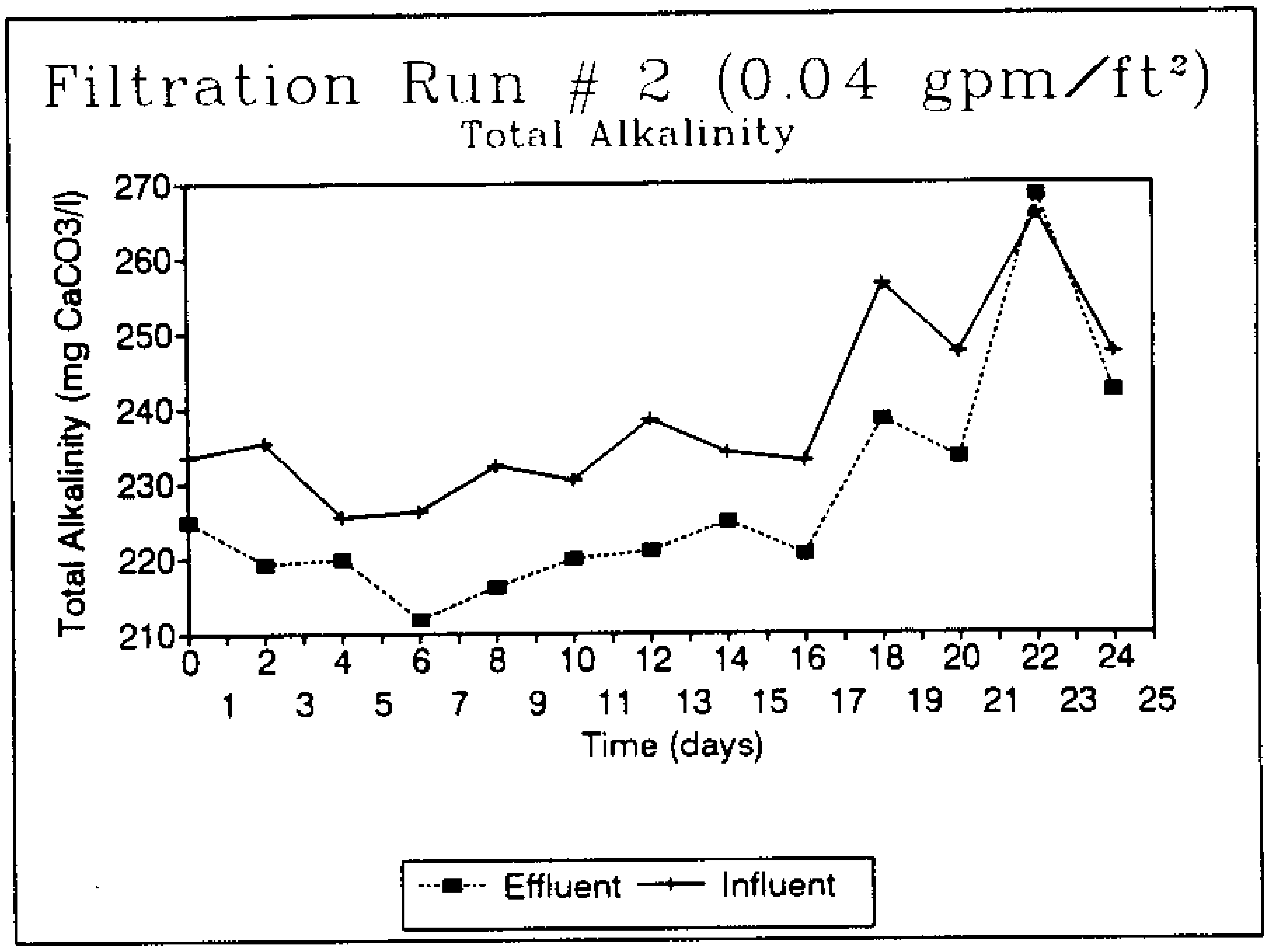

FIG. B-9.- Total Alkalinity for Filtration Run 2

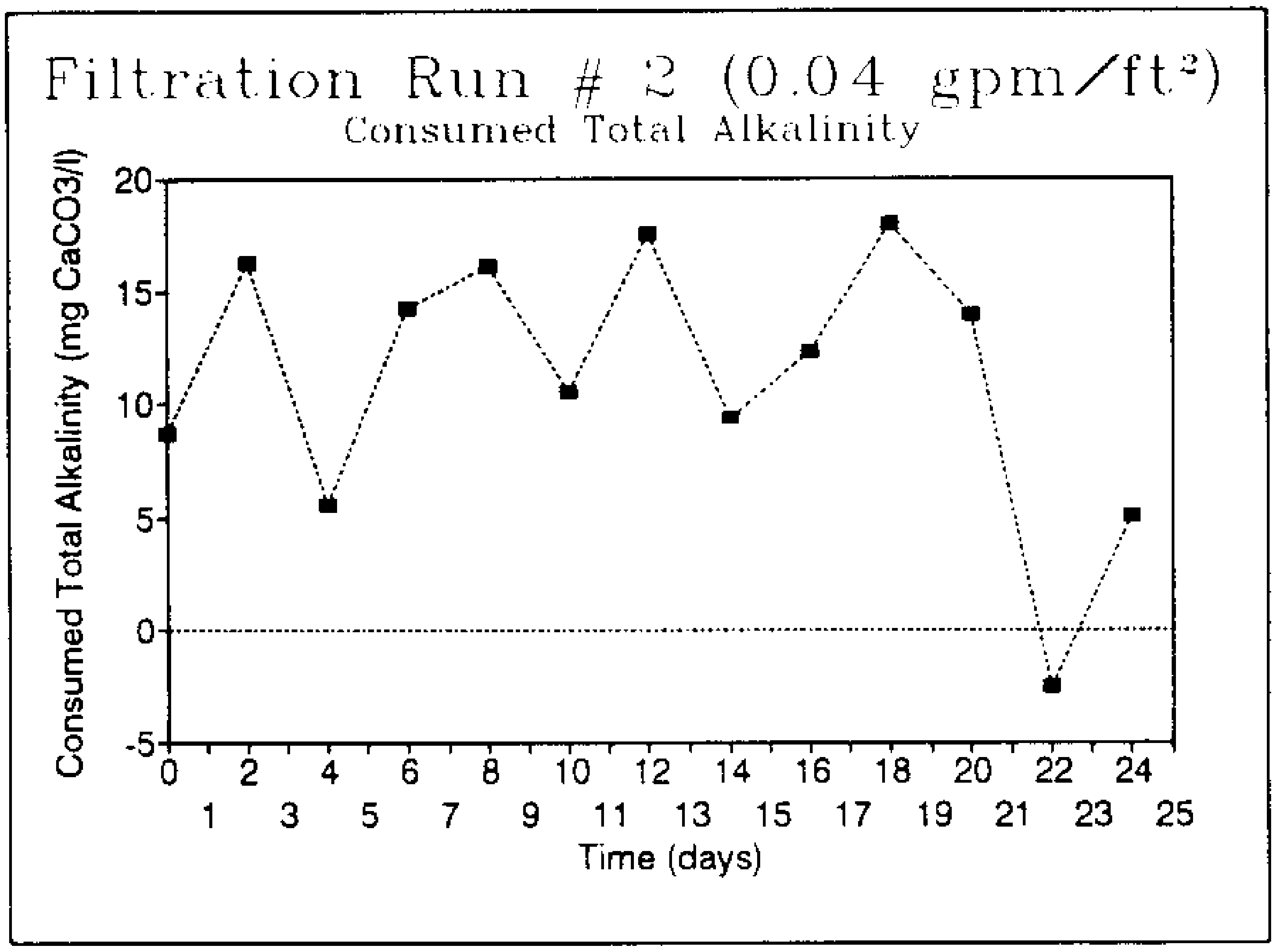

FIG. B-10.- Consumed Total Alkalinity for Filtration Run 2

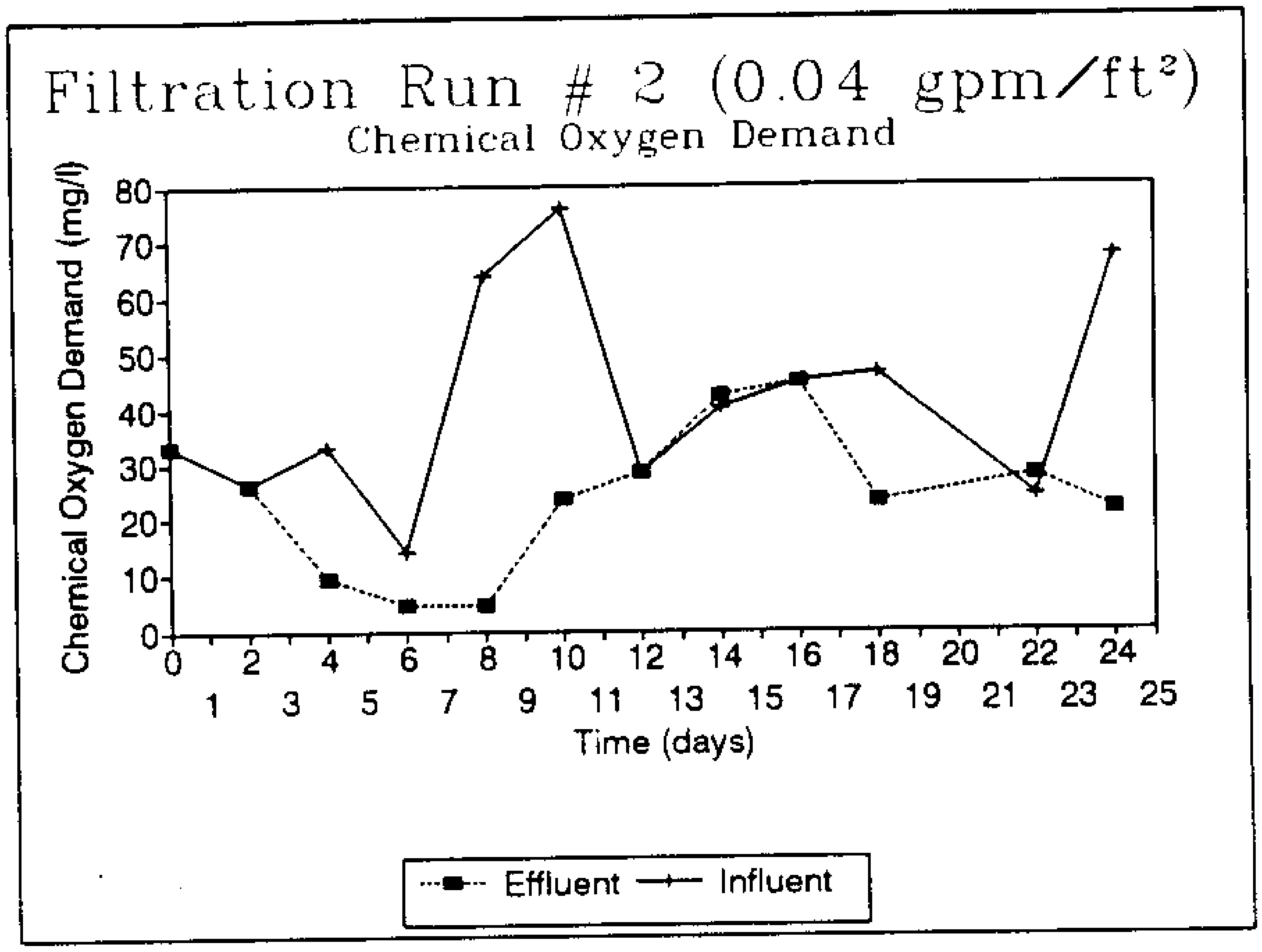

FIG. B-11.- Chemical Oxygen Demand (COD) for Filtration Run 2

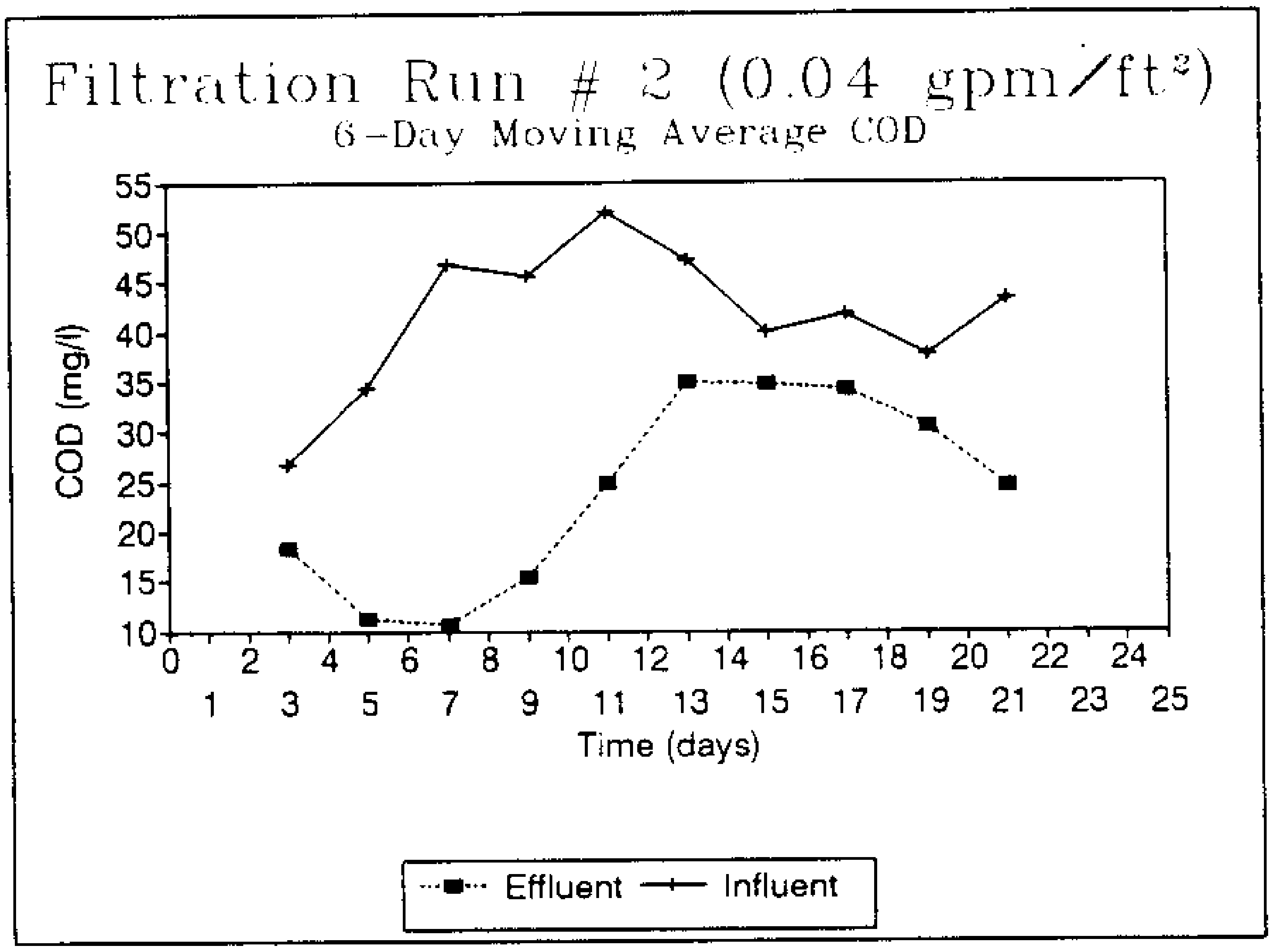

FIG. B-12.- 6-Day Moving Average COD for Filtration Run 2

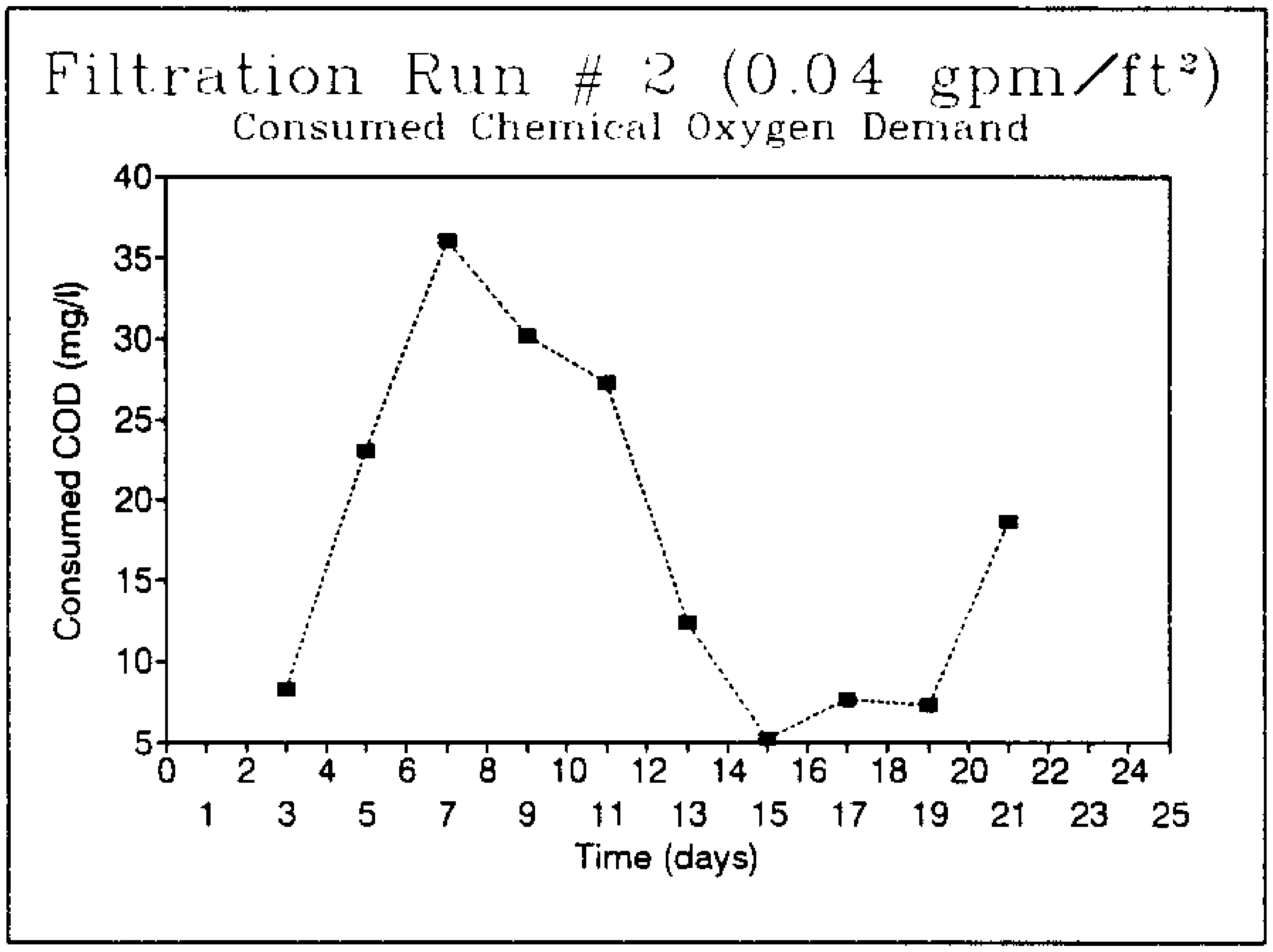

FIG. B-13.- Consumed COD for Filtration Run 2

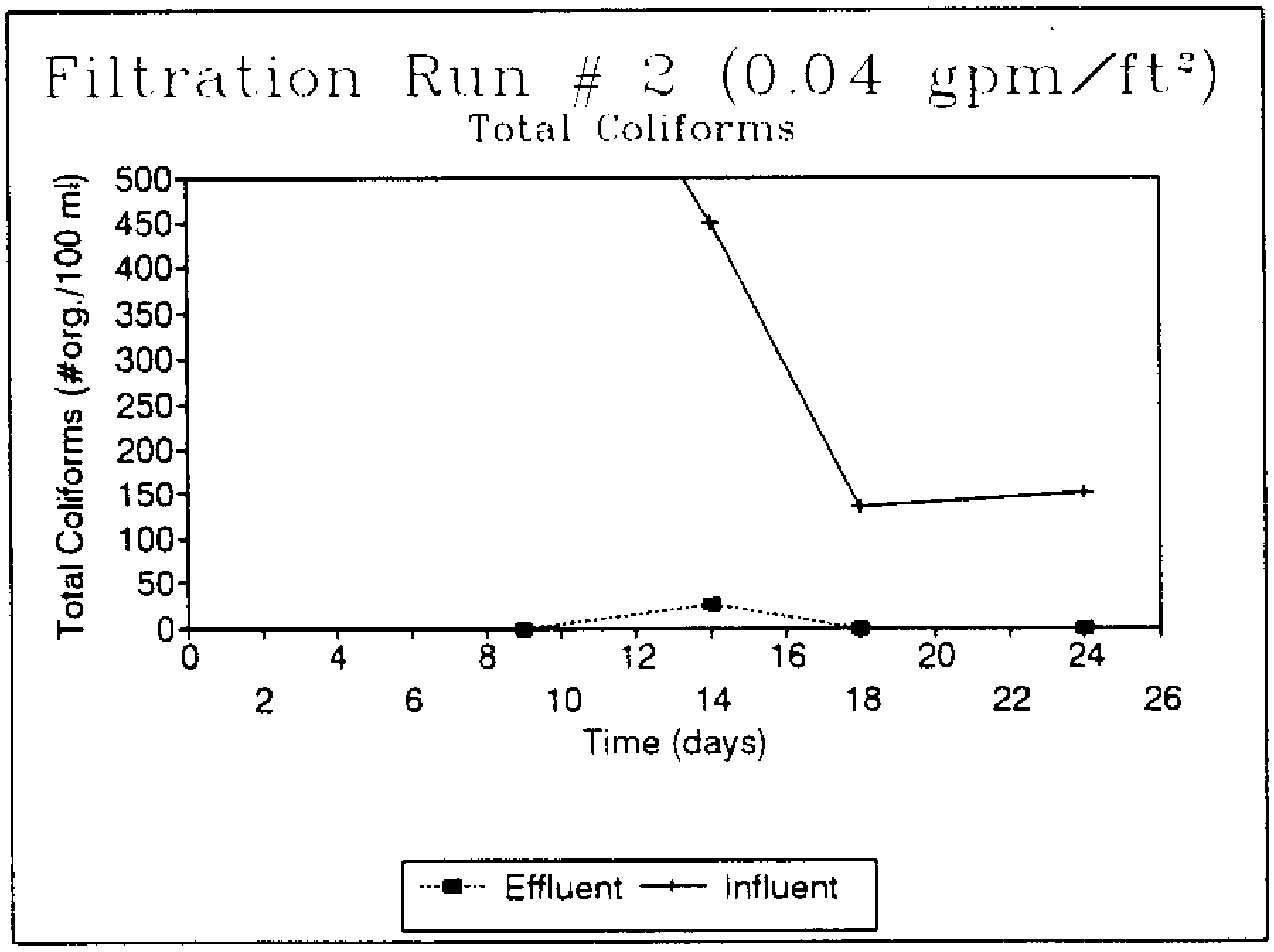

FIG. B-14.- Total Coliforms for Filtration Run 2

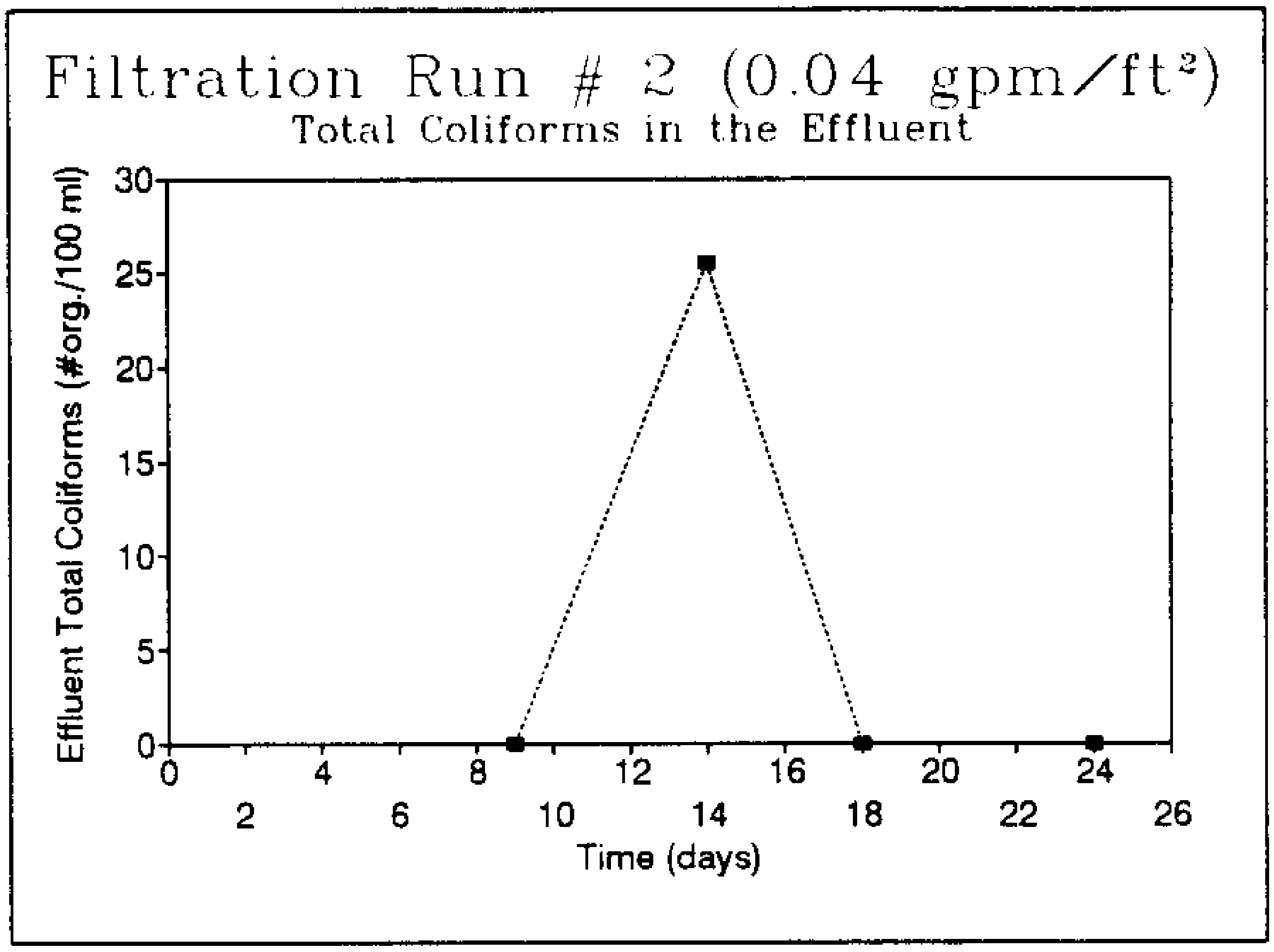

FIG. B-15.- Effluent Total Coliforms for Filtration Run 2

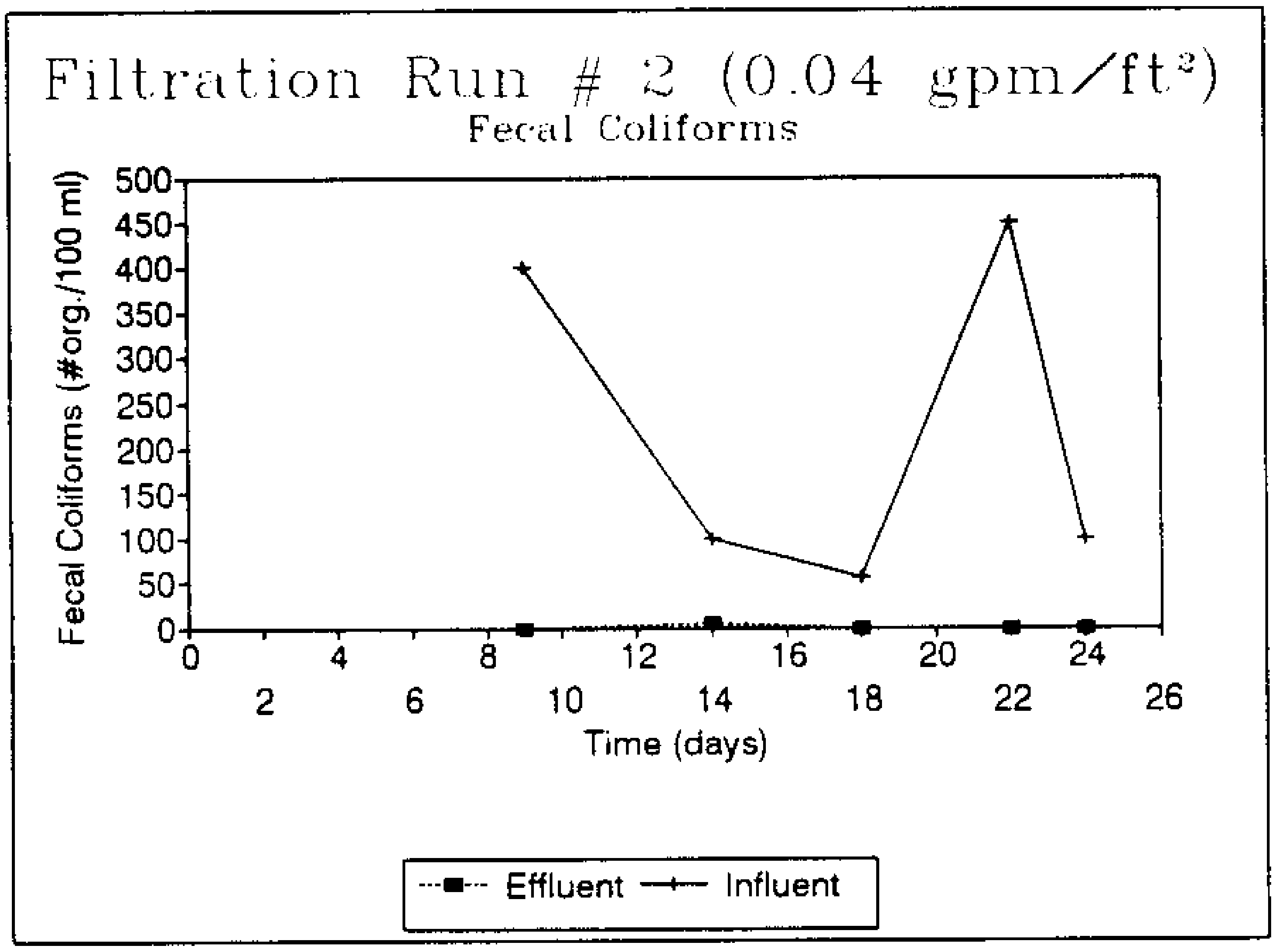

FIG. B-16.- Fecal Coliforms for Filtration Run 2

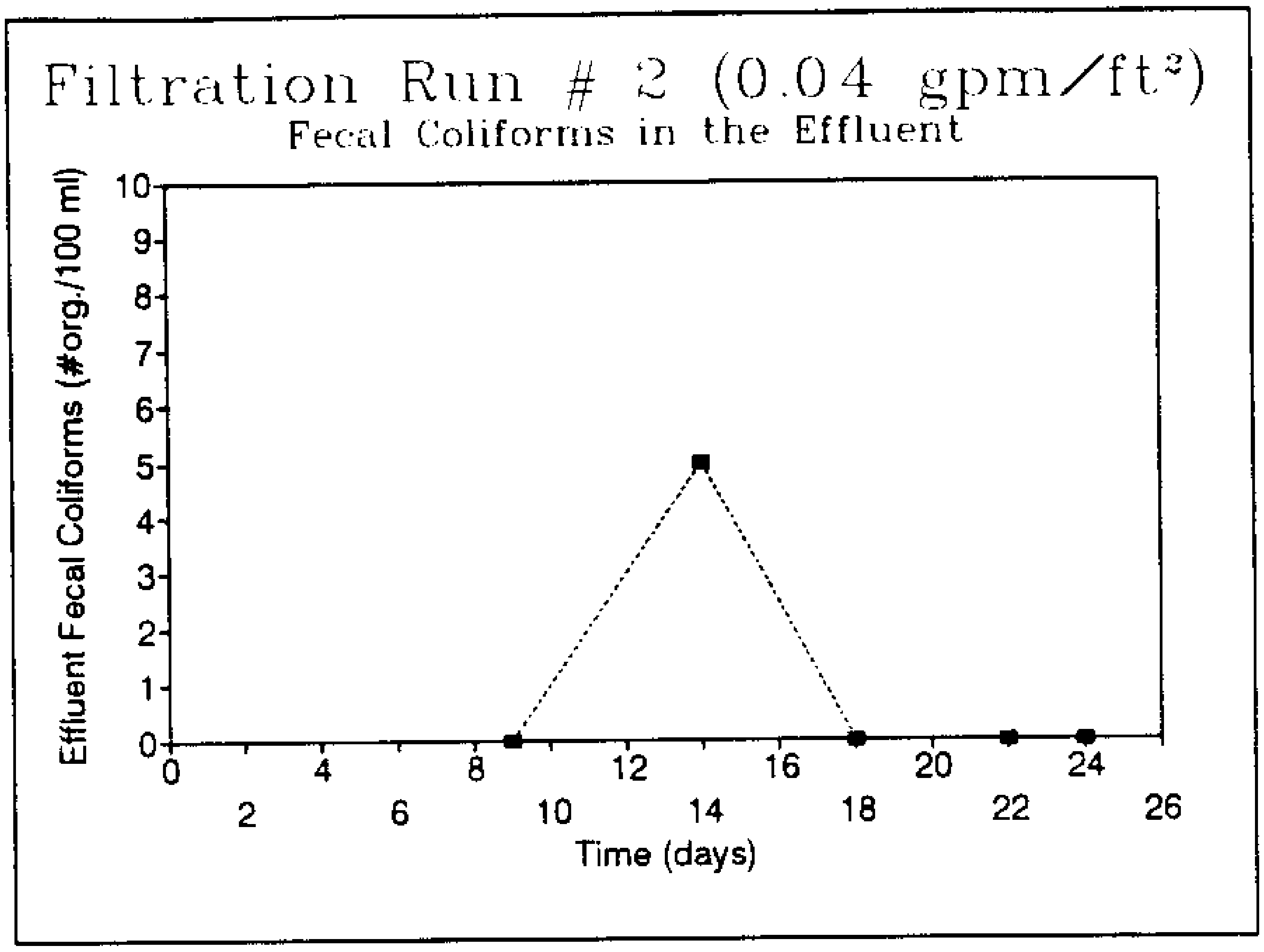

FIG. B-17.- Effluent Fecal Coliforms for Filtration Run 2

Table B-1.- Biochemical Oxygen Demand (Effluent of Last Day)

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	9.23	8.58	9.05	8.55	1	0.0001	1500
0.05%	9.10	8.55	9.05	8.55	1	0.0005	100
0.1%	9.25	8.53	9.05	8.55	1	0.0010	225
0.5%	9.20	8.40	9.05	8.55	1	0.0050	60
Glucose	9.23	4.45	9.05	8.55	1	0.0200	213.75

Table B-2.- Schmutzdecke Biochemical Oxygen Demand

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	9.33	7.68	9.05	8.55	1	0.0001	11500
0.05%	9.40	8.33	9.05	8.55	1	0.0005	1150
0.1%	9.33	8.33	9.05	8.55	1	0.0010	500
0.5%	9.05	7.80	9.05	8.55	1	0.0050	150
Glucose	9.23	4.45	9.05	8.55	1	0.0200	213.75

Table B-3.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.25	4.25	-	
S.A.+P.D.	4.25	8.32	4.07	-	-
Blank	0.00	4.07	4.07	-	
Blank	4.07	8.14	4.07	-	-
Standard	0.00	3.04	3.04	495.19	
Standard	3.04	6.12	3.08	475.96	485.58
Sch.	0.00	4.01	4.01	2884.62	
Sch.	4.01	8.02	4.01	2884.62	2884.62

Table B-4.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	75.50	50.59		
2	72.00	48.24	73.75	49.41

Table B-5.- Schmutzdecke pH

Sample	pH	Average pH
1	7.93	
2	7.90	7.92

Table B-6.- Schmutzdecke Turbidity

Sample	Turbidity (NTU)	Average Turbidity (NTU)
1	160	
2	150	155

Table B-7.- Schmutzdecke Alkalinity

A = 2.50008
B = 40.00
C = 18.6

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	9.7	11.9	2.2	0.1014437	55.79	
2	14.4	16.7	2.3	0.1014437	58.33	57.06

Table B-8.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	TNTC	TNTC
2	TNTC	TNTC

TNTC = Too Numerous To Count

Table B-9.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
24	16.16181	10	16.17878	1697		16.17416	462	
4	16.39540	10	16.41463	1923	1810	16.40953	510	486

Table B-10.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
4E	37.87270	20	37.90683	1706.50		37.89666	508.50		1198.00	
11E	36.89924	20	36.93138	1607.00	1656.75	36.92114	512.00	510.25	1095.00	1146.50

Appendix C: Illustrations for Filtration Run 3

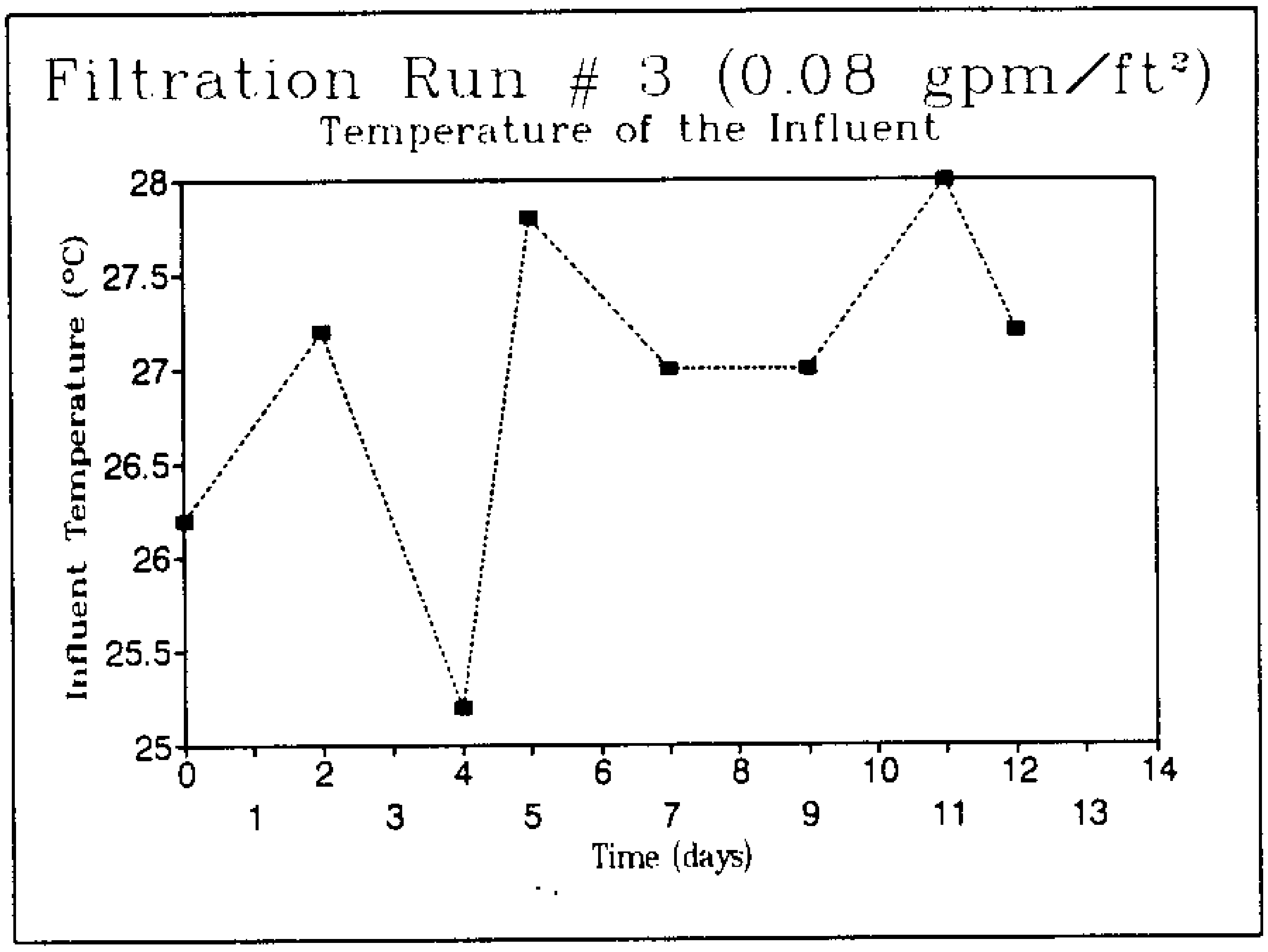

FIG. C-1.- Influent Temperature for Filtration Run 3

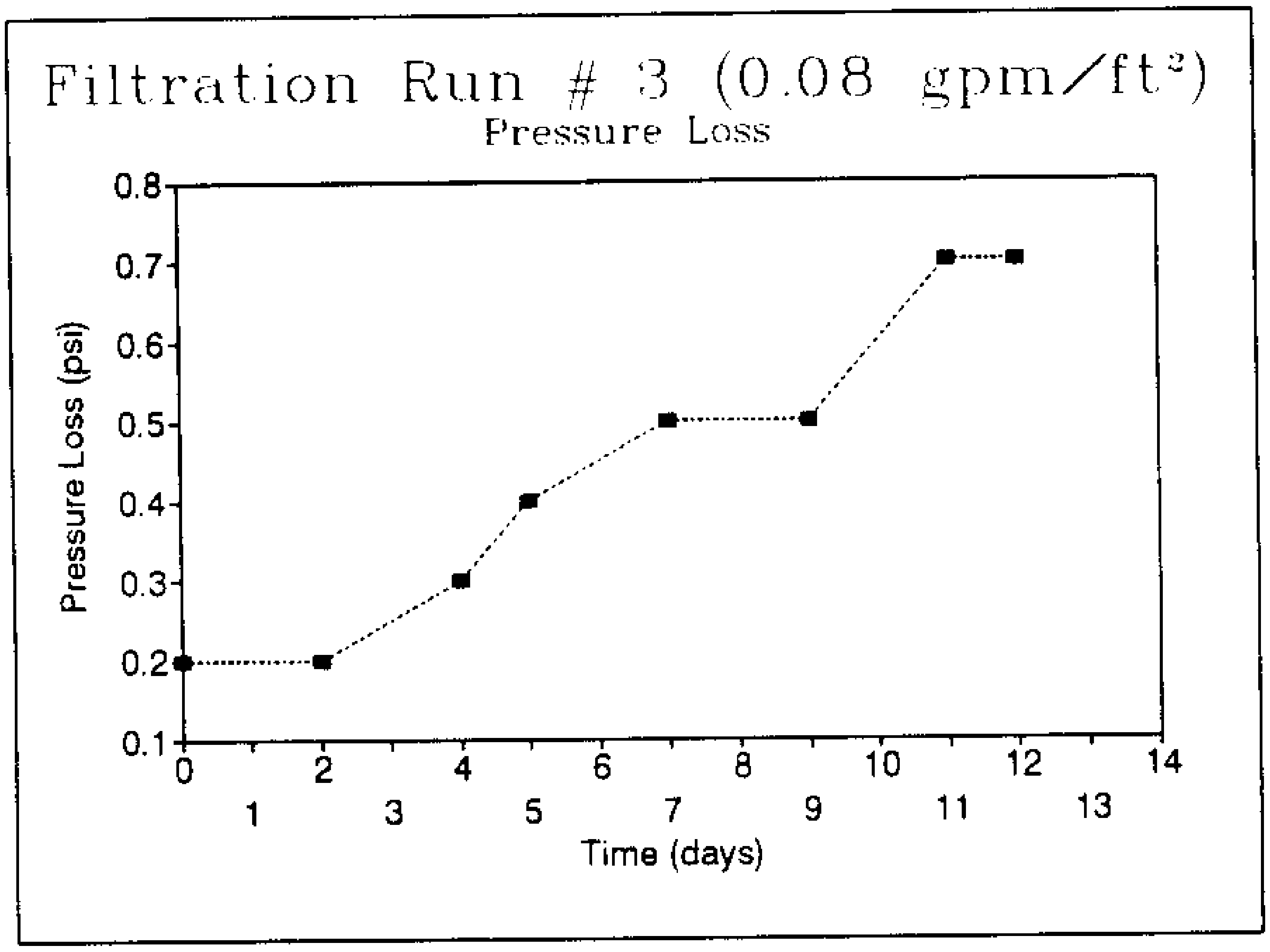

FIG. C-2.- Pressure Loss for Filtration Run 3

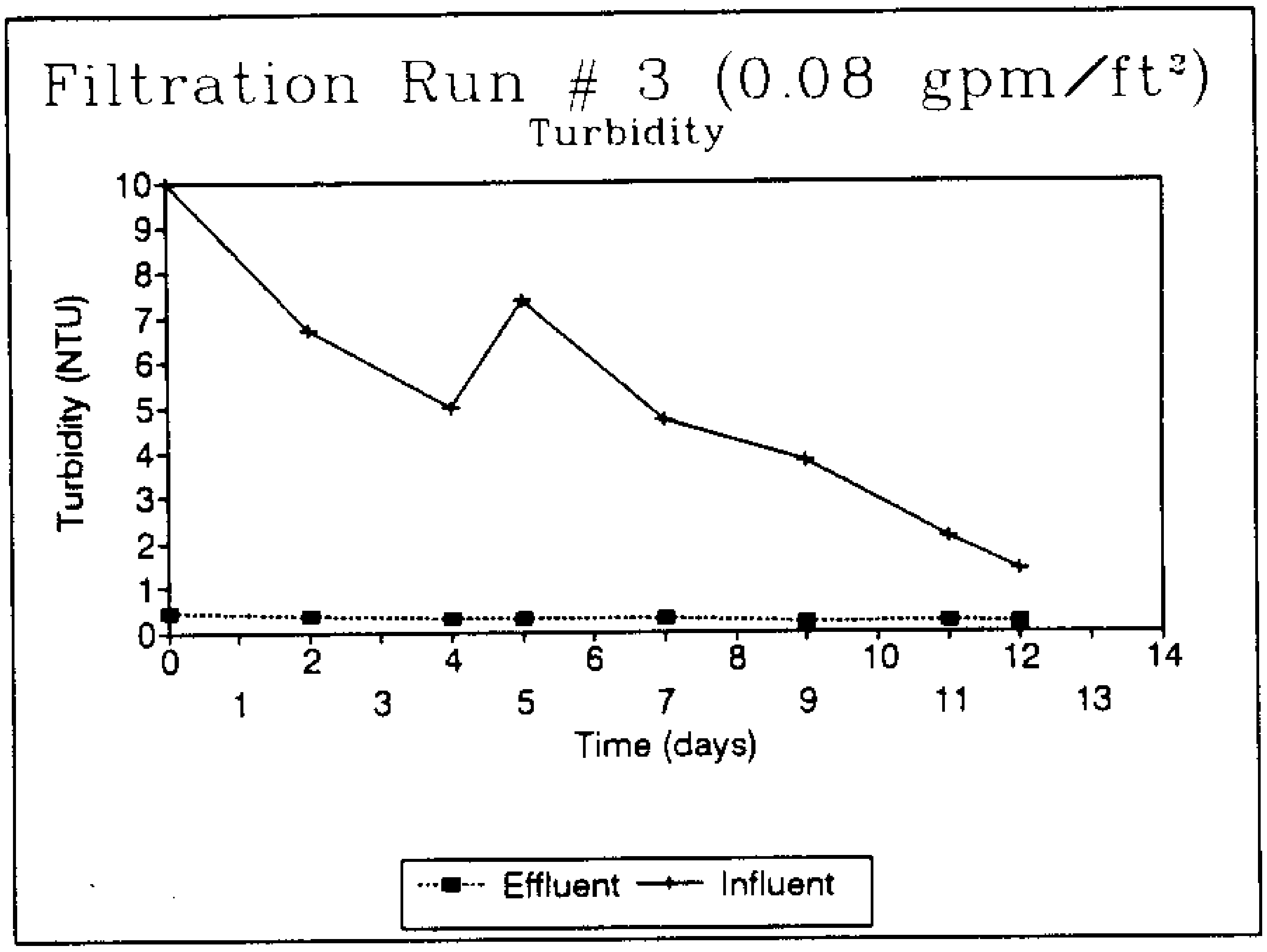

FIG. C-3.- Turbidity for Filtration Run 3

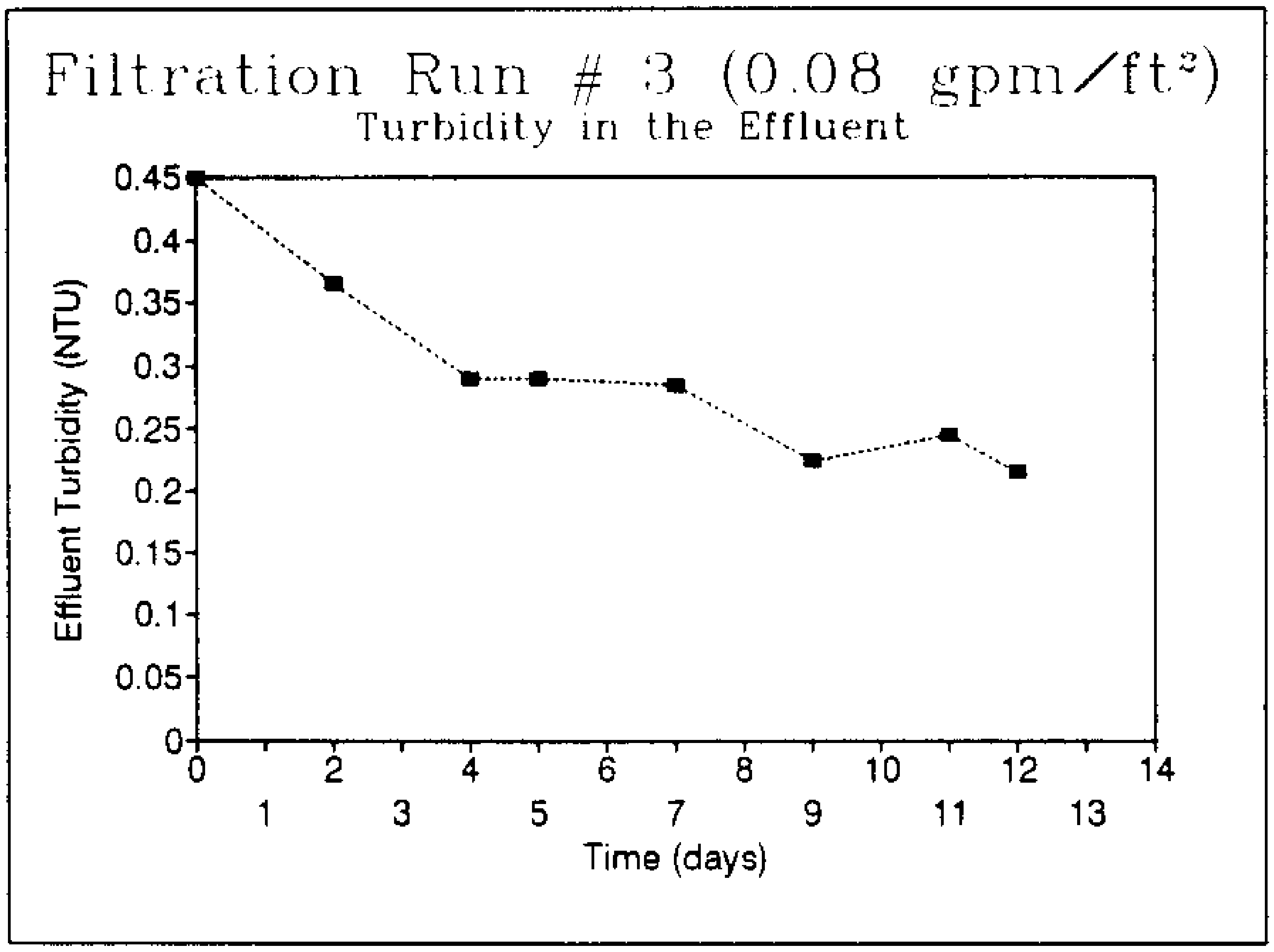

FIG. C-4.- Effluent Turbidity for Filtration Run 3

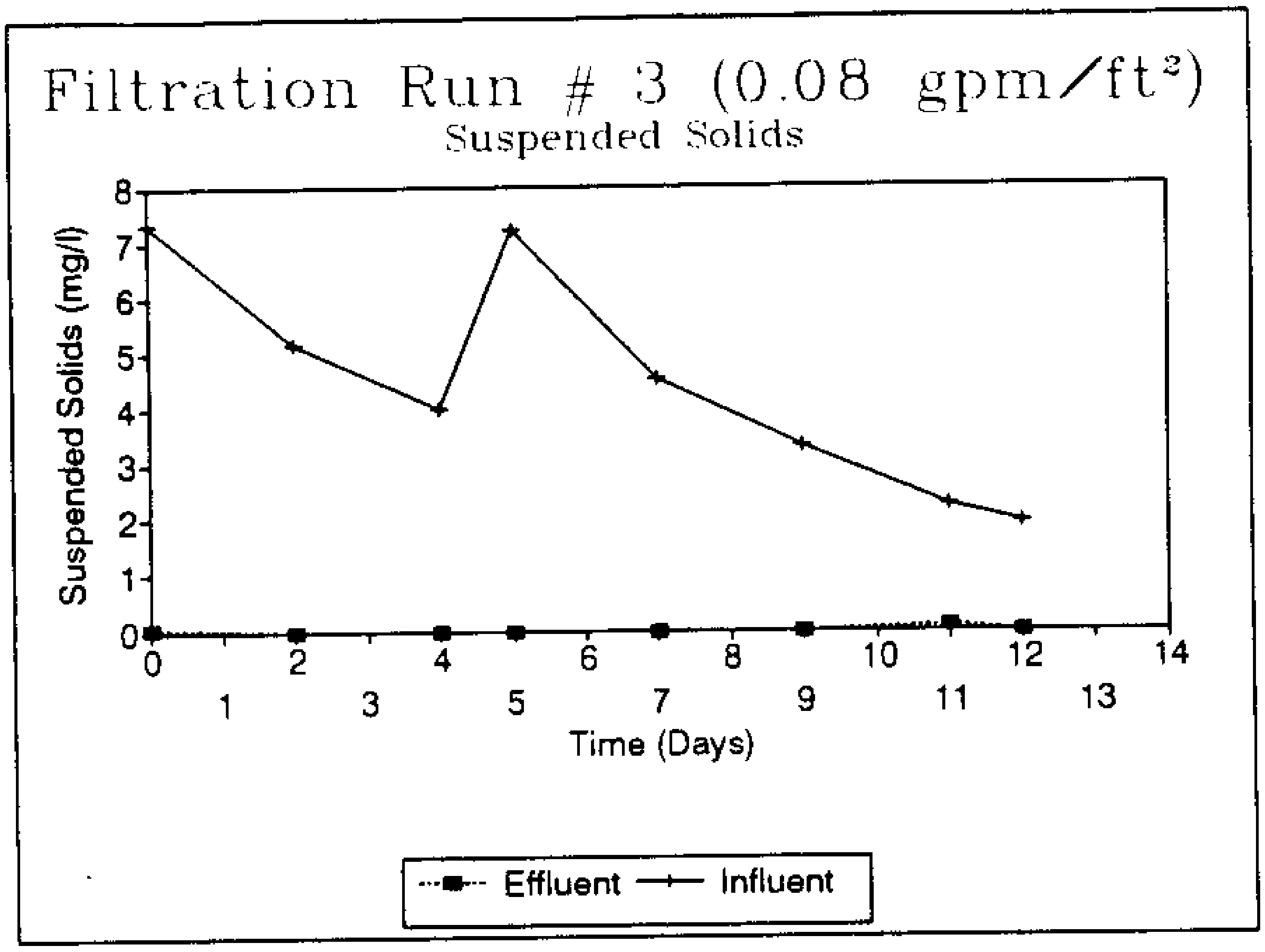

FIG. C-5.- Suspended Solids for Filtration Run 3

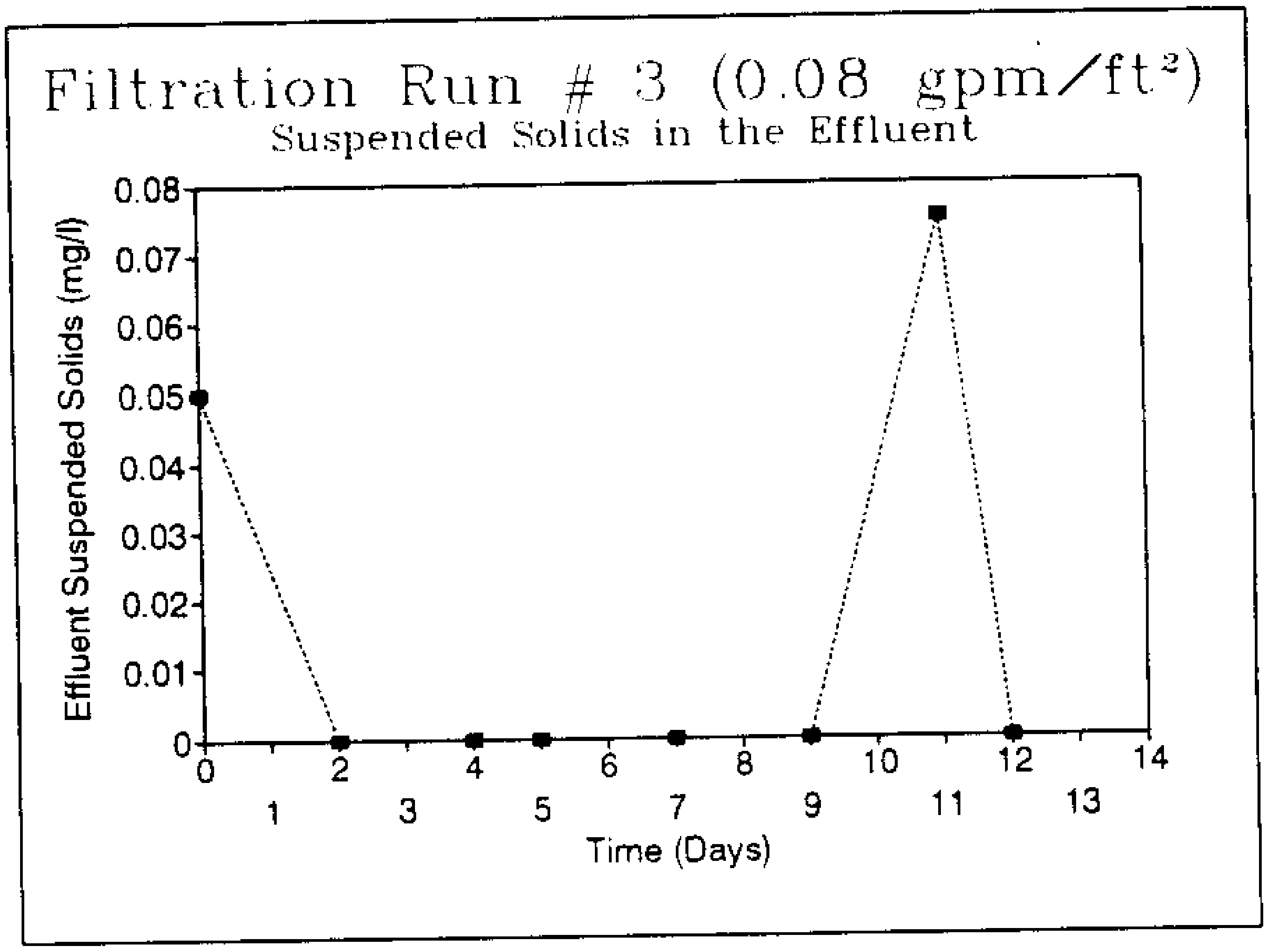

FIG. C-6.- Effluent Suspended Solids for Filtration Run 3

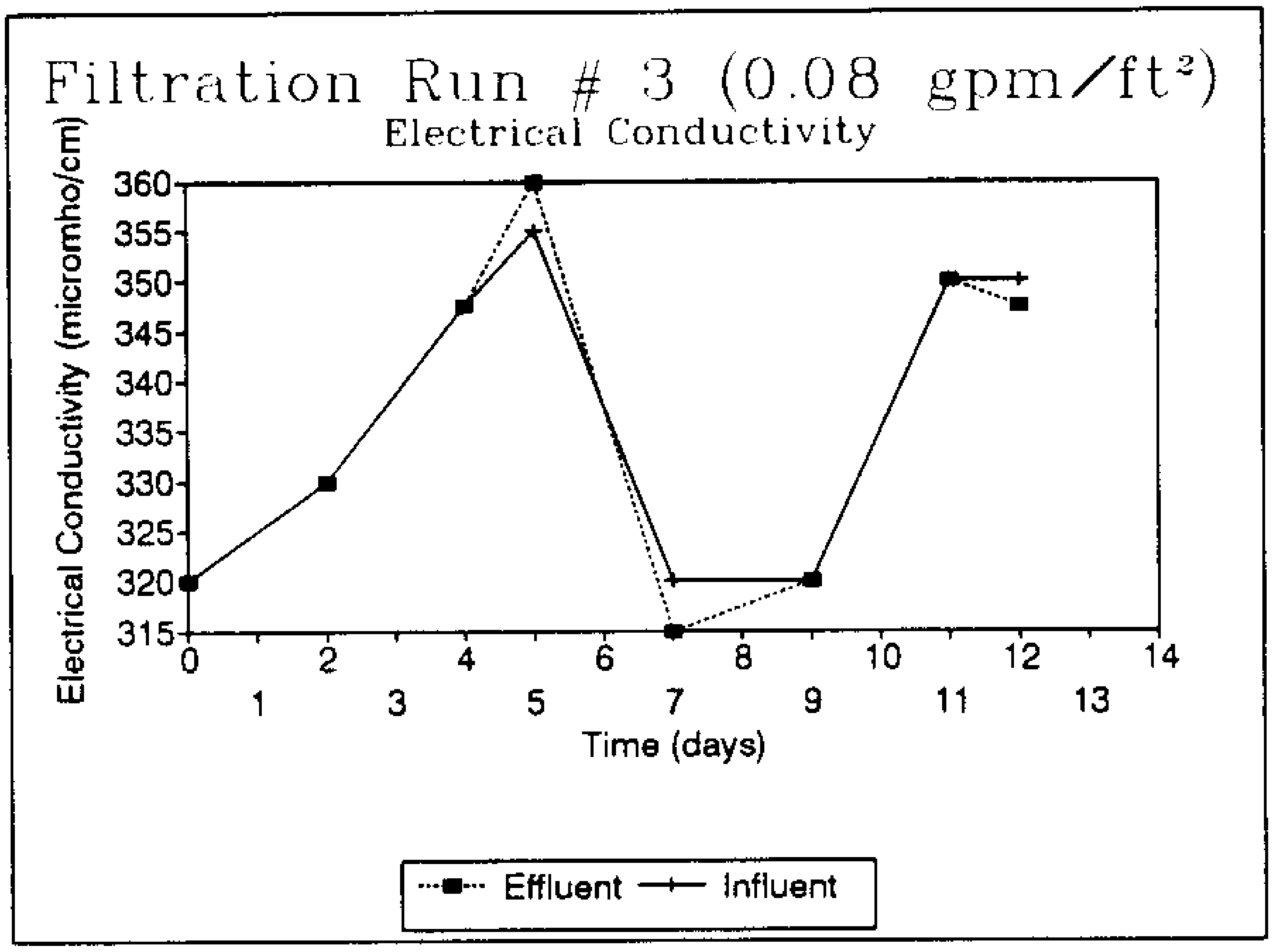

FIG. C-7.- Electrical Conductivity for Filtration Run 3

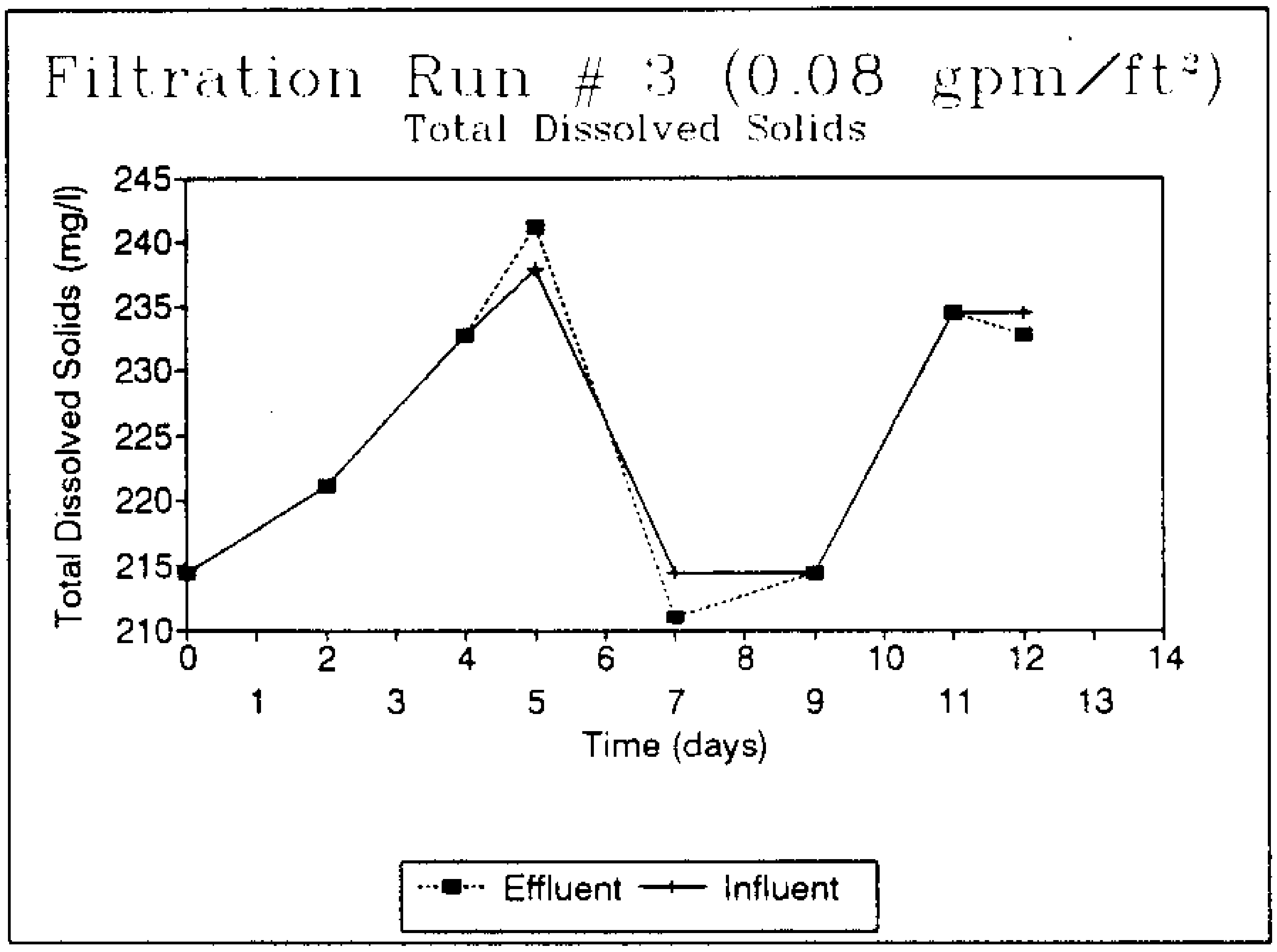

FIG. C-8.- Total Dissolved Solids for Filtration Run 3

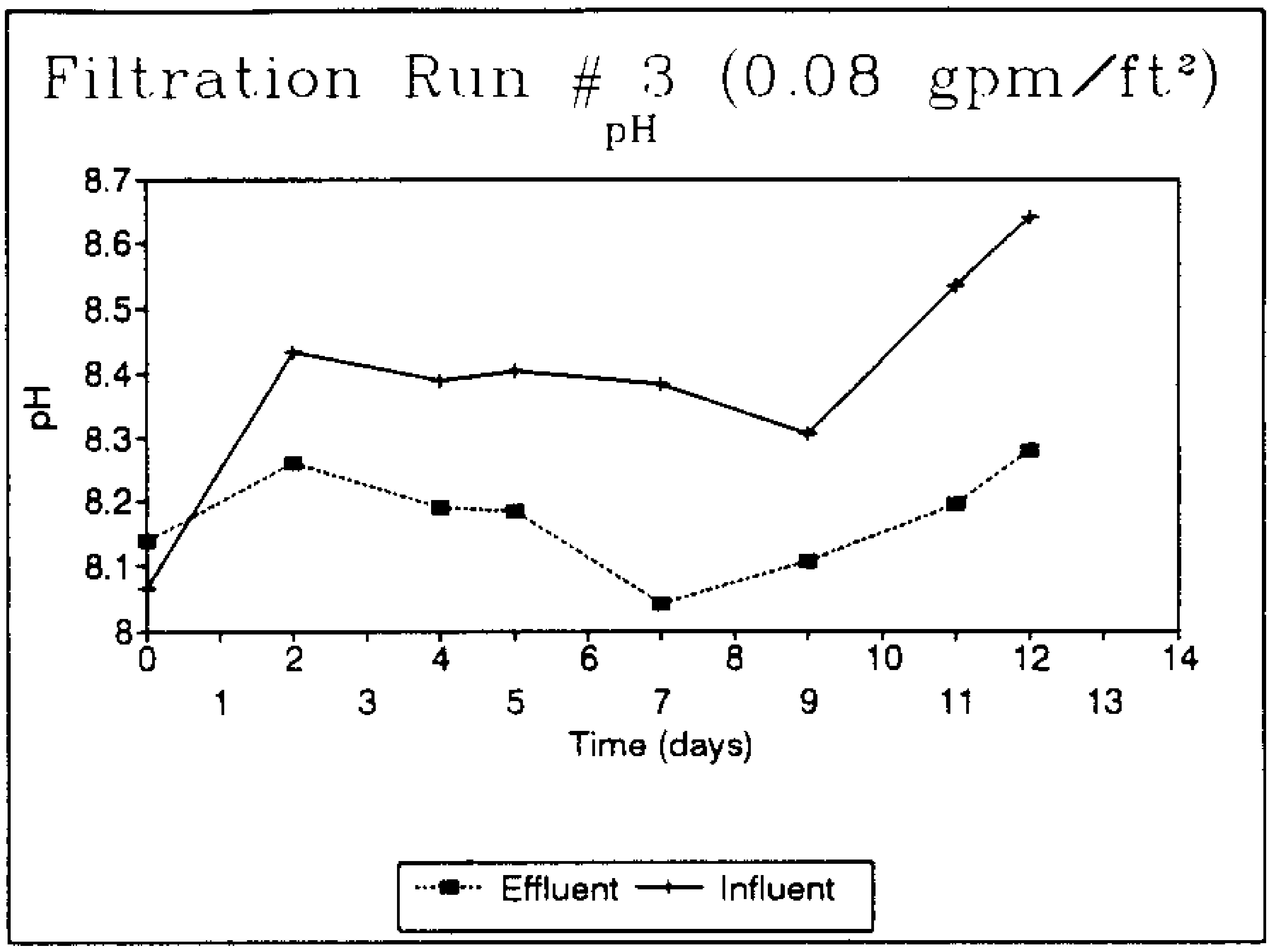

FIG. C-9.- pH for Filtration Run 3

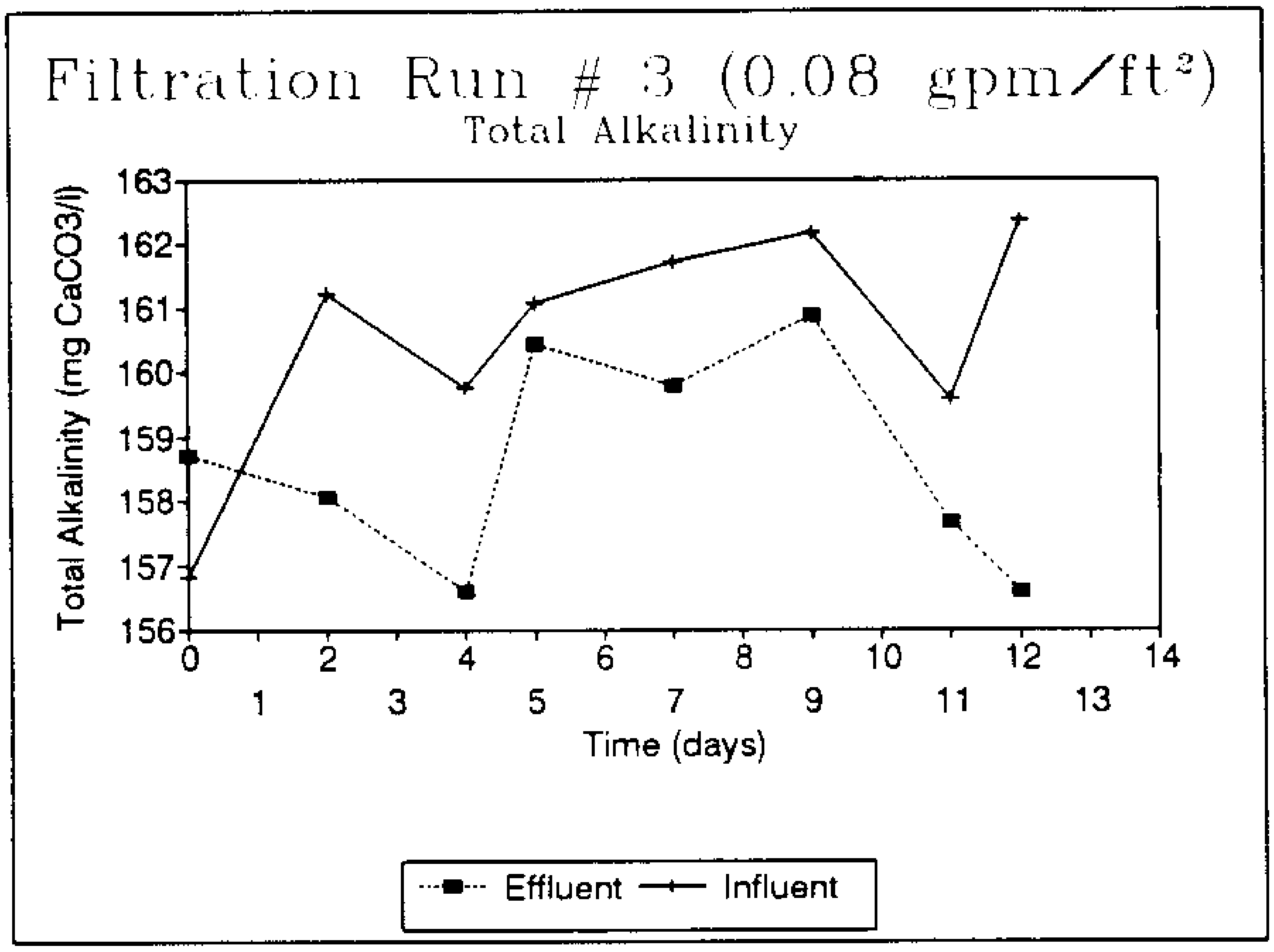

FIG. C-10.- Total Alkalinity for Filtration Run 3

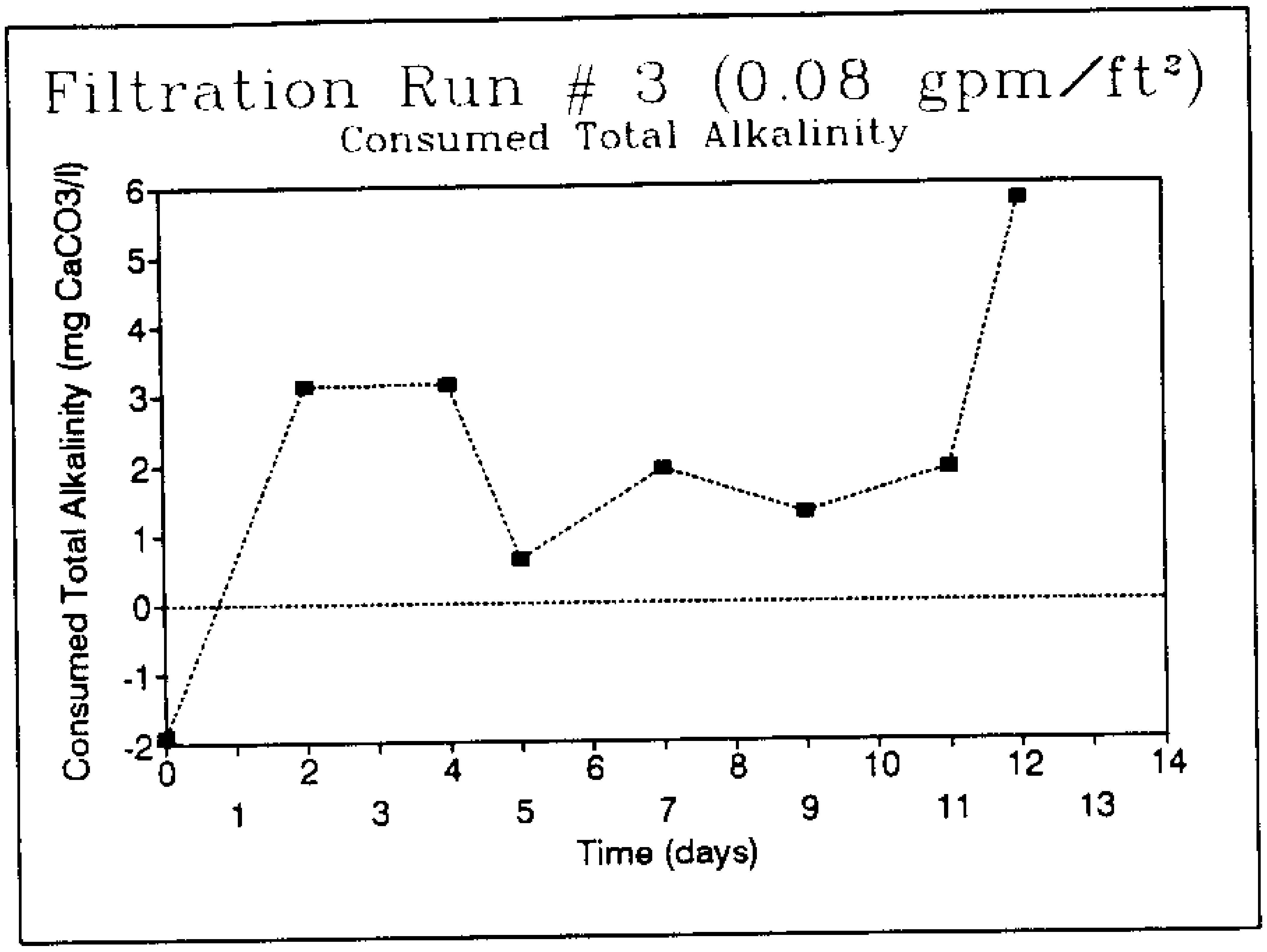

FIG. C-11.- Consumed Total Alkalinity for Filtration Run 3

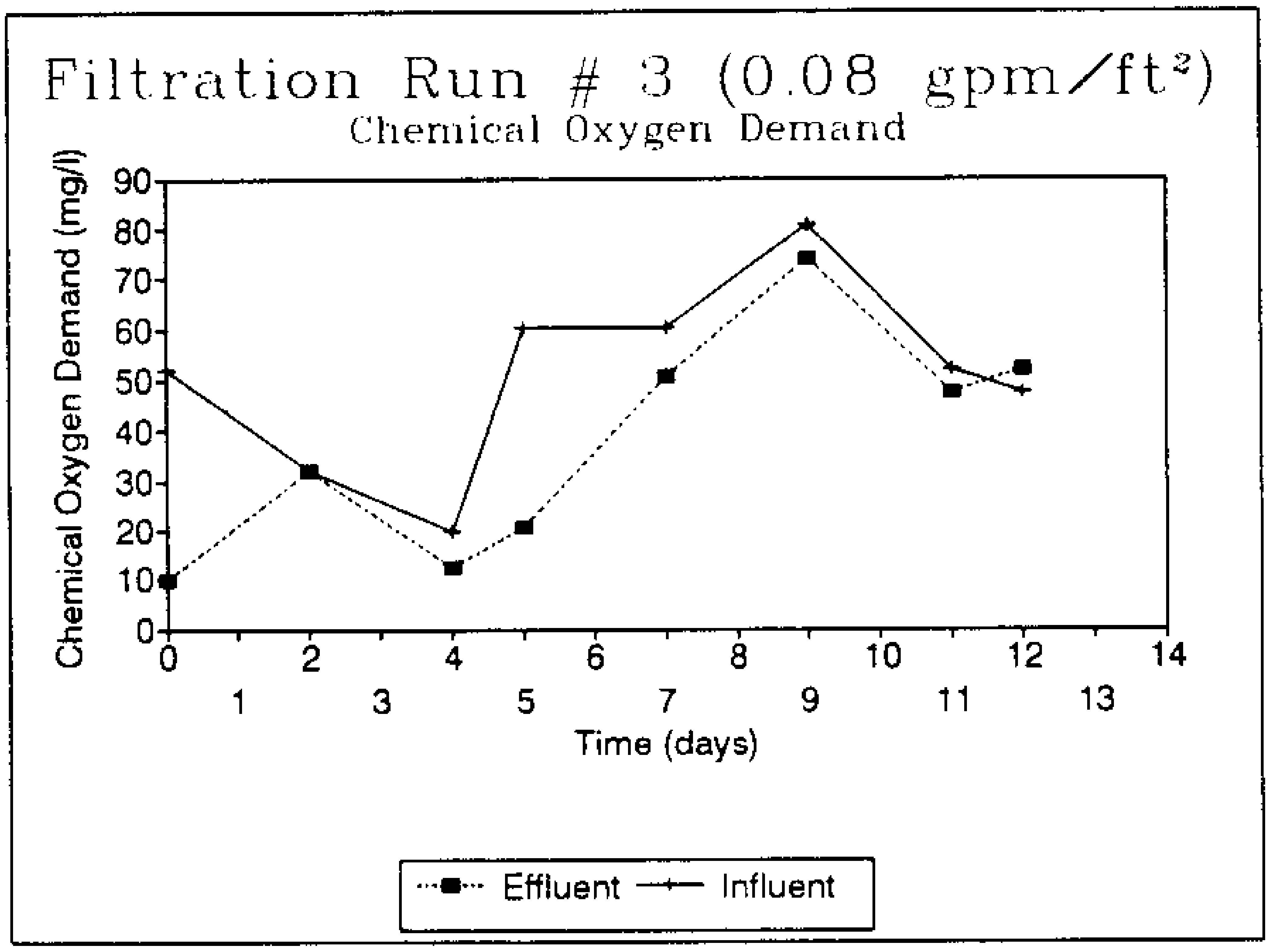

FIG. C-12.- Chemical Oxygen Demand (COD) for Filtration Run 3

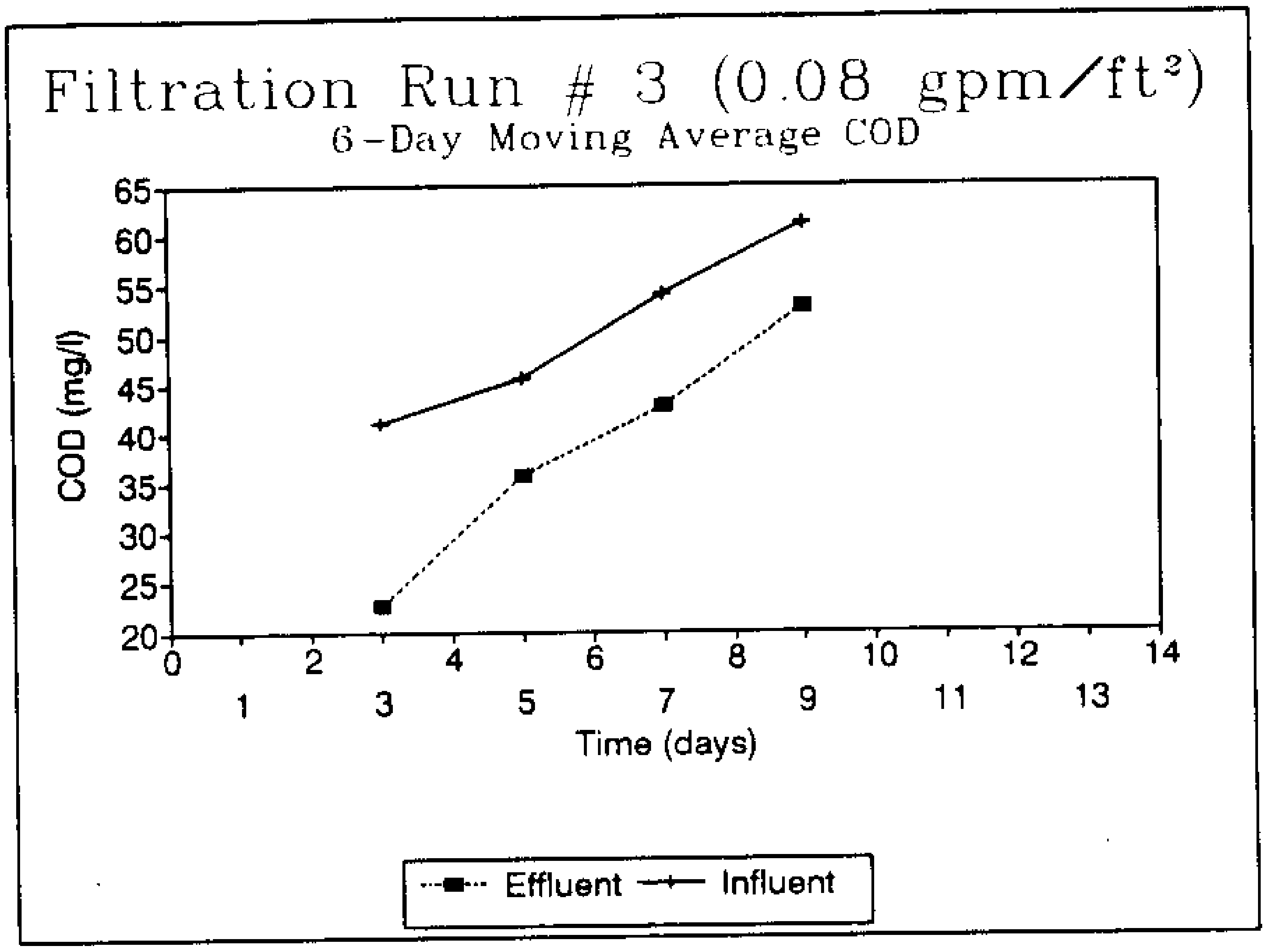

FIG. C-13.- 6-Day Moving Average COD for Filtration Run 3

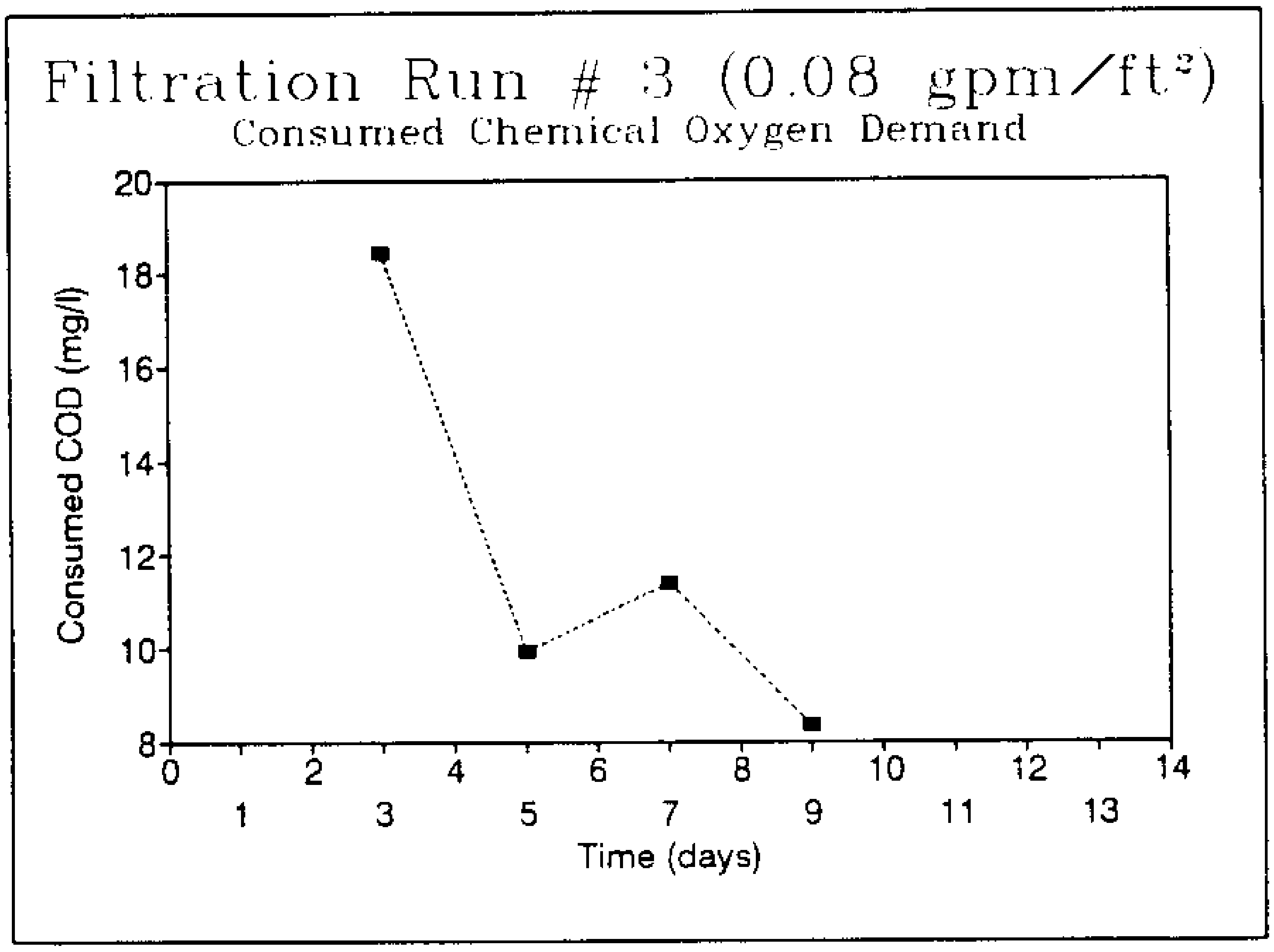

FIG. C-14.- Consumed COD for Filtration Run 3

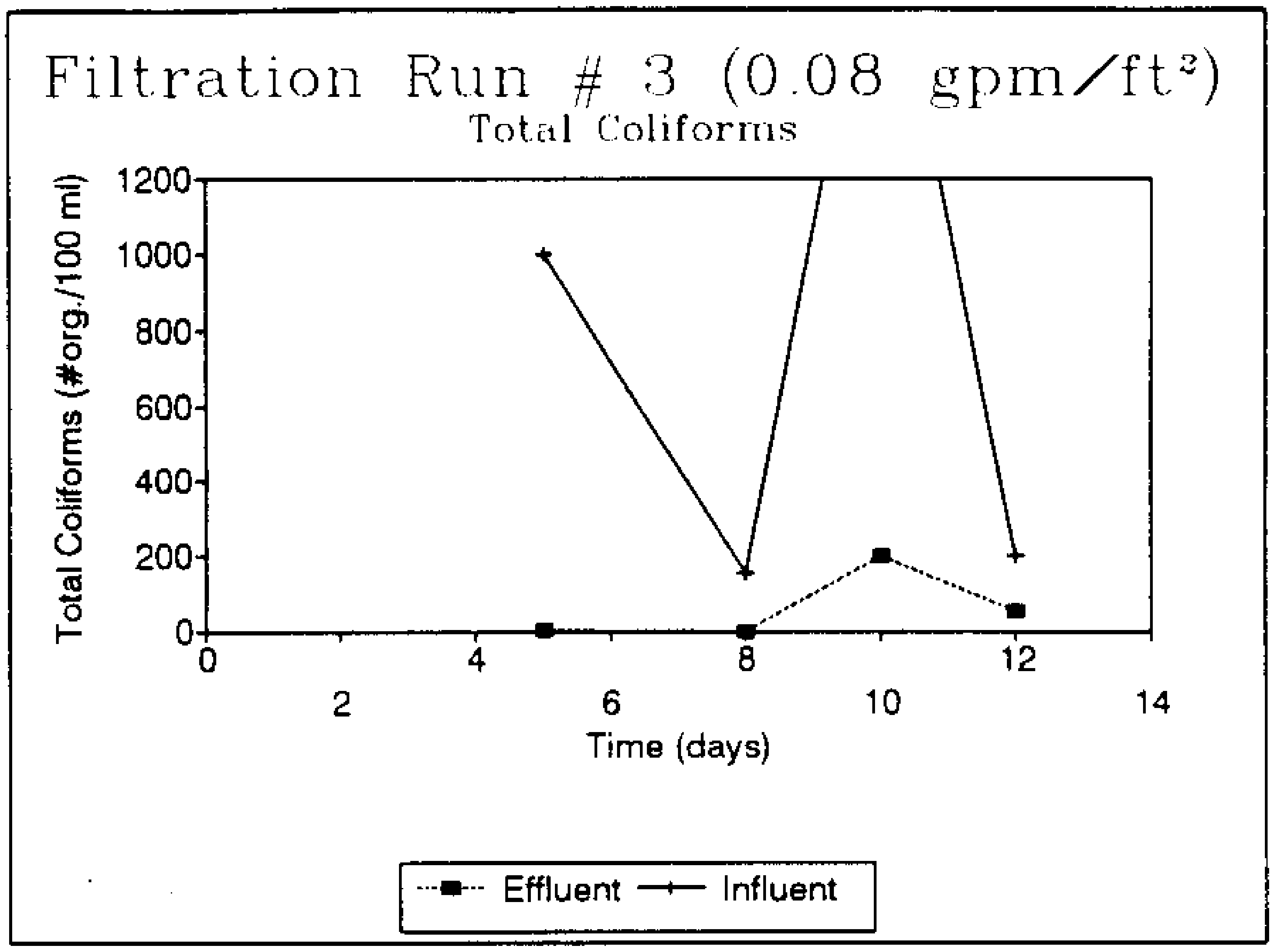

FIG. C-15.- Total Coliforms for Filtration Run 3

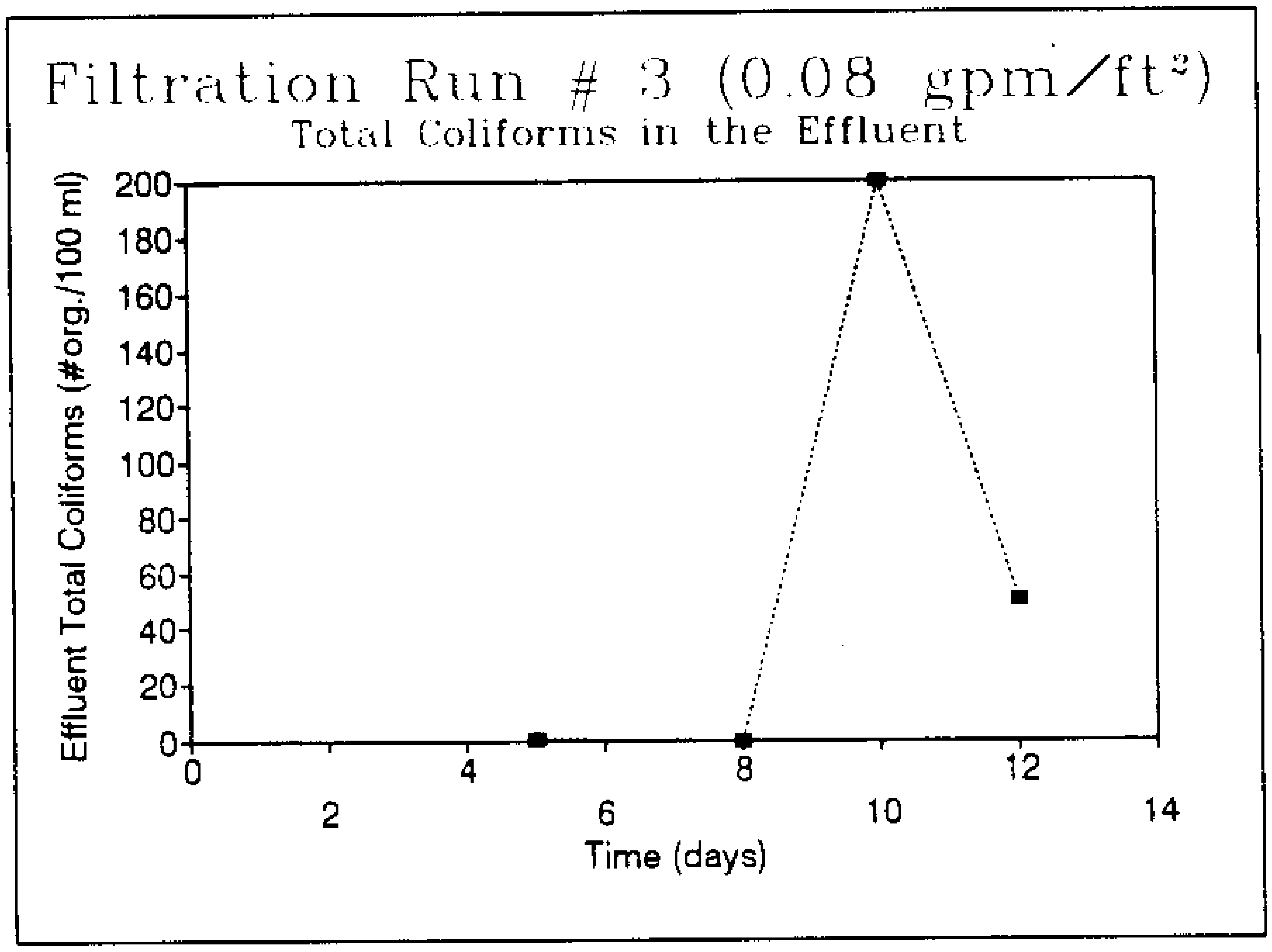

FIG. C-16.- Effluent Total Coliforms for Filtration Run 3

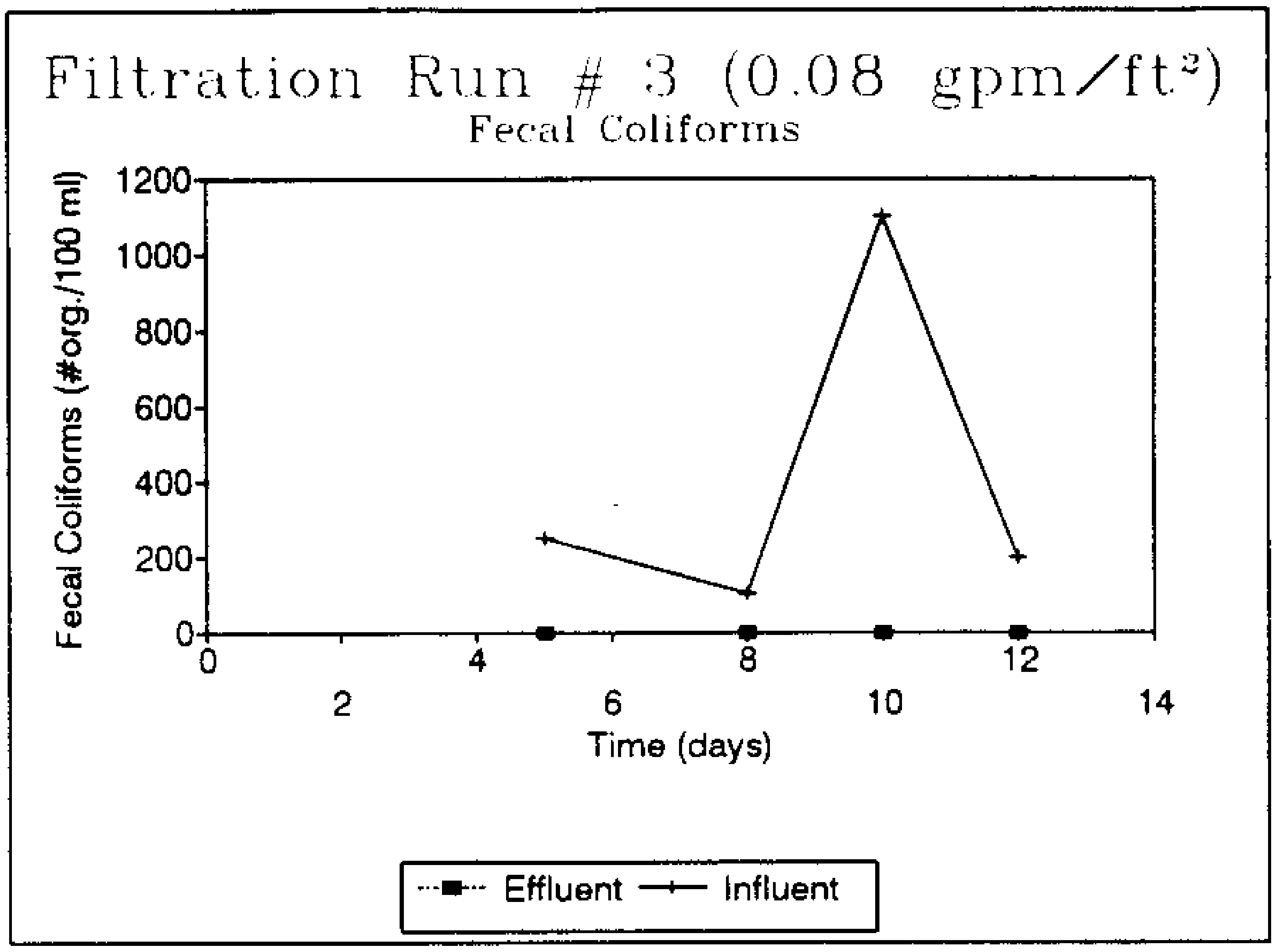

FIG. C-17.- Fecal Coliforms for Filtration Run 3

Table C-1.- Biochemical Oxygen Demand (Effluent of Last Day)

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	8.48	6.95	8.40	7.33	1	0.0001	4500
0.05%	8.50	7.00	8.40	7.33	1	0.0005	850
0.1%	8.50	6.33	8.40	7.33	1	0.0010	1100
0.5%	8.50	6.85	8.40	7.33	1	0.0050	115
Glucose	8.40	3.38	8.40	7.33	1	0.0200	197.5

Table C-2.- Schmutzdecke Biochemical Oxygen Demand

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	8.45	7.05	8.40	7.33	1	0.0001	3250
0.05%	8.45	7.28	8.40	7.33	1	0.0005	200
0.1%	8.48	7.38	8.40	7.33	1	0.0010	25
0.5%	8.50	7.35	8.40	7.33	1	0.0050	15
Glucose	8.40	3.38	8.40	7.33	1	0.0200	197.5

Table C-3.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.21	4.21	-	
S.A.+P.D.	4.21	8.45	4.24	-	-
Blank	0.00	4.43	4.43	-	
Blank	4.43	8.86	4.43	-	-
Standard	0.00	3.29	3.29	539.64	
Standard	3.29	6.46	3.17	596.45	568.05
Sch.	0.00	4.09	4.09	16094.67	
Sch.	4.09	8.18	4.09	16094.67	16094.67

Table C-4.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	84.50	56.62		
2	84.00	56.28	84.25	56.45

Table C-5.- Schmutzdecke pH

Sample	pH	Average pH
1	8.03	
2	8.02	8.03

Table C-6.- Schmutzdecke Turbidity

Sample	Turbidity (NTU)	Average Turbidity (NTU)
1	2900.00	
2	3000.00	2950.00

Table C-7.- Schmutzdecke Alkalinity

A = 2.50008
B = 40.00
C = 18.45

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	17.85	21.00	3.15	0.10226845	80.54	
2	21.00	24.20	3.20	0.10226845	81.81	81.18

Table C-8.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	10000	40000
2	0	30000
Average	5000	35000

Table C-9.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
28	16.14269	5	16.16644	4750		16.16335	618	
108	18.47795	5	18.50008	4426	4588	18.49693	630	624

Table C-10.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
1	38.82474	20	38.90847	4186.50		38.89503	672.00		3514.50	
12	37.50097	20	37.58811	4357.05	4271.775	37.57520	645.55	658.77	3711.50	3613.00

Appendix D: Illustrations for Filtration Run 4

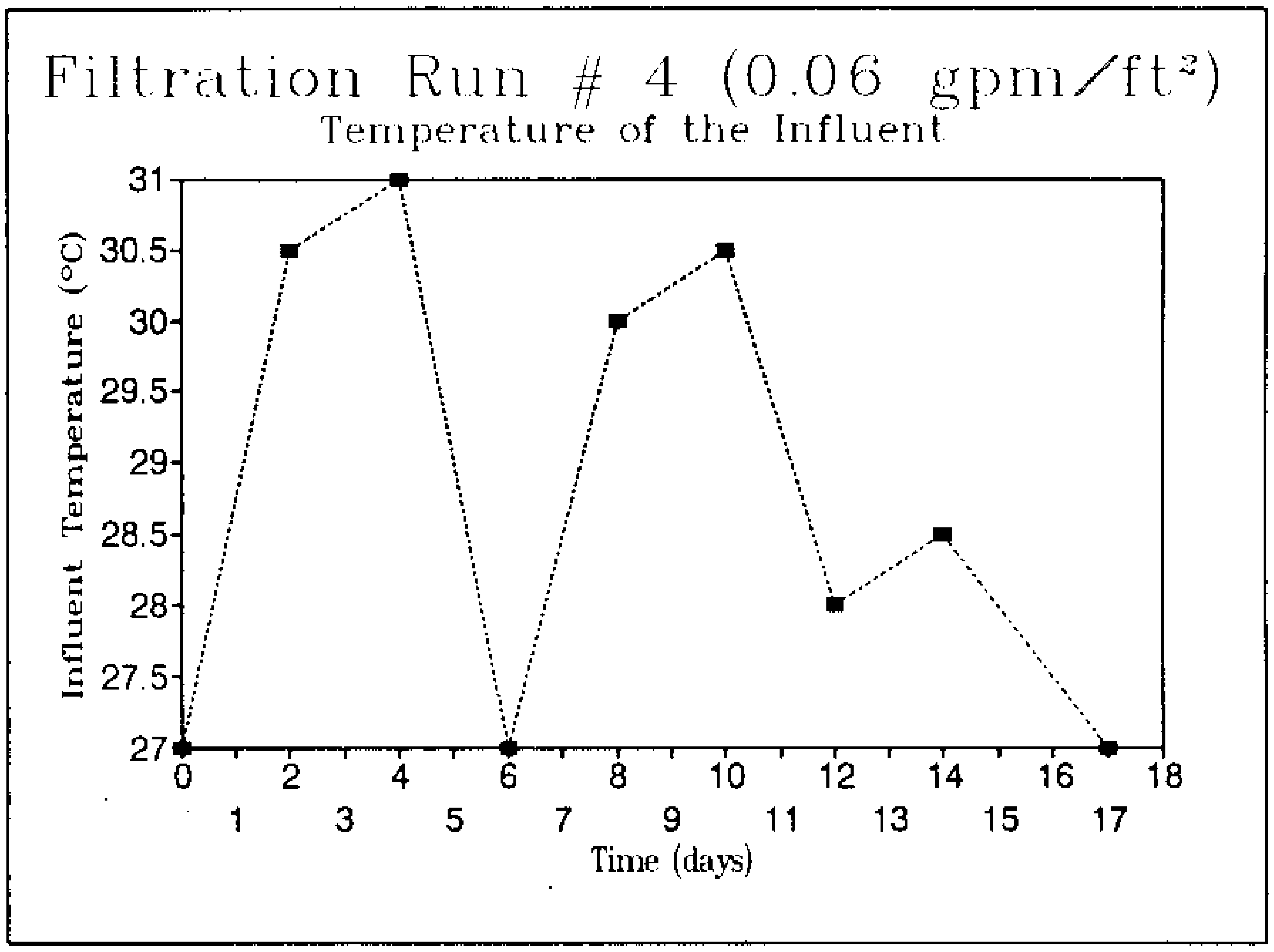

FIG. D-1.- Influent Temperature for Filtration Run 4

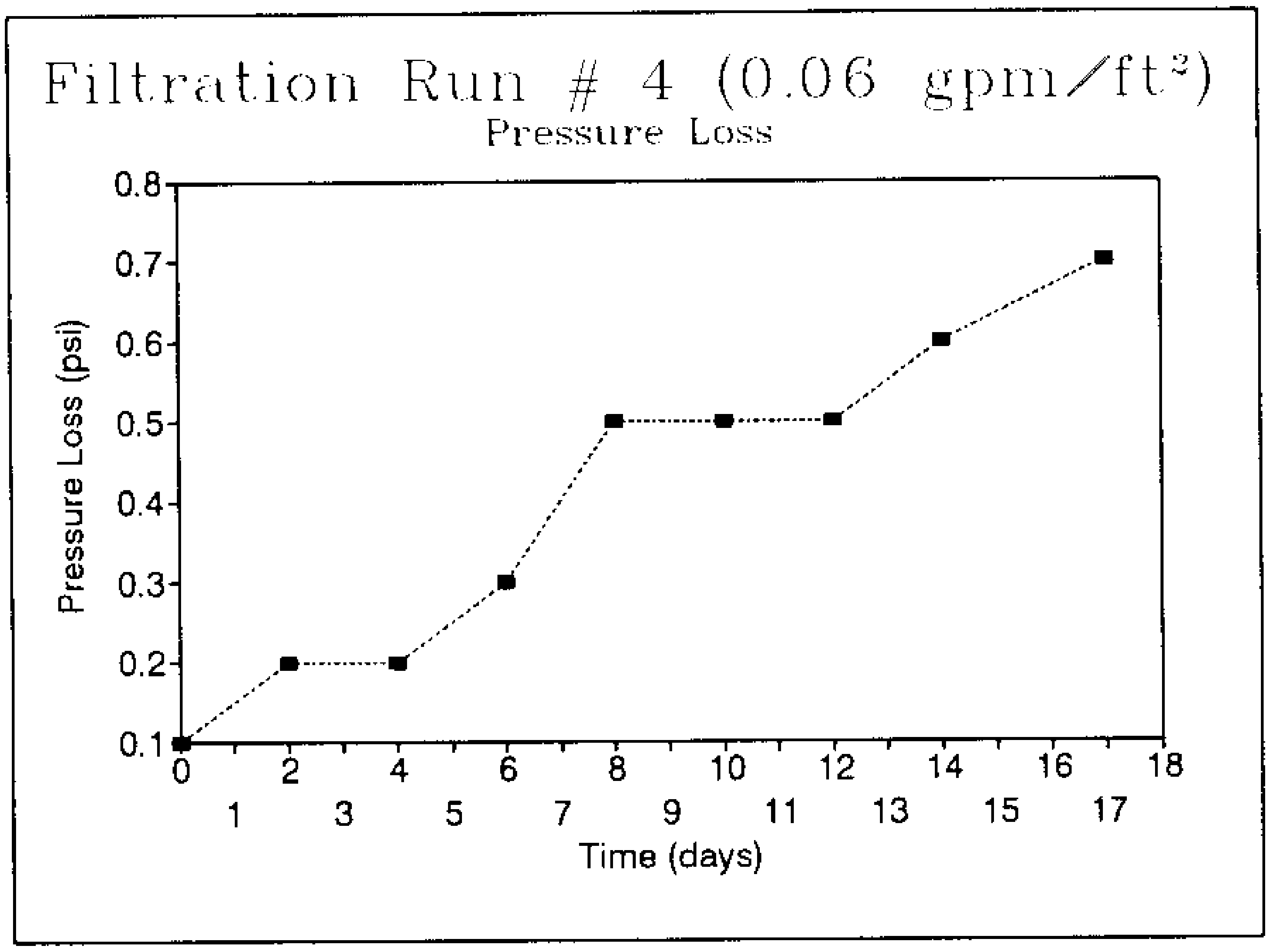

FIG. D-2.- Pressure Loss for Filtration Run 4

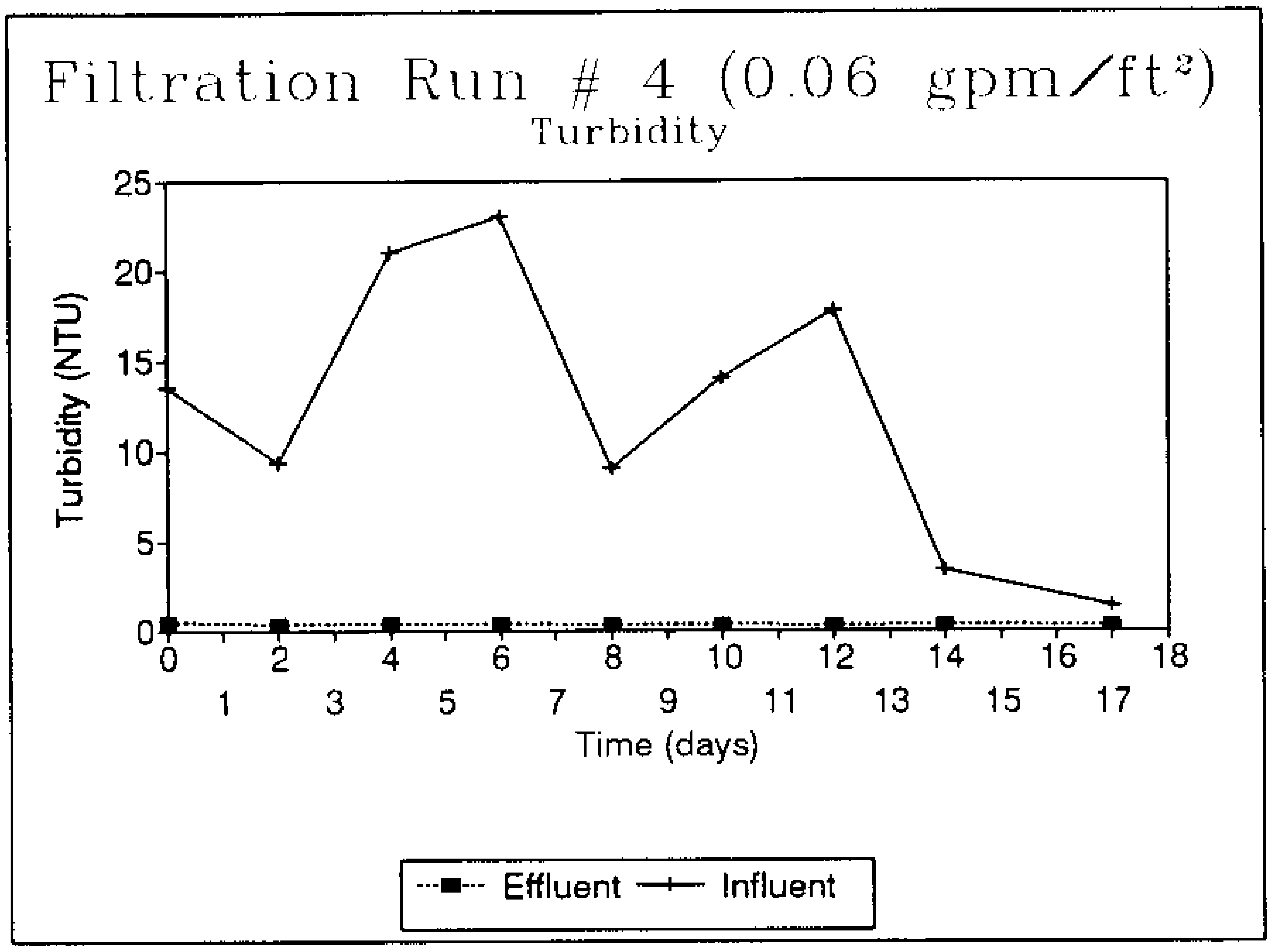

FIG. D-3.- Turbidity for Filtration Run 4

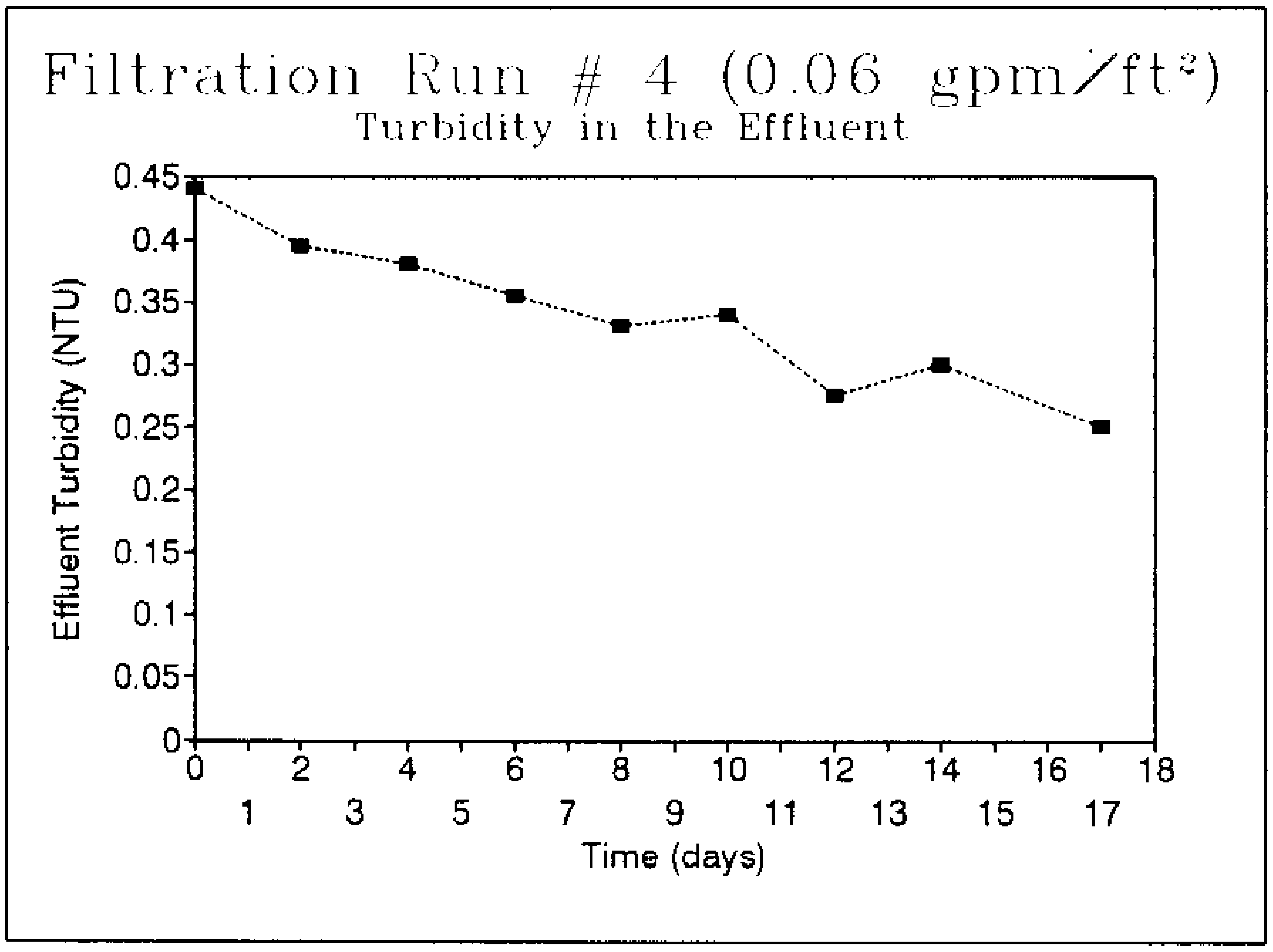

FIG. D-4.- Effluent Turbidity for Filtration Run 4

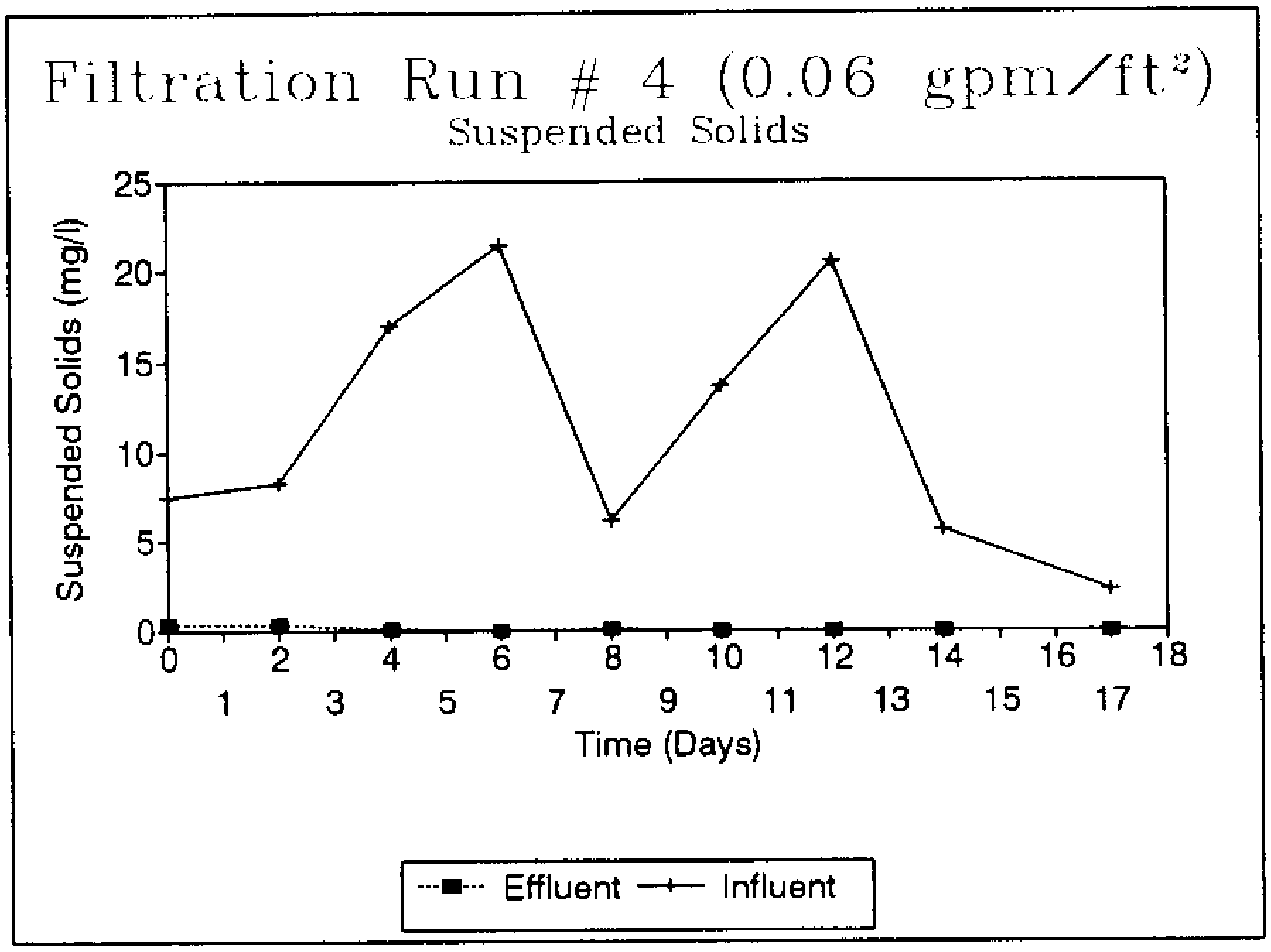

FIG. D-5.- Suspended Solids for Filtration Run 4

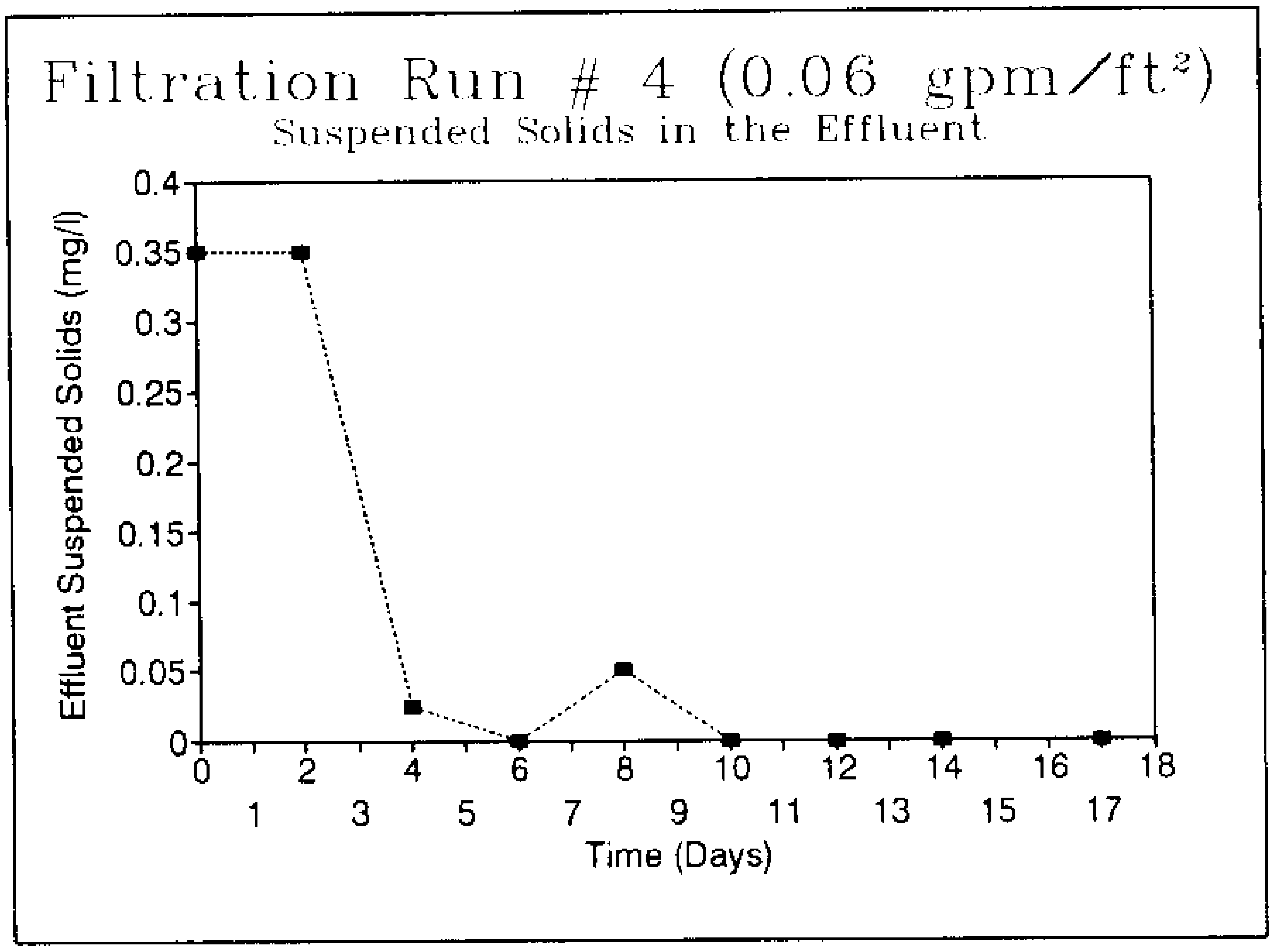

FIG. D-6.- Effluent Suspended Solids for Filtration Run 4

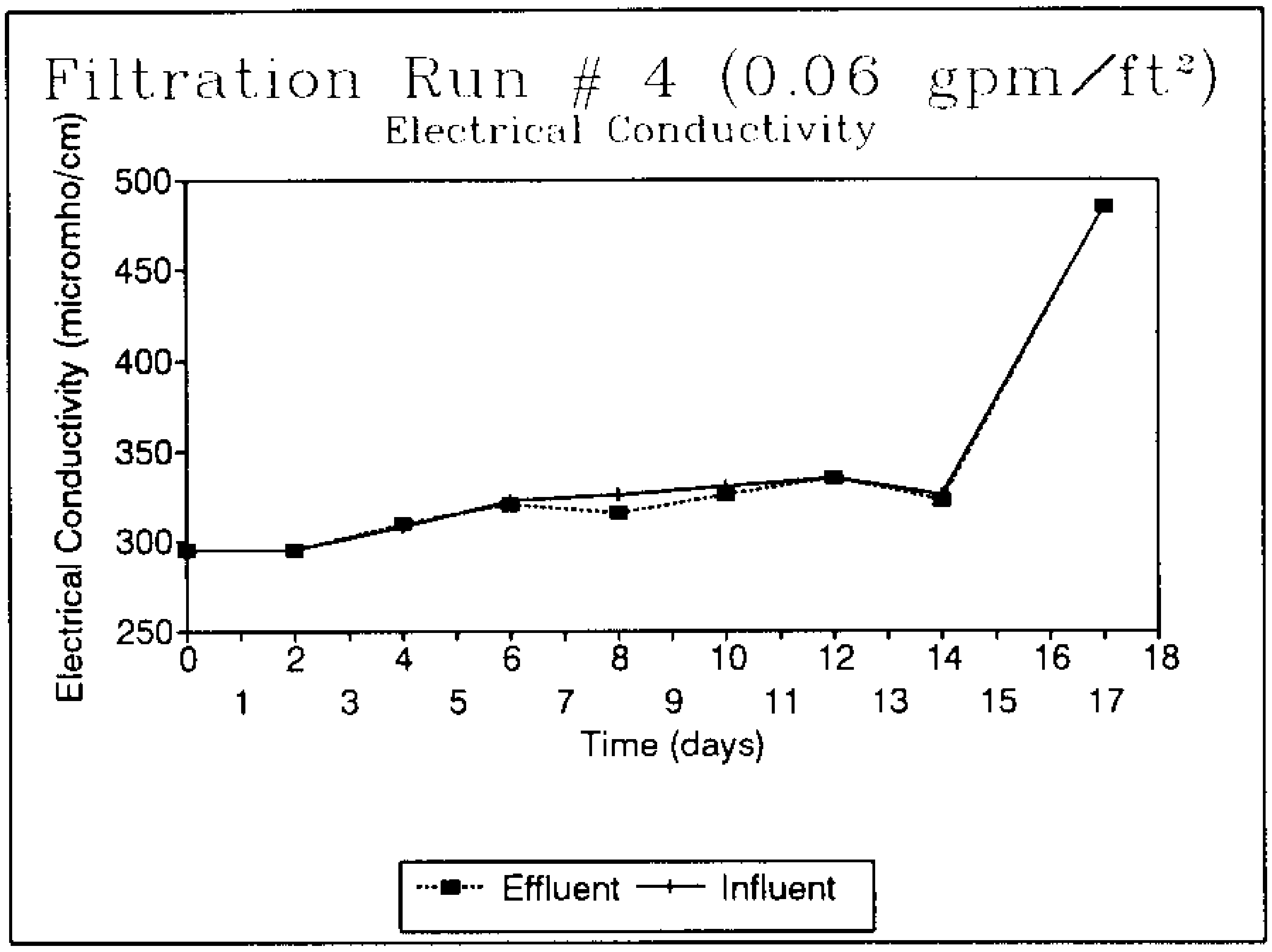

FIG. D-7.- Electrical Conductivity for Filtration Run 4

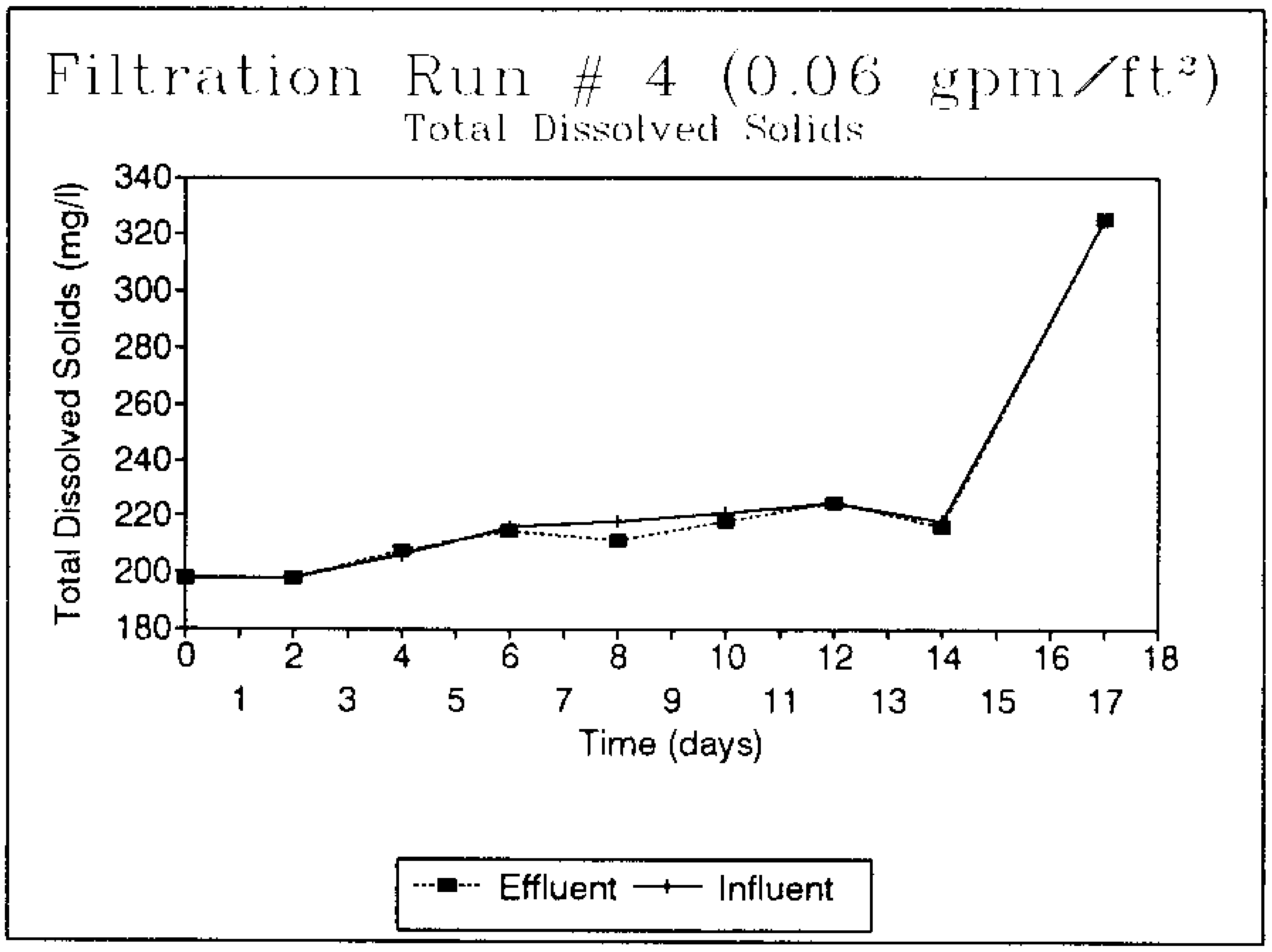

FIG. D-8.- Total Dissolved Solids for Filtration Run 4

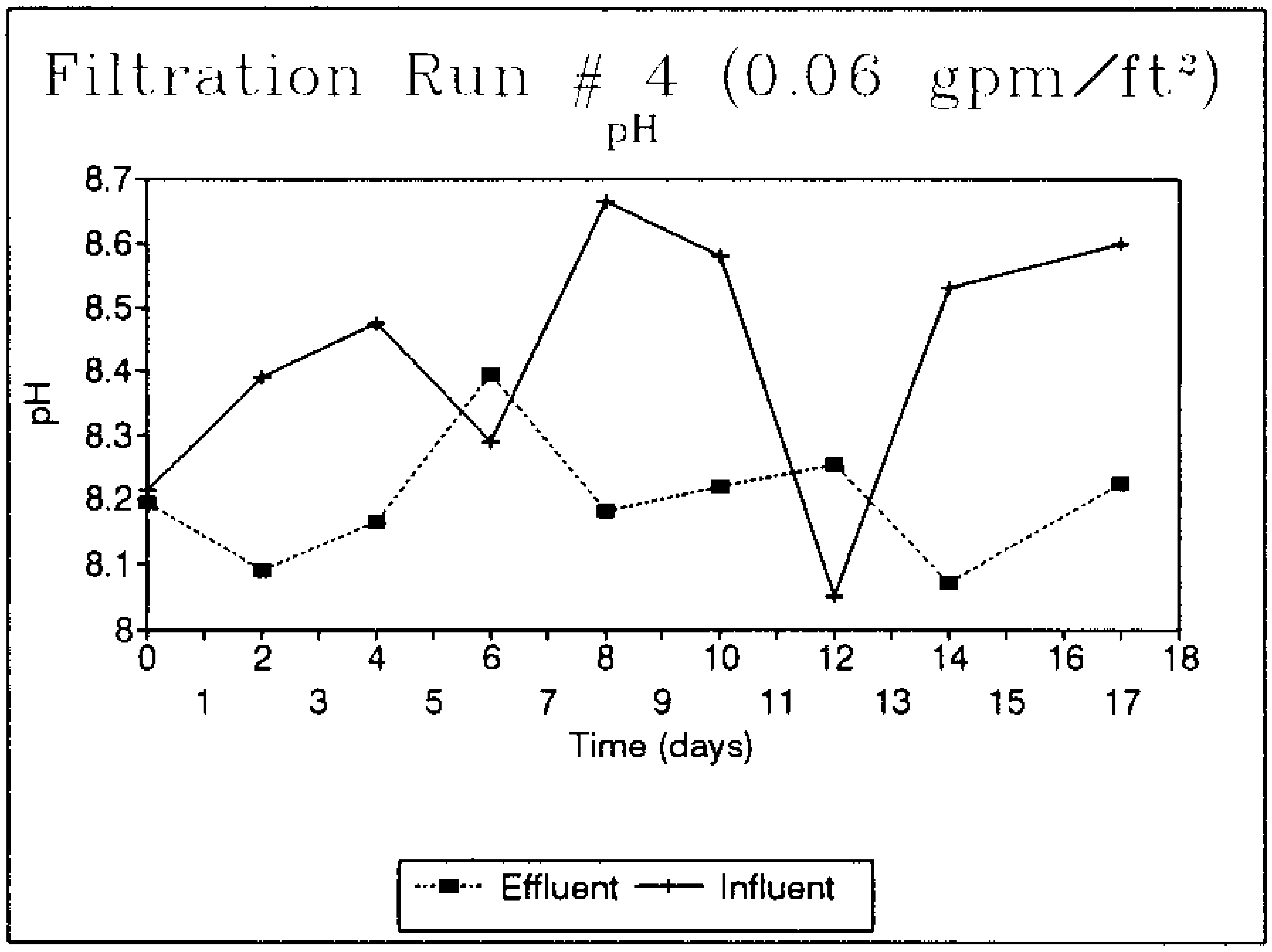

FIG. D-9.- pH for Filtration Run 4

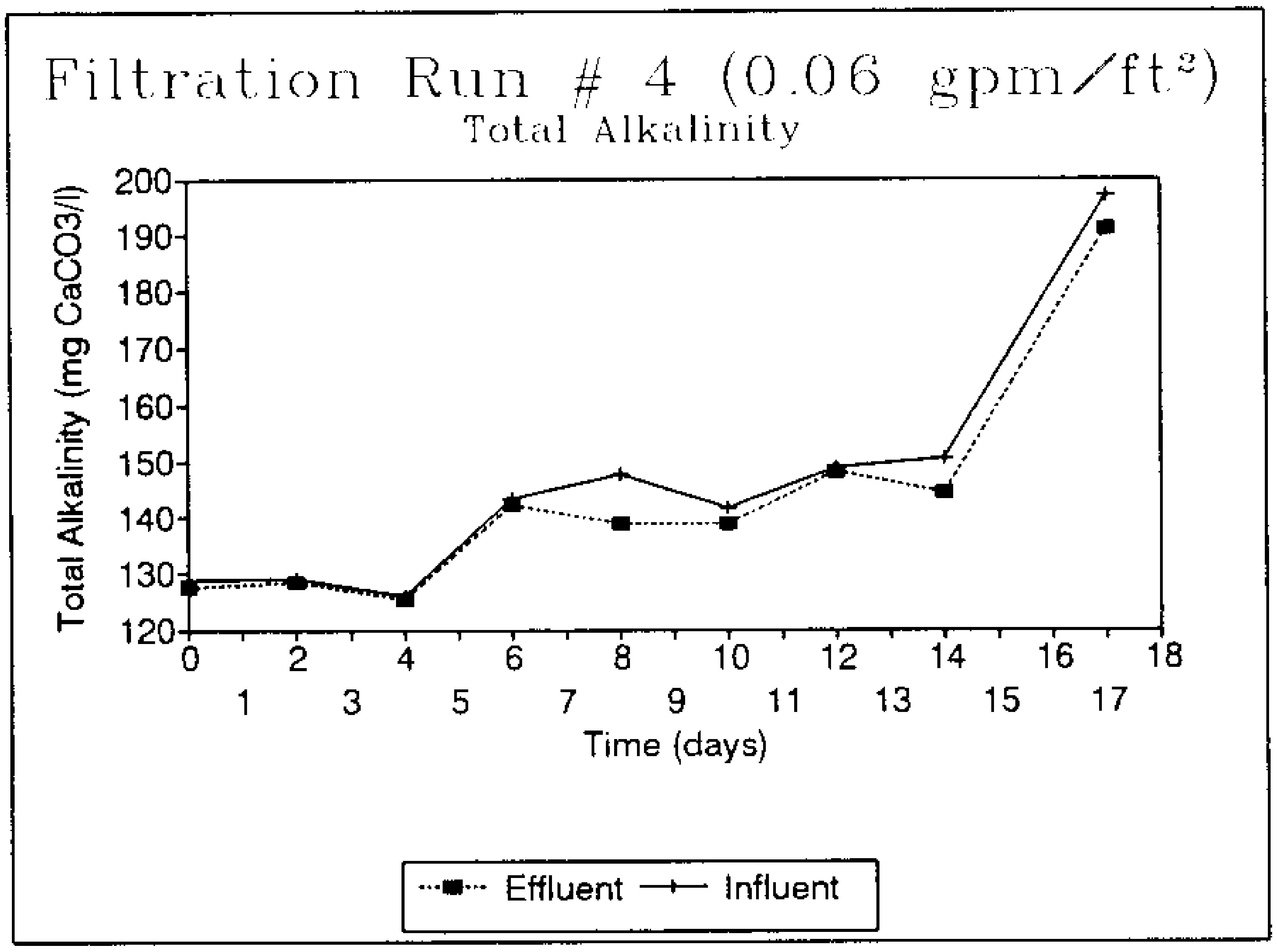

FIG. D-10.- Total Alkalinity for Filtration Run 4

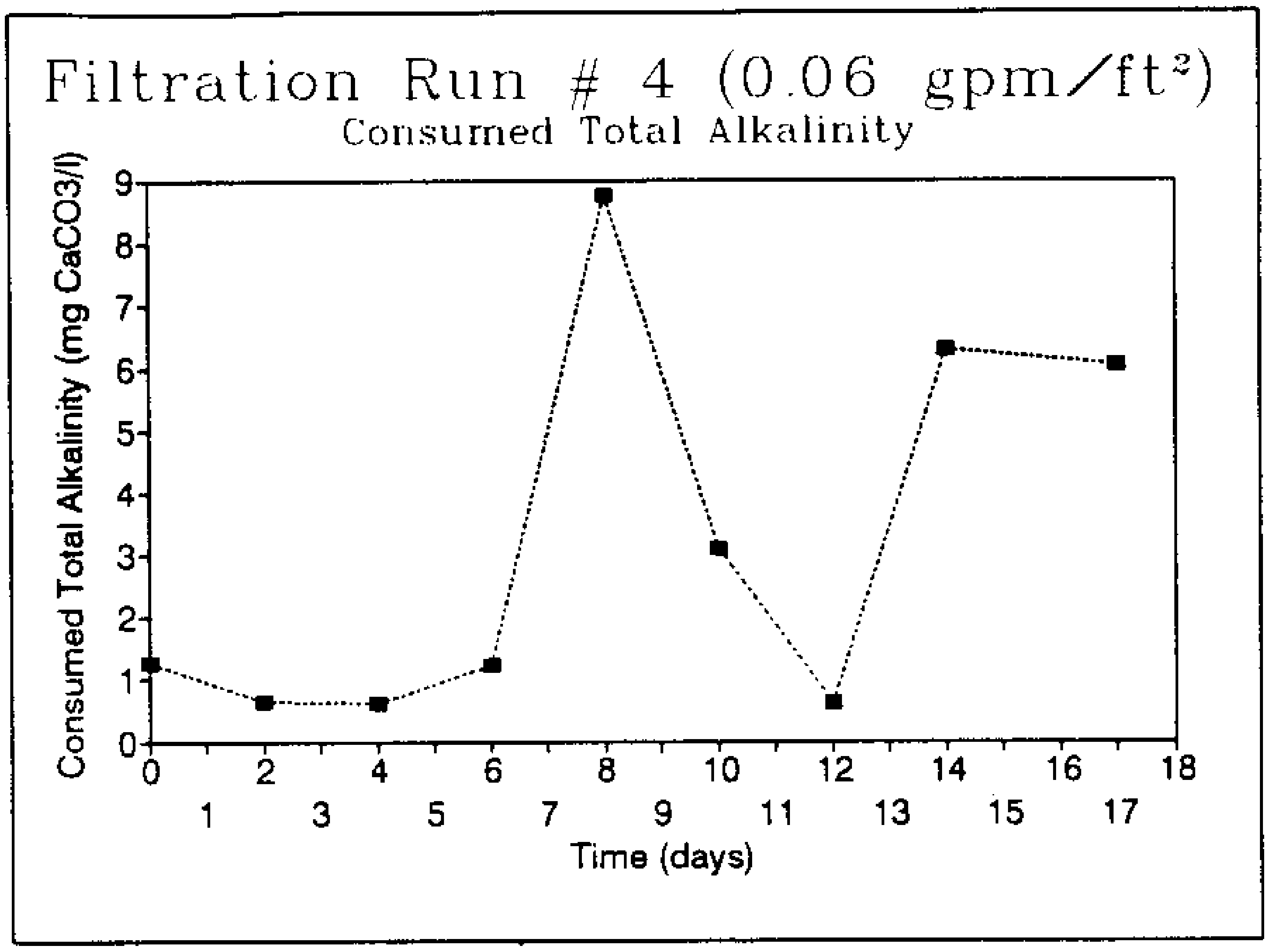

FIG. D-11.- Consumed Total Alkalinity for Filtration Run 4

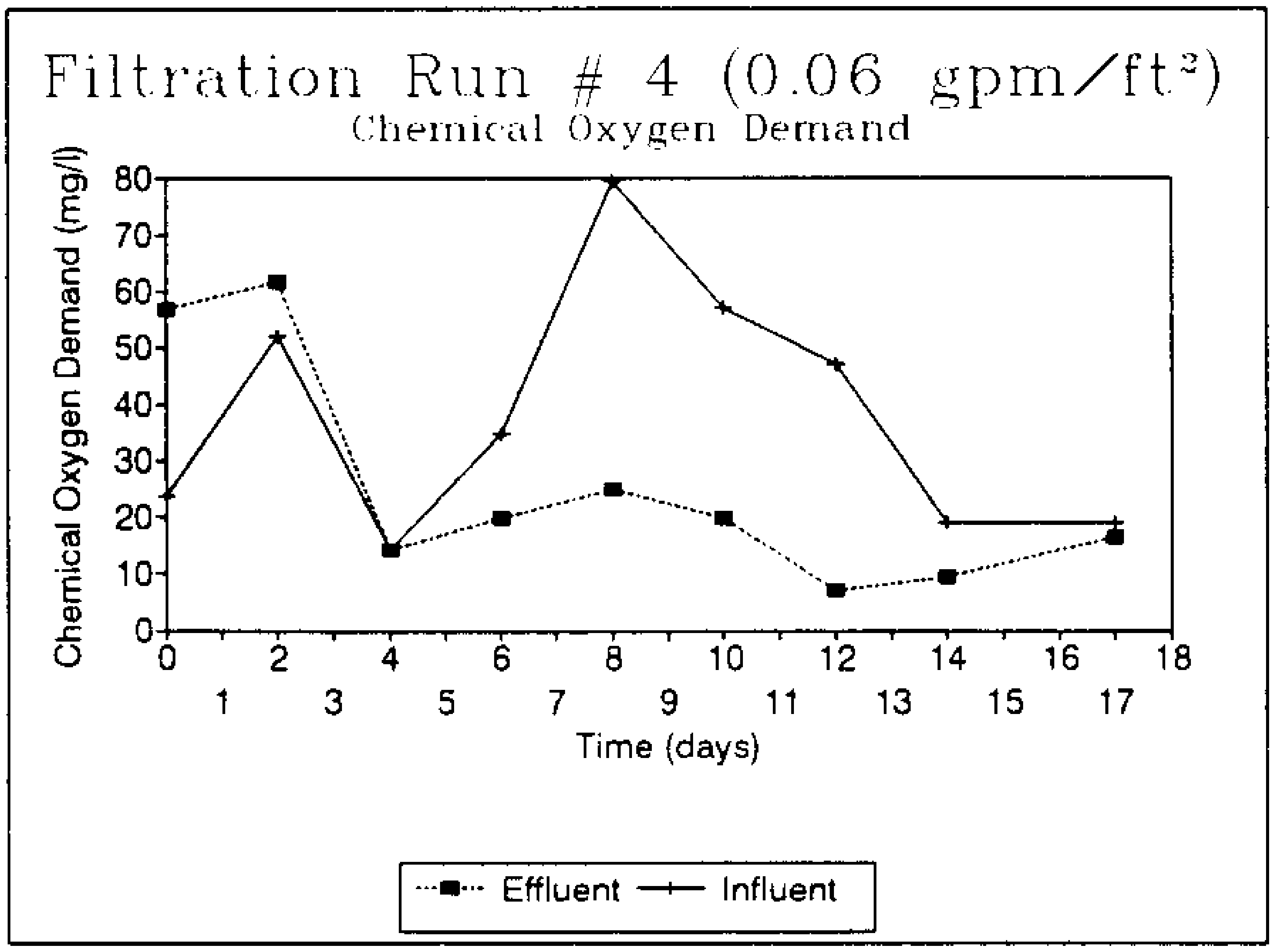

FIG. D-12.- Chemical Oxygen Demand (COD) for Filtration Run 4

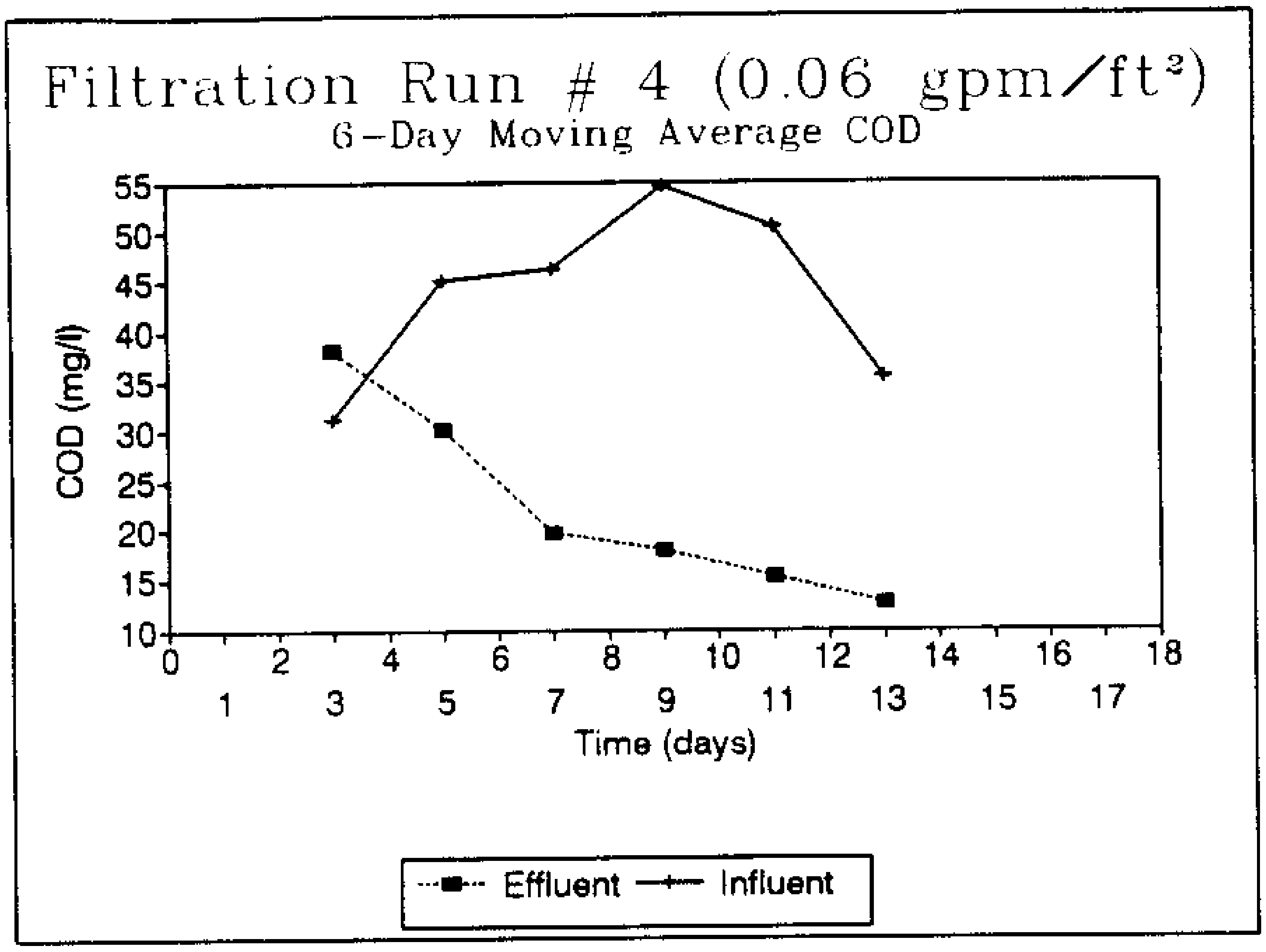

FIG. D-13.- 6-Day Moving Average COD for Filtration Run 4

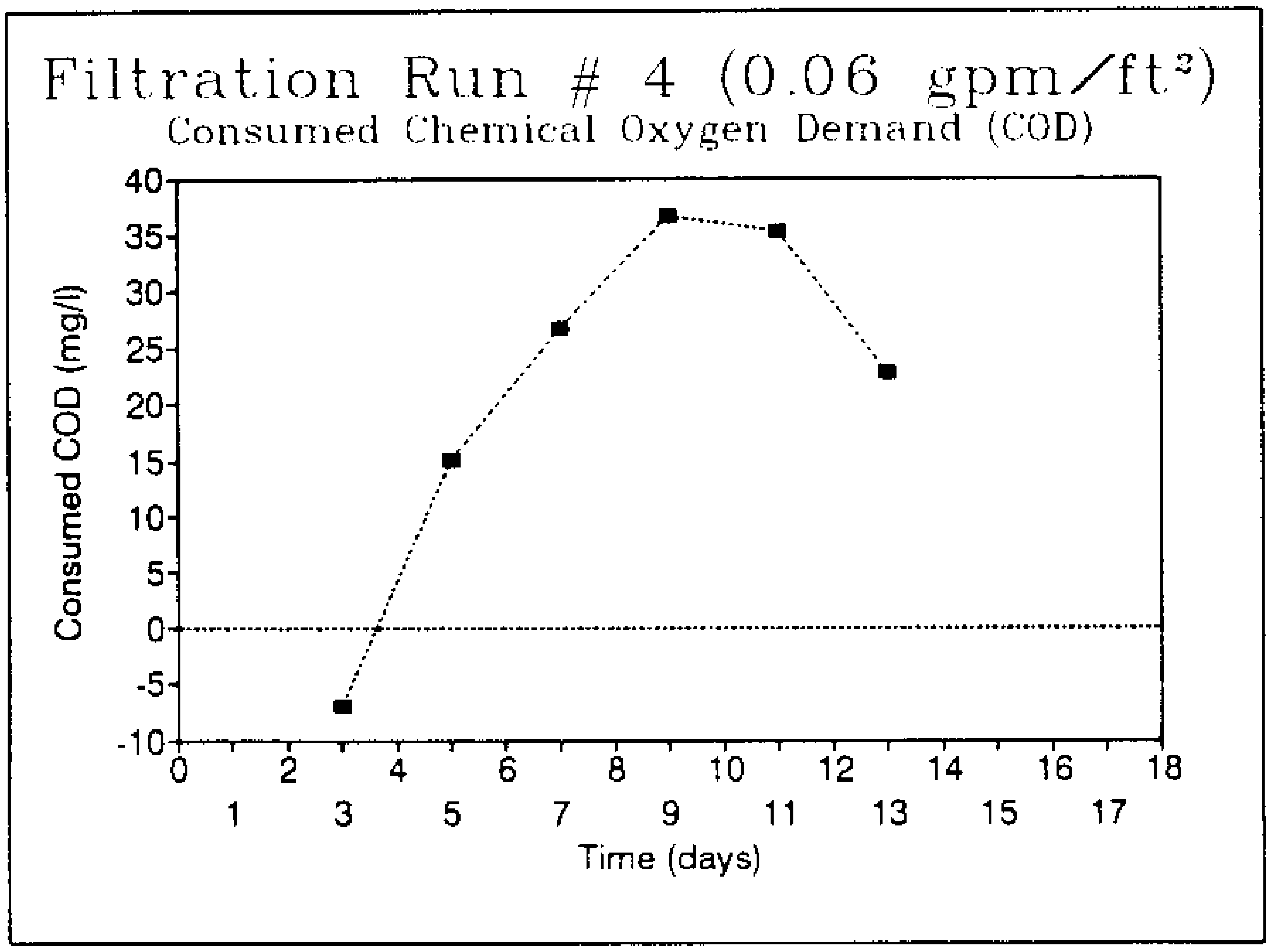

FIG. D-14.- Consumed COD for Filtration Run 4

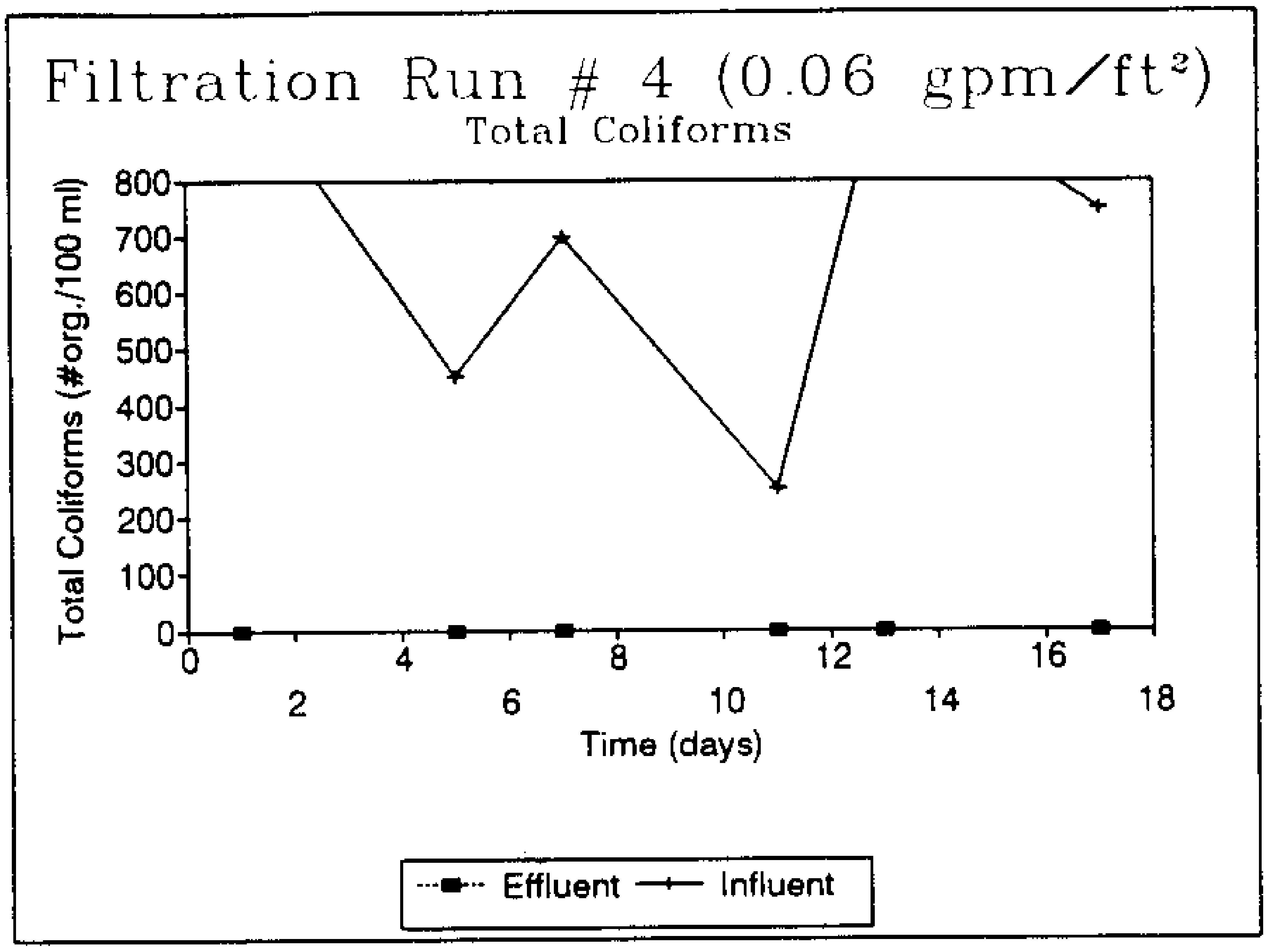

FIG. D-15.- Total Coliforms for Filtration Run 4

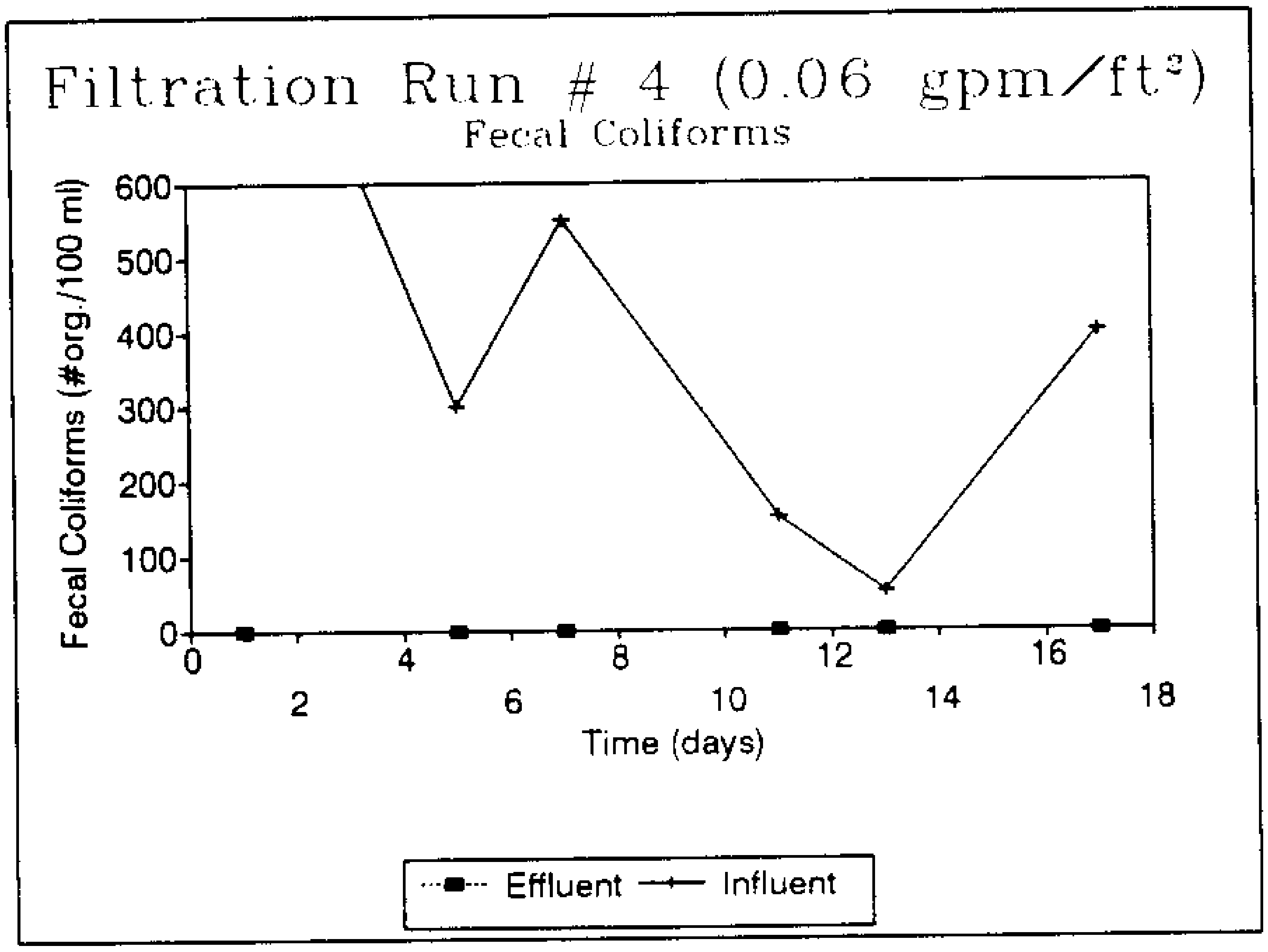

Figure D-16 : Fecal Coliforms for Filtration Run 4

Table D-1.- Biochemical Oxygen Demand (Effluent of Last Day)

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	7.48	7.43	7.63	7.43	1	0.0001	-1500
0.05%	7.40	7.35	7.63	7.43	1	0.0005	-300
0.1%	7.38	7.40	7.63	7.43	1	0.0010	-225
0.5%	7.38	7.28	7.63	7.43	1	0.0050	-20
Glucose	7.63	3.75	7.63	7.43	1	0.0200	183.75

Table D-2.- Schmutzdecke Biochemical Oxygen Demand

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	7.35	7.08	7.63	7.43	1	0.0001	750
0.05%	7.33	7.10	7.63	7.43	1	0.0005	50
0.1%	7.30	7.10	7.63	7.43	1	0.0010	0
0.5%	7.30	6.78	7.63	7.43	1	0.0050	65
Glucose	7.63	3.75	7.63	7.43	1	0.0200	183.75

Table D-3.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.25	4.25	-	
S.A.+P.D.	4.25	8.32	4.07	-	-
Blank	0.00	4.07	4.07	-	
Blank	4.07	8.14	4.07	-	-
Standard	0.00	3.04	3.04	495.19	
Standard	3.04	6.12	3.08	475.96	485.58
Sch.	0.00	4.01	4.01	2884.62	
Sch.	4.01	8.02	4.01	2884.62	2884.62

Table D-4.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	88	58.96		
2	87	58.29	87.50	58.63

Table D-5.- Schmutzdecke pH

Sample	pH	Average pH
1	8.10	
2	8.13	8.12

Table D-6.- Schmutzdecke Turbidity

Sample	Turbidity (NTU)	Average Turbidity (NTU)
1	4575	
2	4525	4550

Table D-7.- Schmutzdecke Alkalinity

A = 2.50018
B = 40.00
C = 19.45

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	32.90	36.95	4.05	0.09701431	98.23	
2	36.95	40.75	3.80	0.09701431	92.16	95.20

Table D-9.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
1	13.94020	5	13.98981	9922		13.98200	1562	
0	14.49385	5	14.53571	8372	9147	14.52912	1318	1440

Table D-10.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
1E	38.21108	20	38.36943	7917.50		38.34604	1169.50		6748.00	
12E	37.50035	20	37.65680	7822.50	7870	37.63320	1180.00	1174.75	6642.50	6695.25

Appendix E: Illustrations for Filtration Run 5

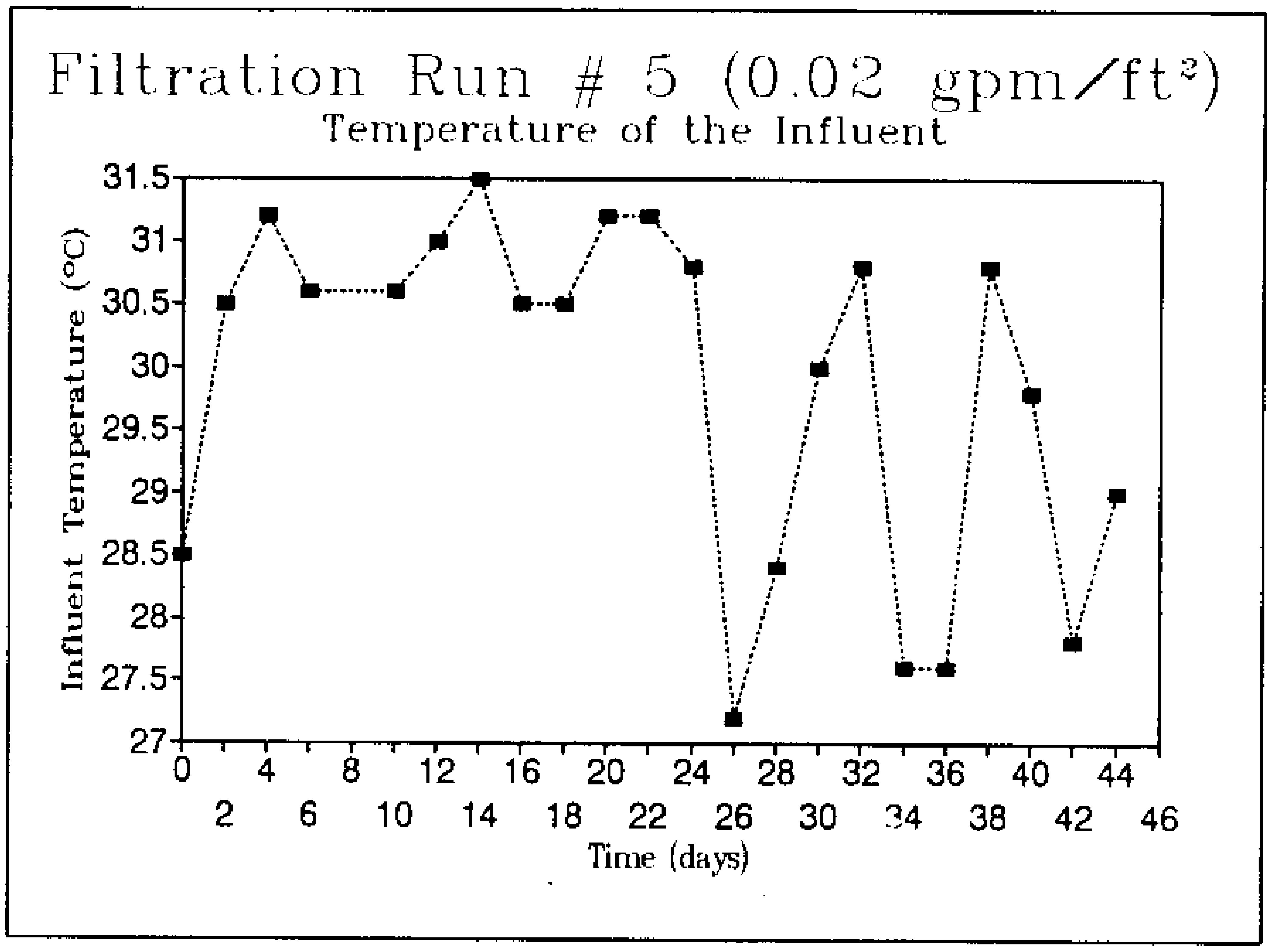

FIG. E-1.- Influent Temperature for Filtration Run 5

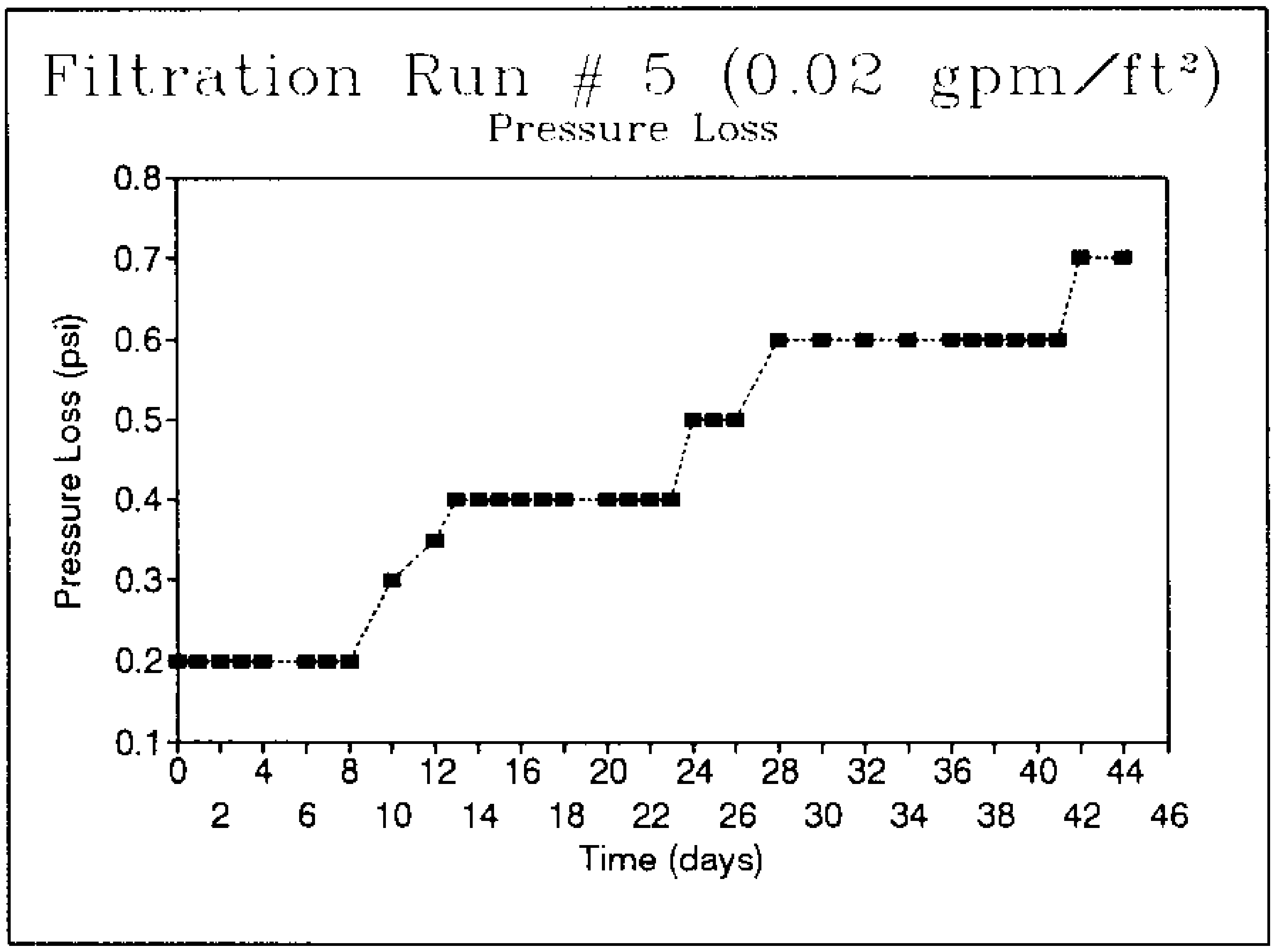

FIG. E-2.- Pressure Loss for Filtration Run 5

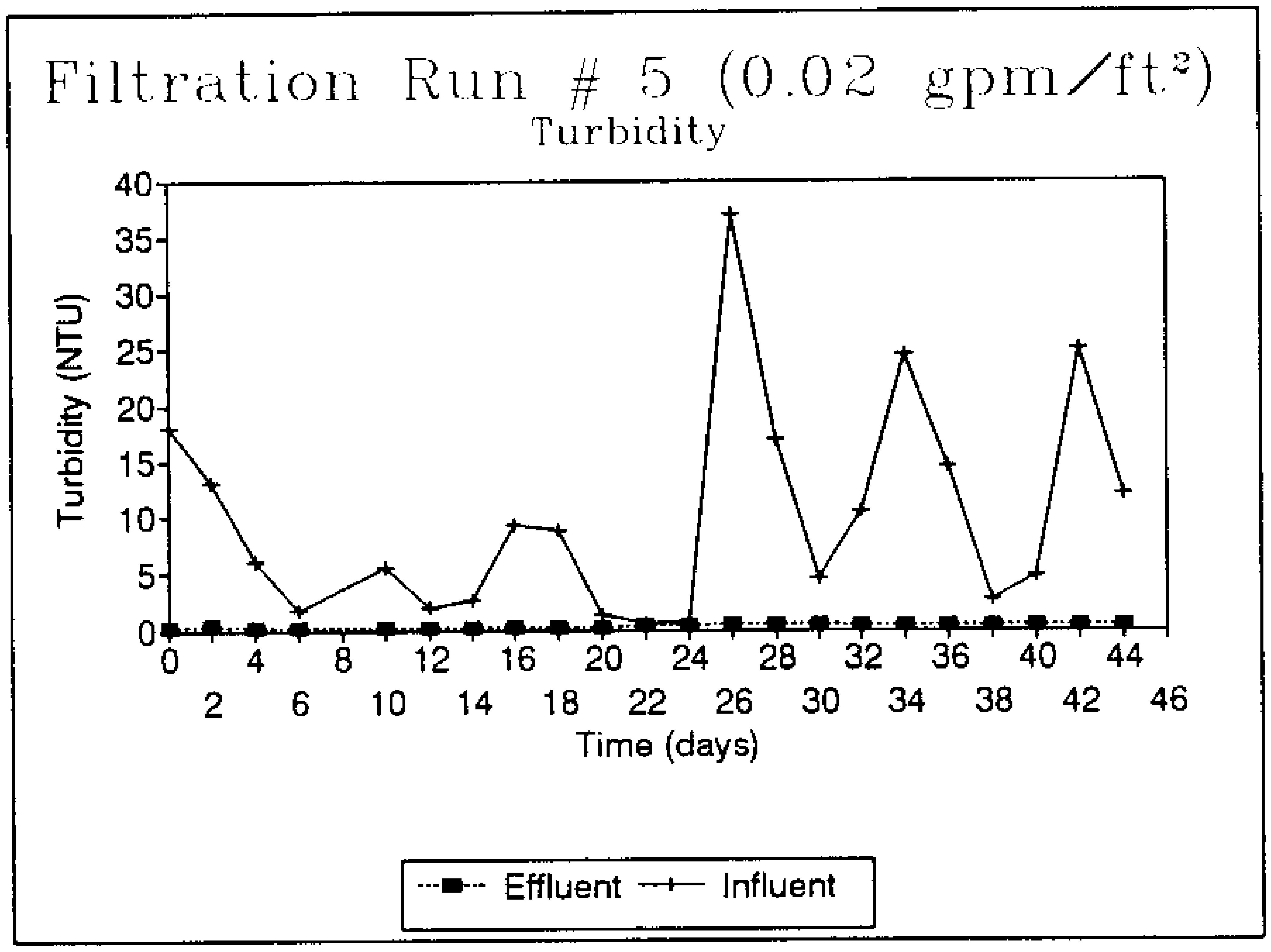

FIG. E-3.- Turbidity for Filtration Run 5

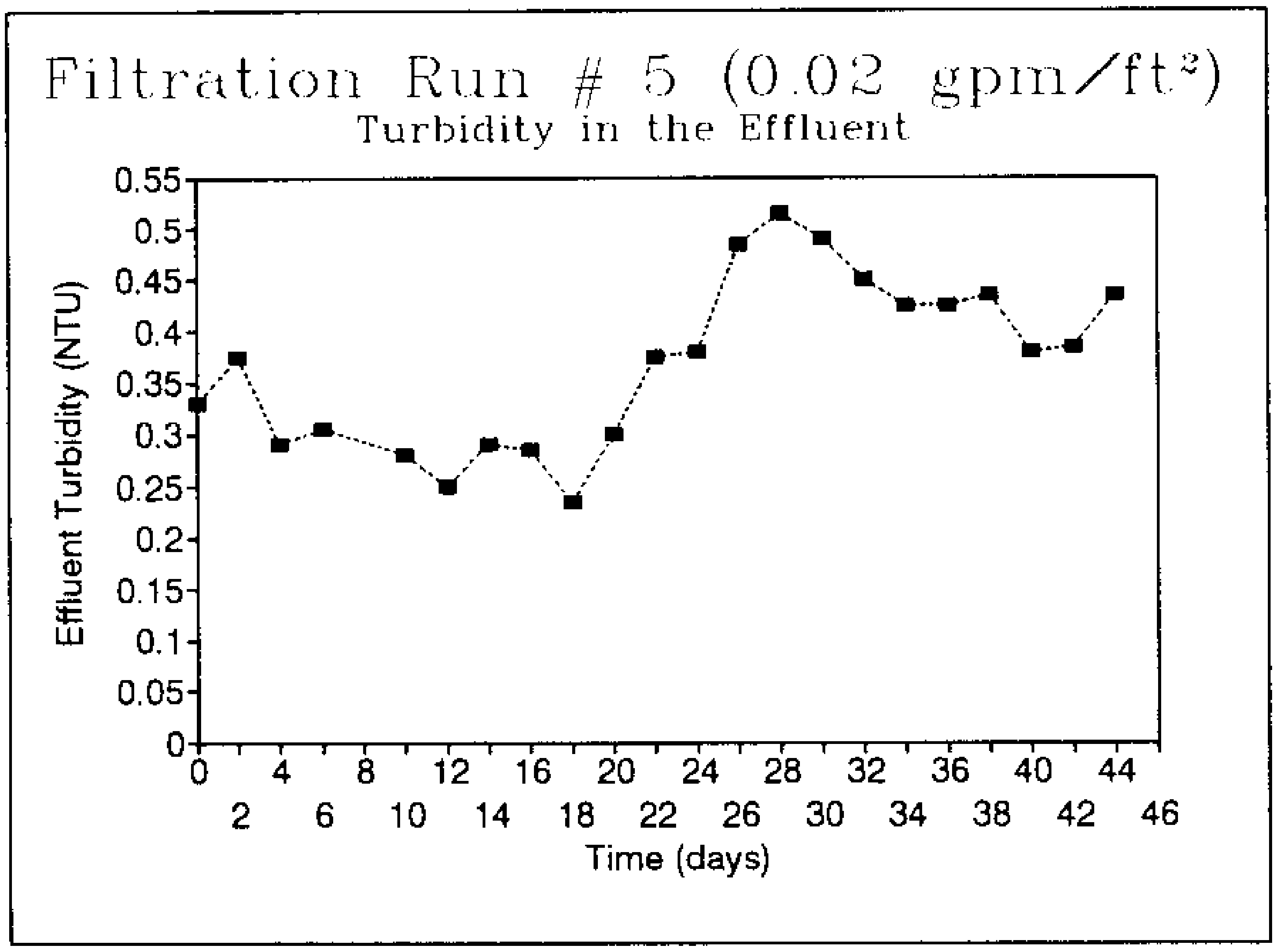

FIG. E-4.- Effluent Turbidity for Filtration Run 5

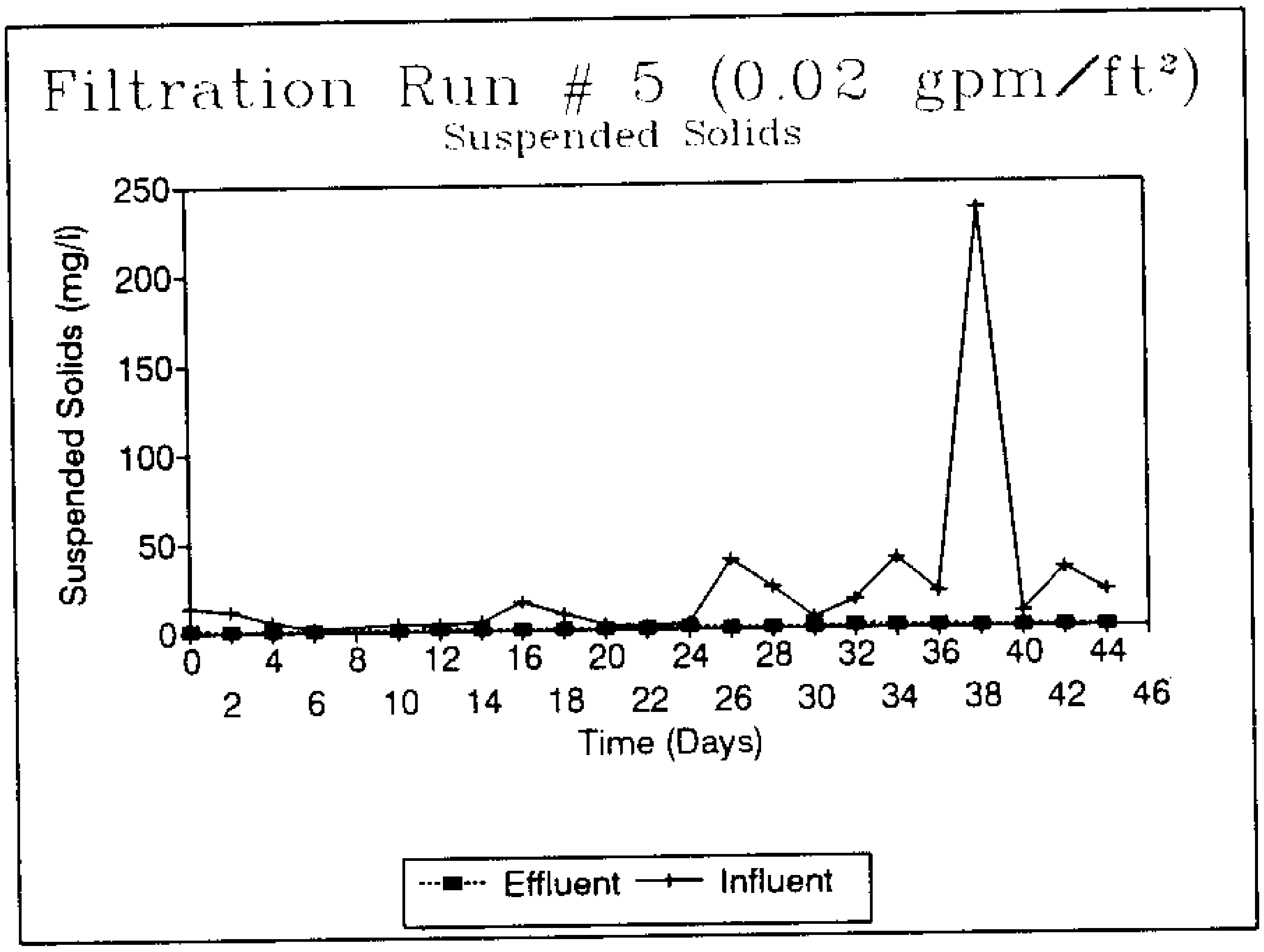

FIG. E-5.- Suspended Solids for Filtration Run 5

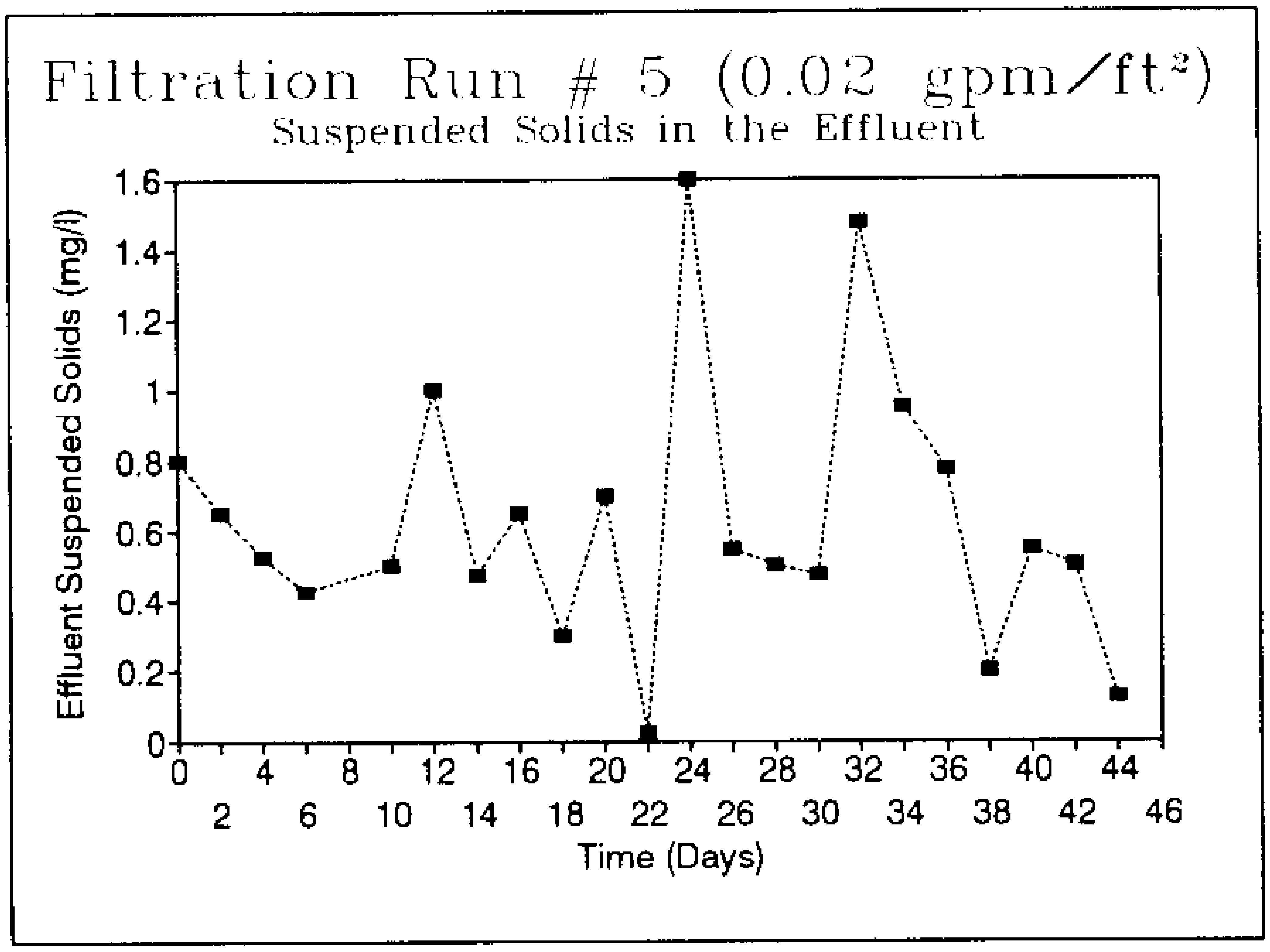

FIG. E-6.- Effluent Suspended Solids for Filtration Run 5

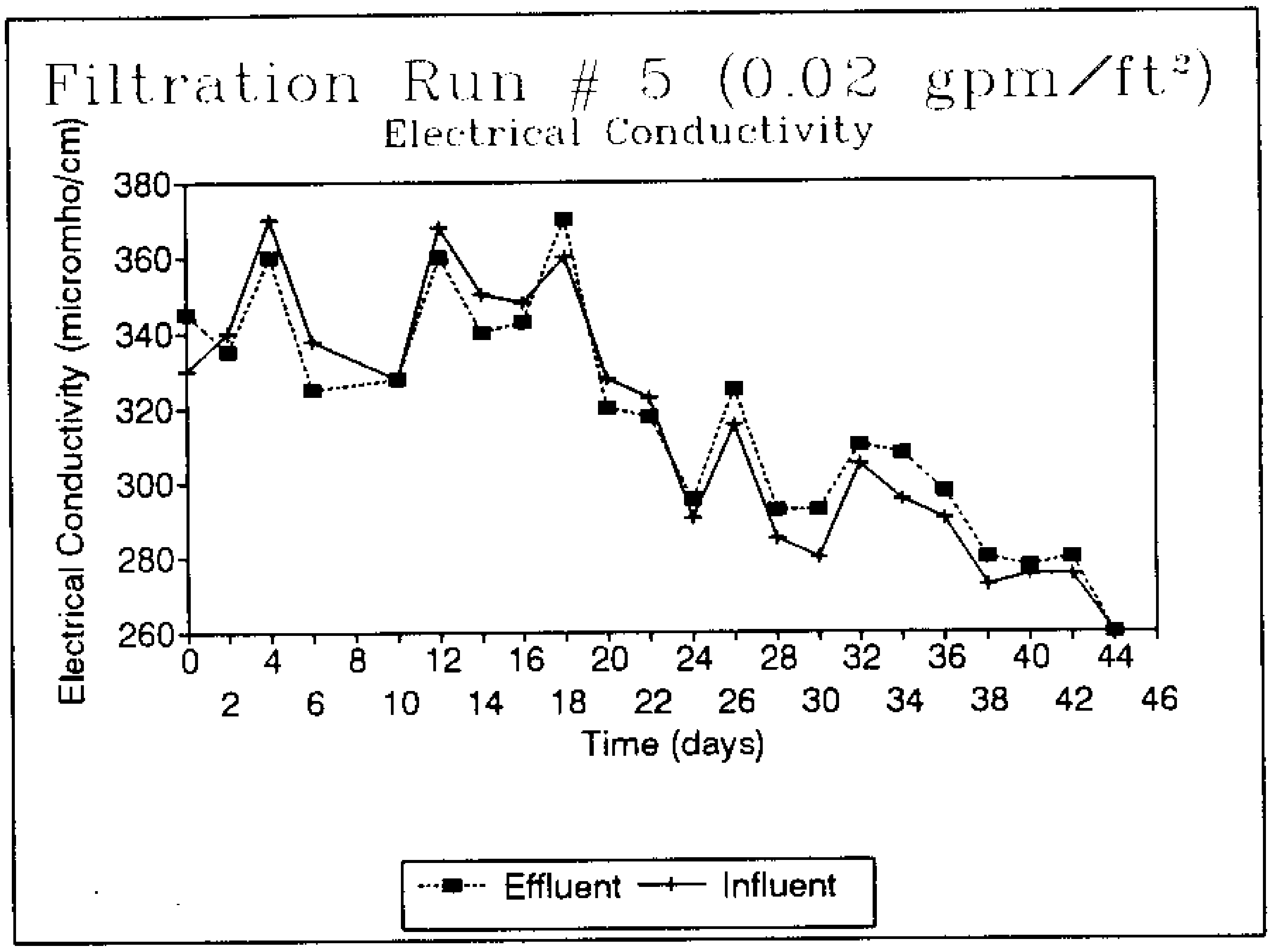

FIG. E-7.- Electrical Conductivity for Filtration Run 5

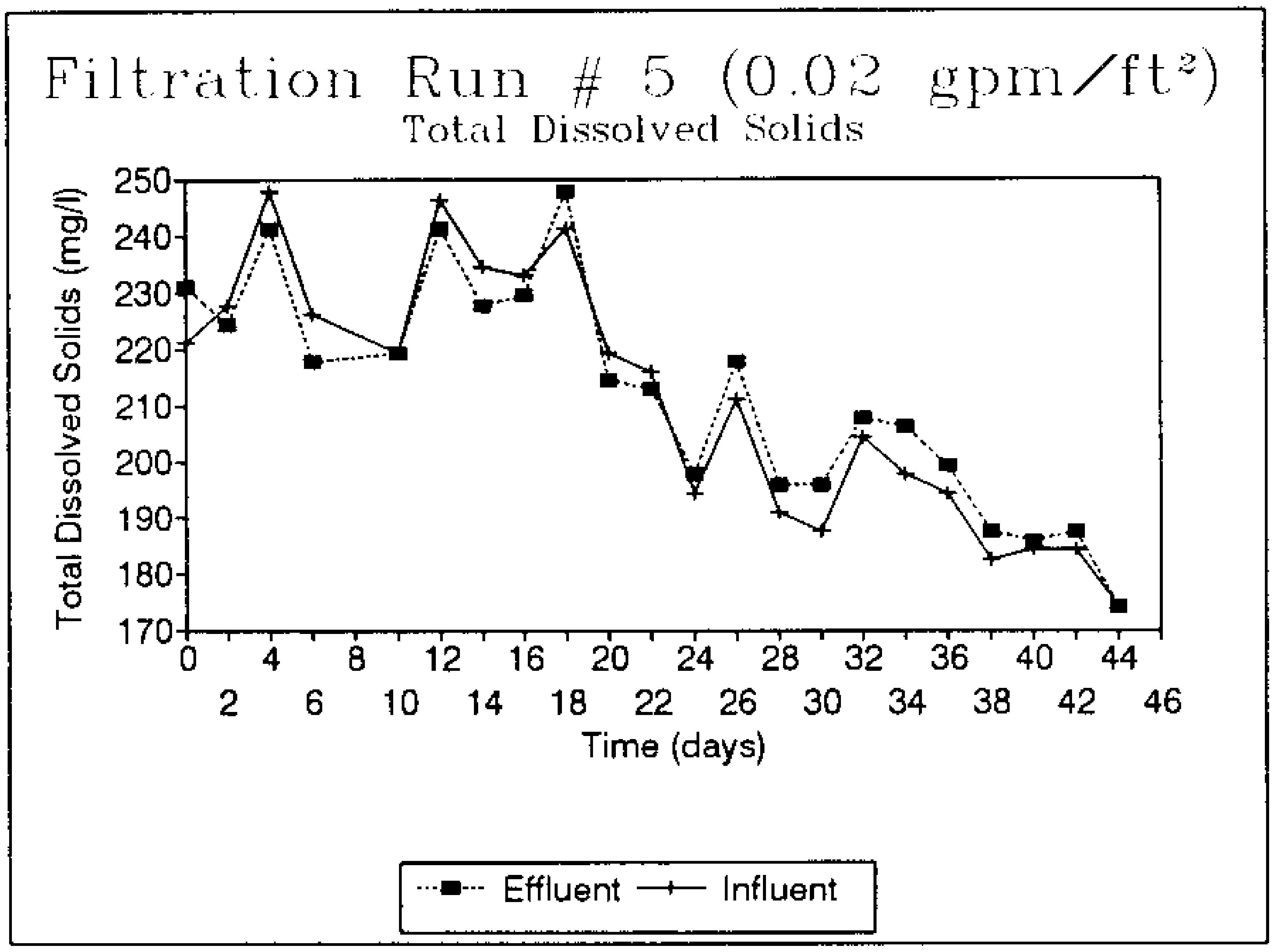

FIG. E-8.- Total Dissolved Solids for Filtration Run 5

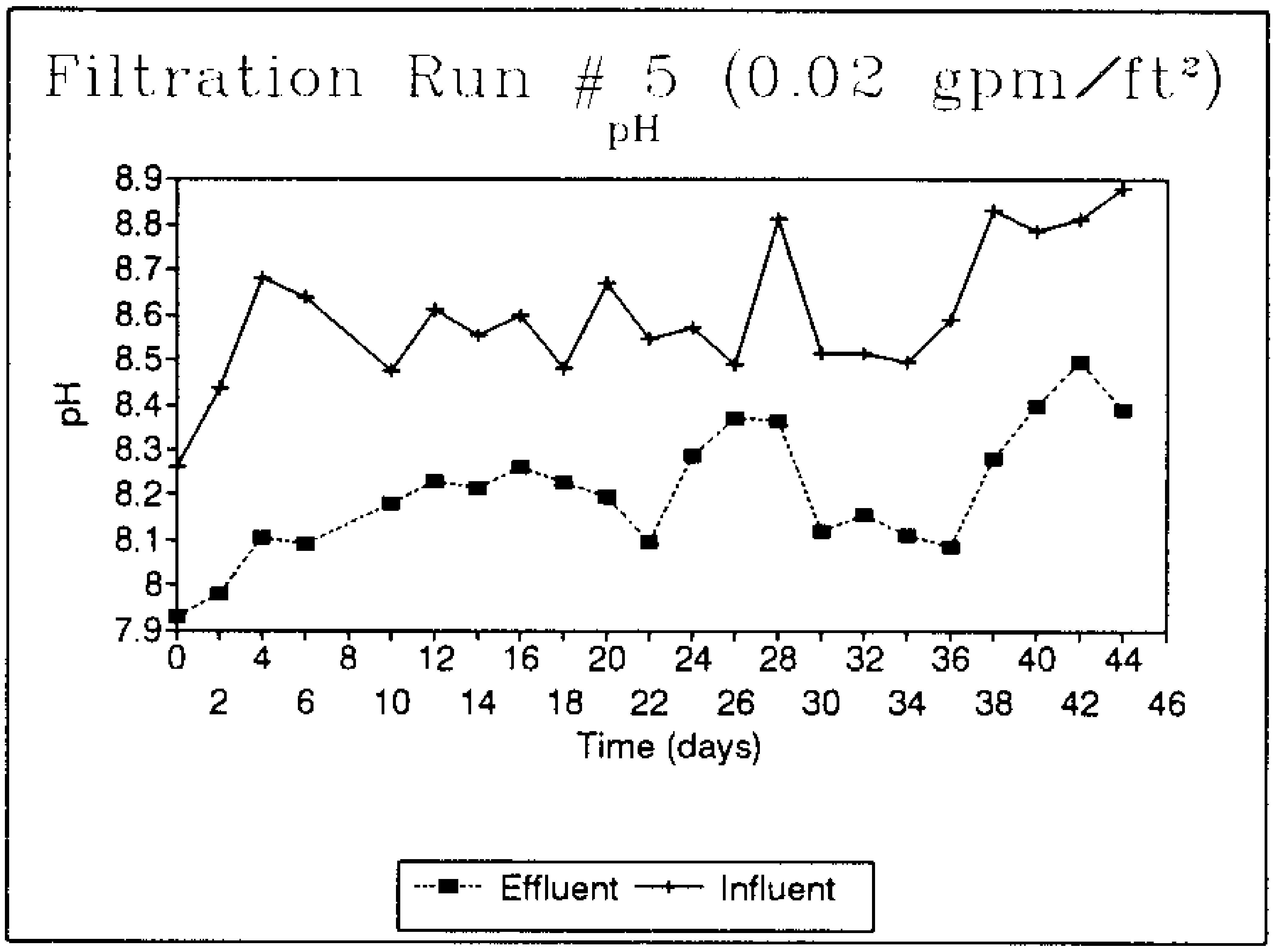

FIG. E-9.- pH for Filtration Run 5

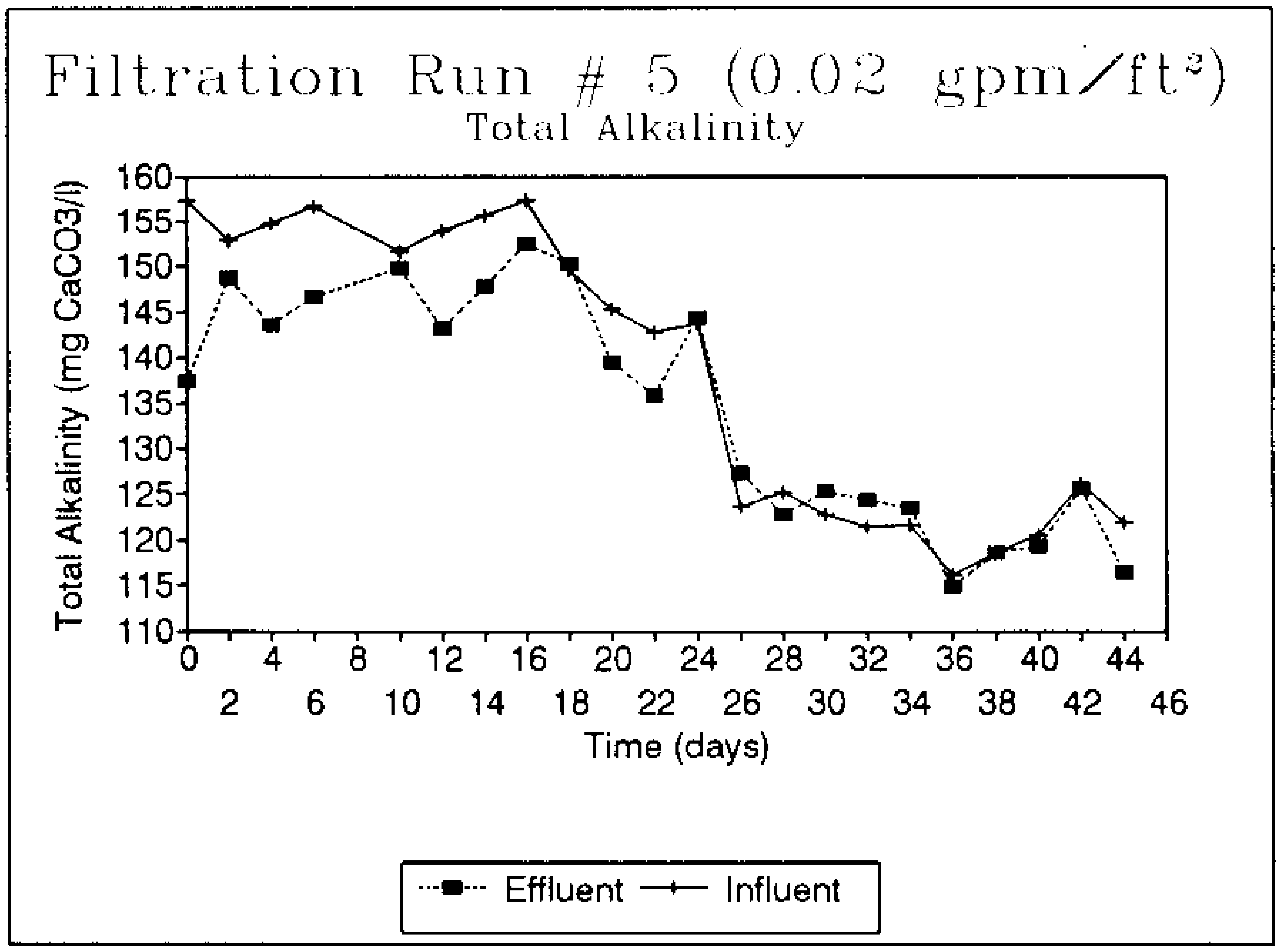

FIG. E-10.- Total Alkalinity for Filtration Run 5

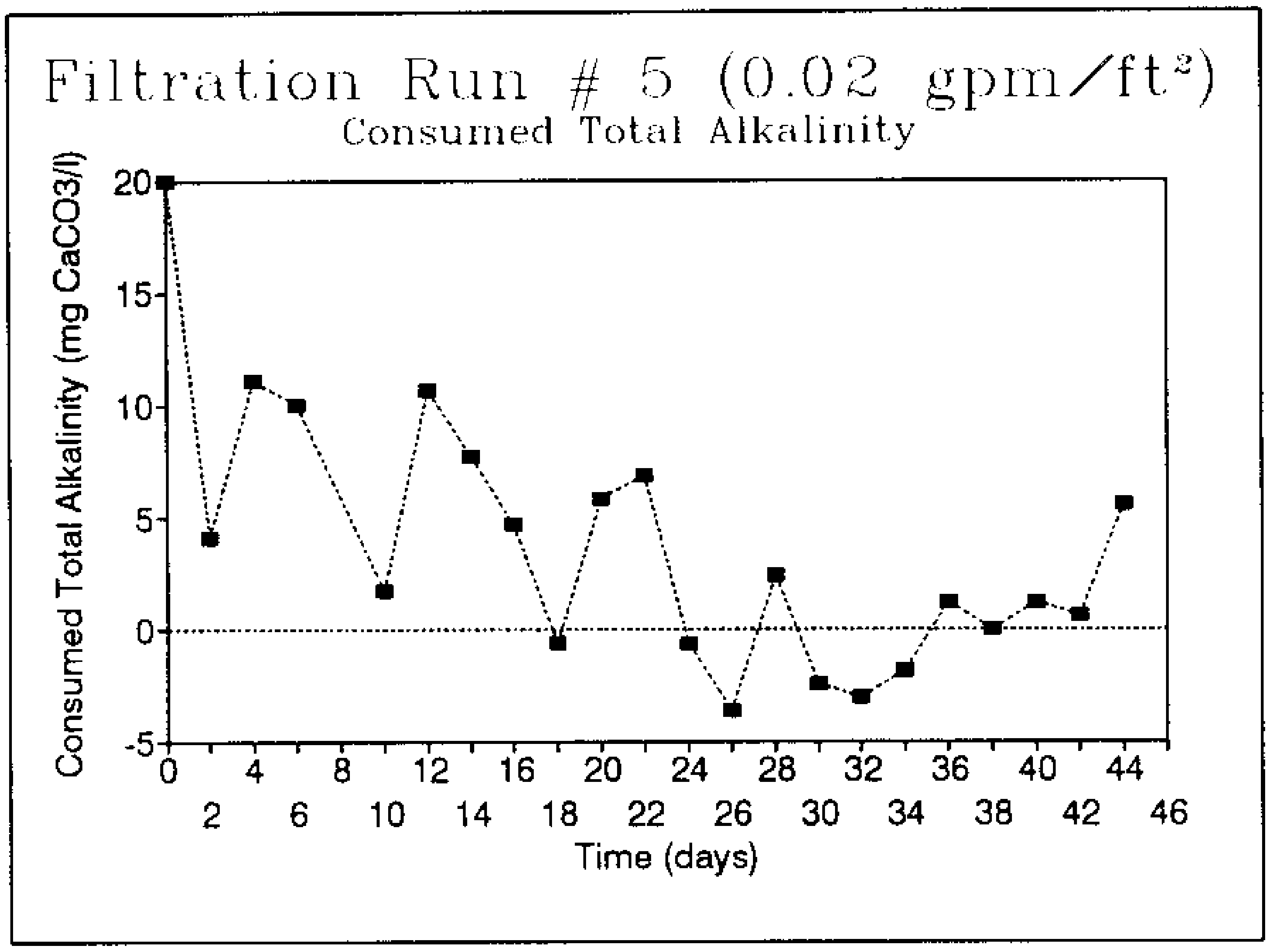

FIG. E-11.- Consumed Total Alkalinity for Filtration Run 5

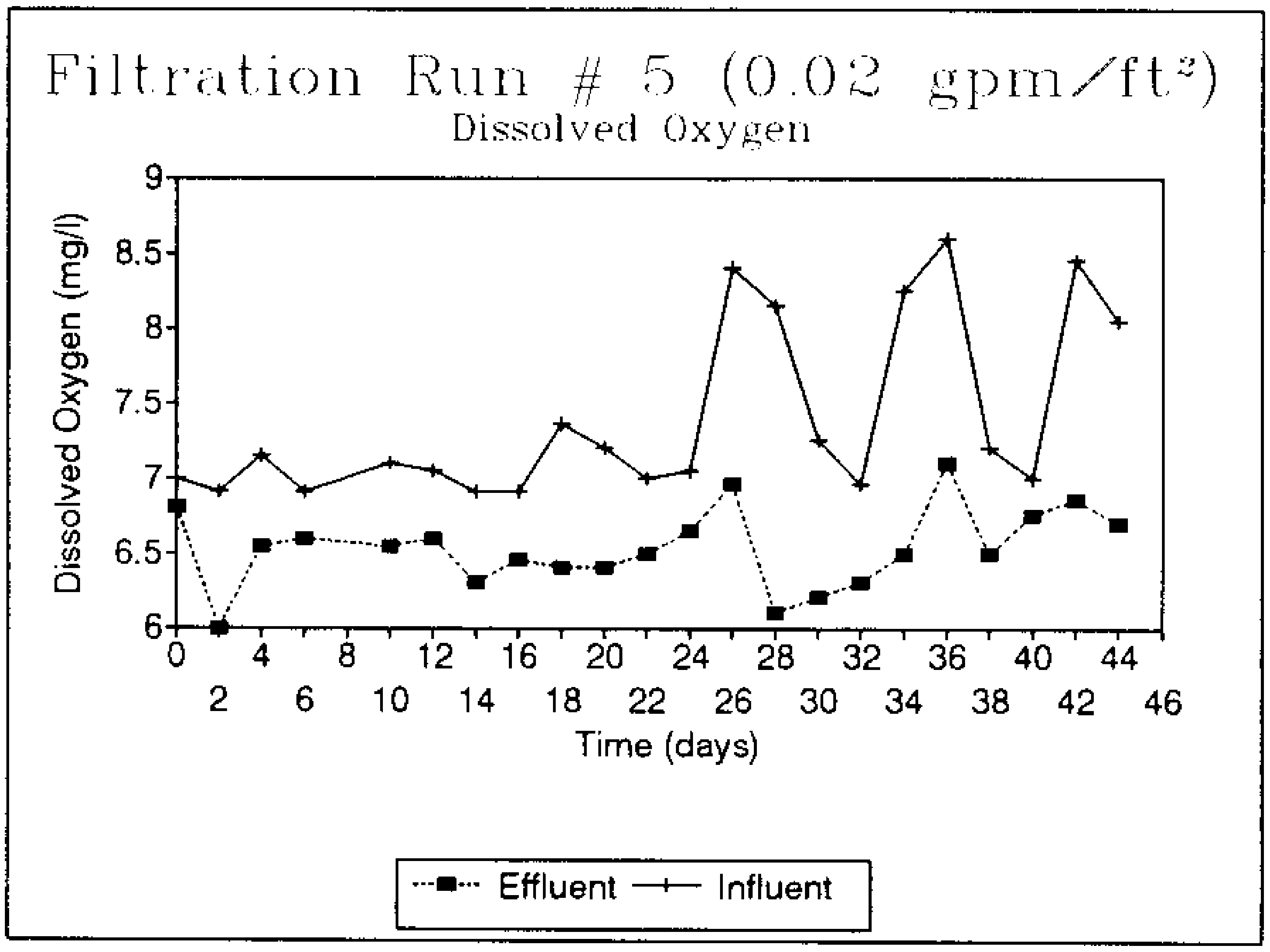

FIG. E-12.- Dissolved Oxygen for Filtration Run 5

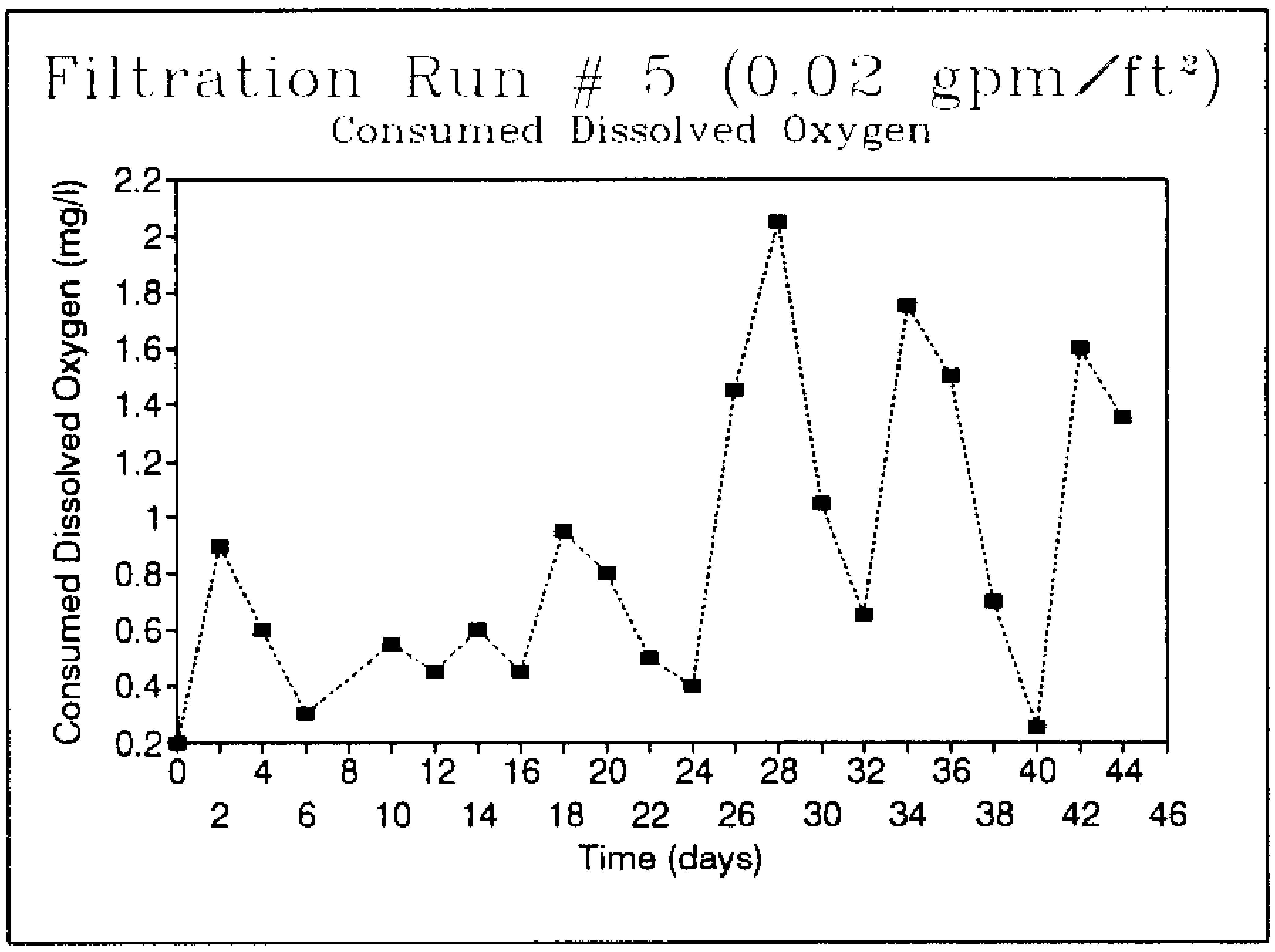

FIG. E-13.- Consumed Dissolved Oxygen for Filtration Run 5

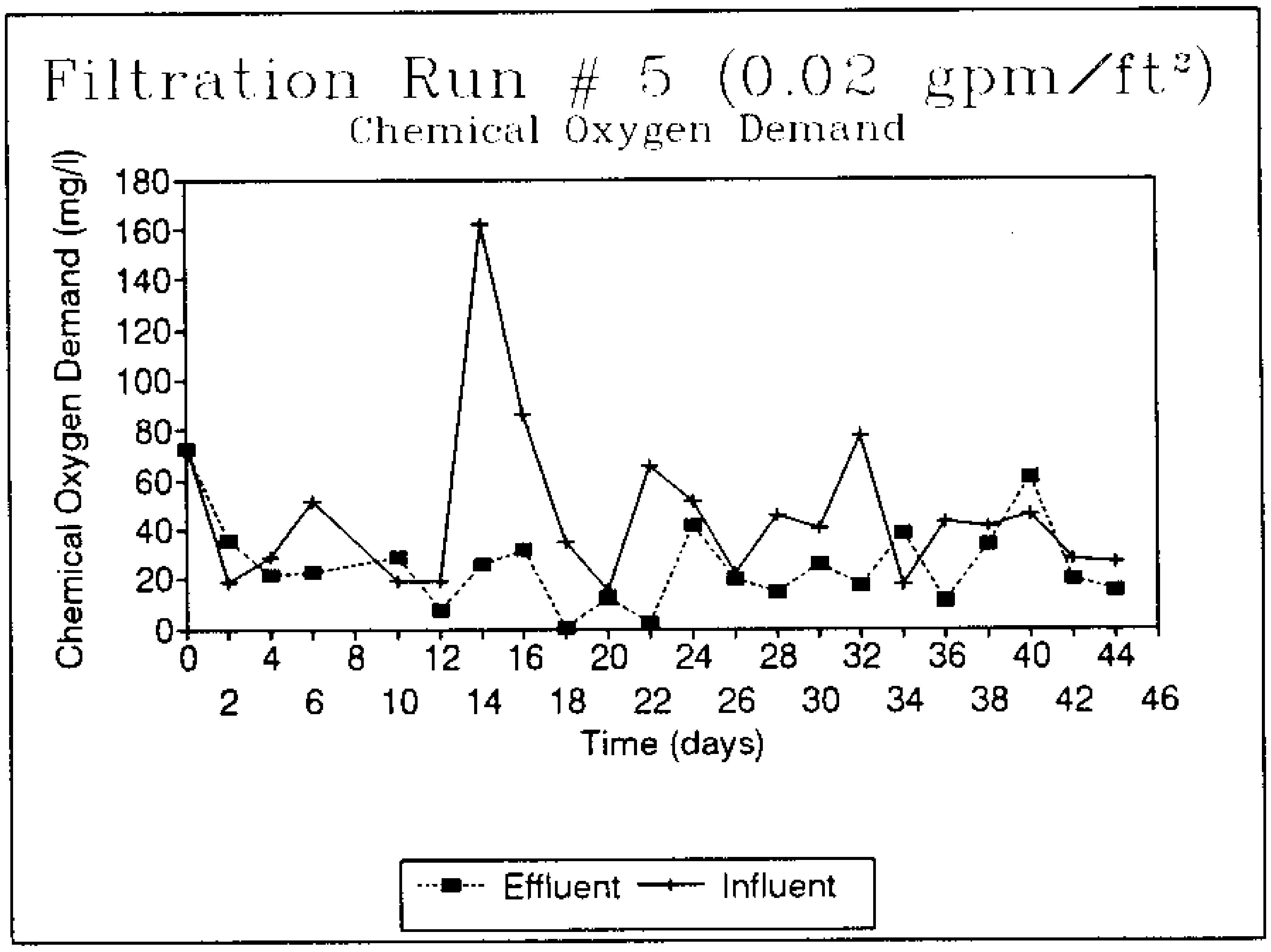

FIG. E-14.- Chemical Oxygen Demand (COD) for Filtration Run 5

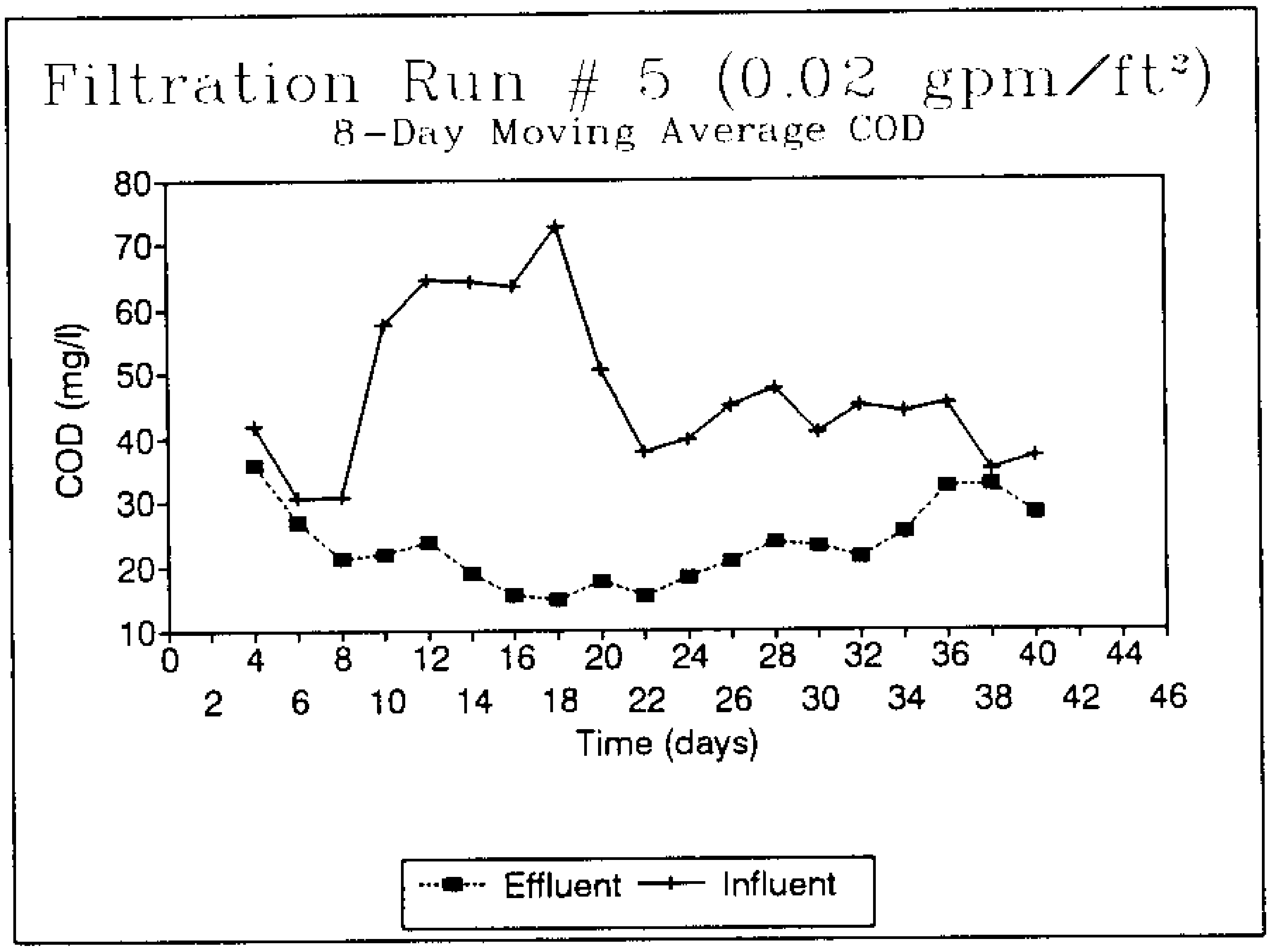

FIG. E-15.- 8-Day Moving Average COD for Filtration Run 5

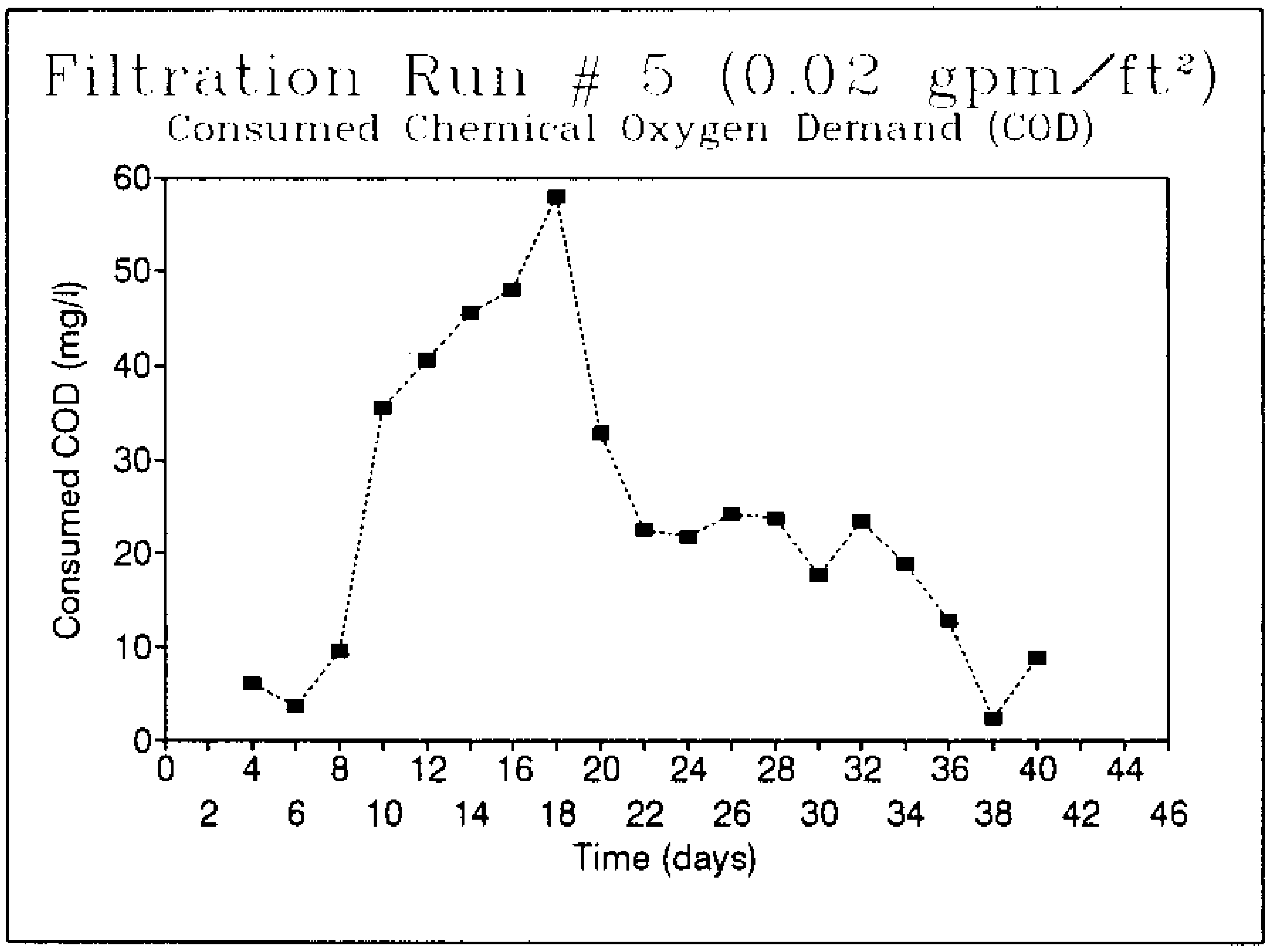

FIG. E-16.- Consumed COD for Filtration Run 5

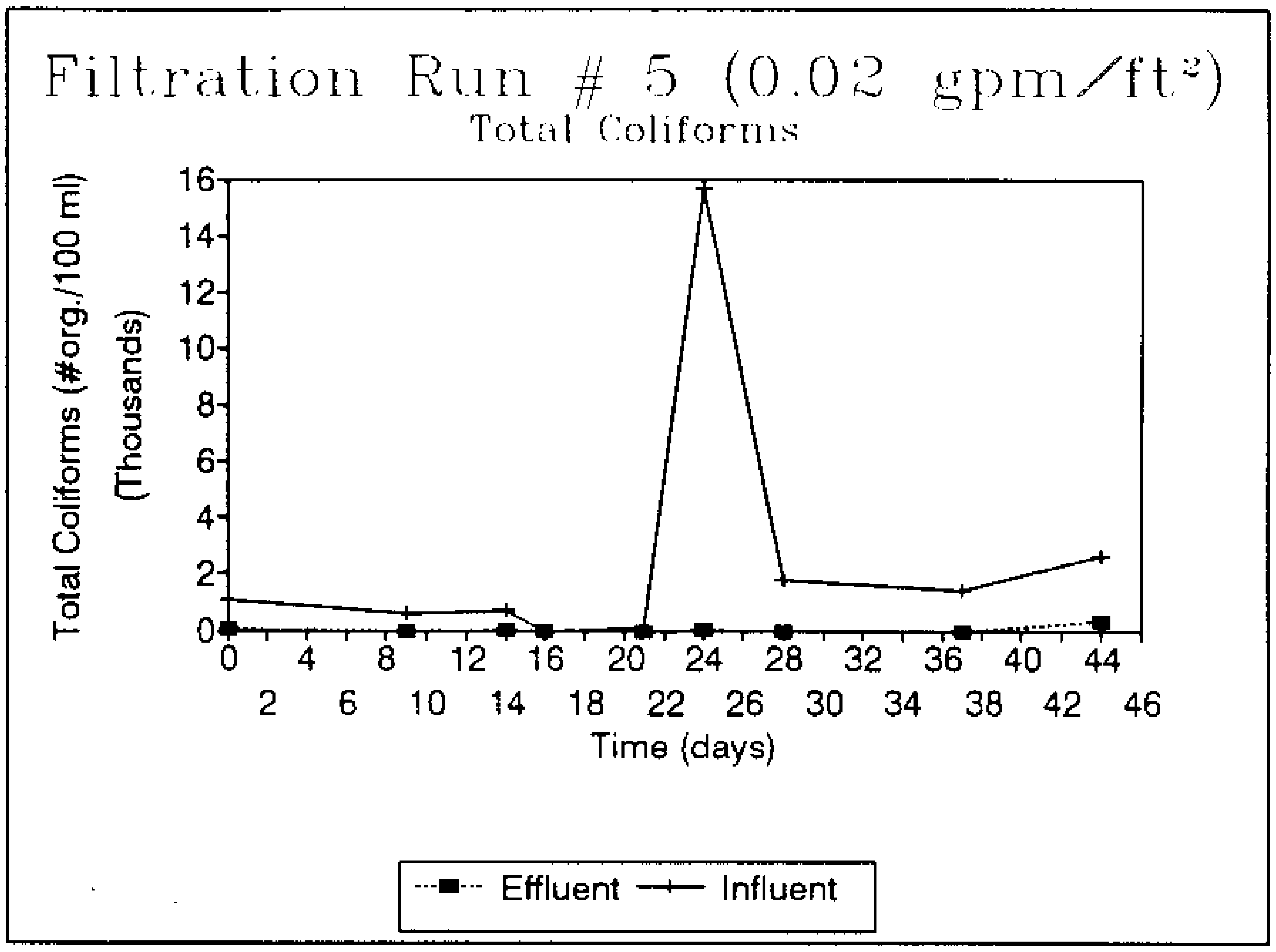

FIG. E-17.- Total Coliforms for Filtration Run 5

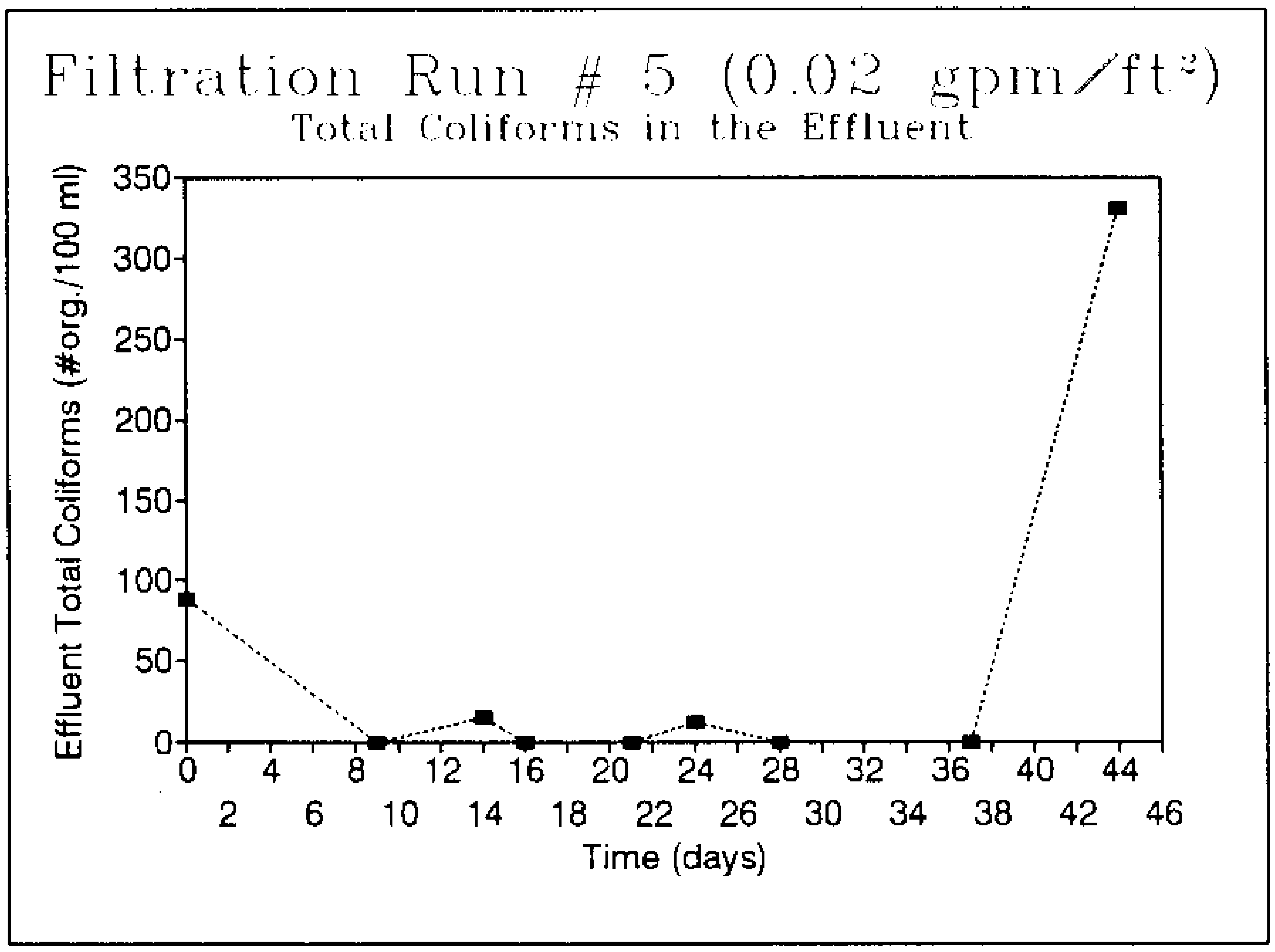

FIG. E-18.- Effluent Total Coliforms for Filtration Run 5

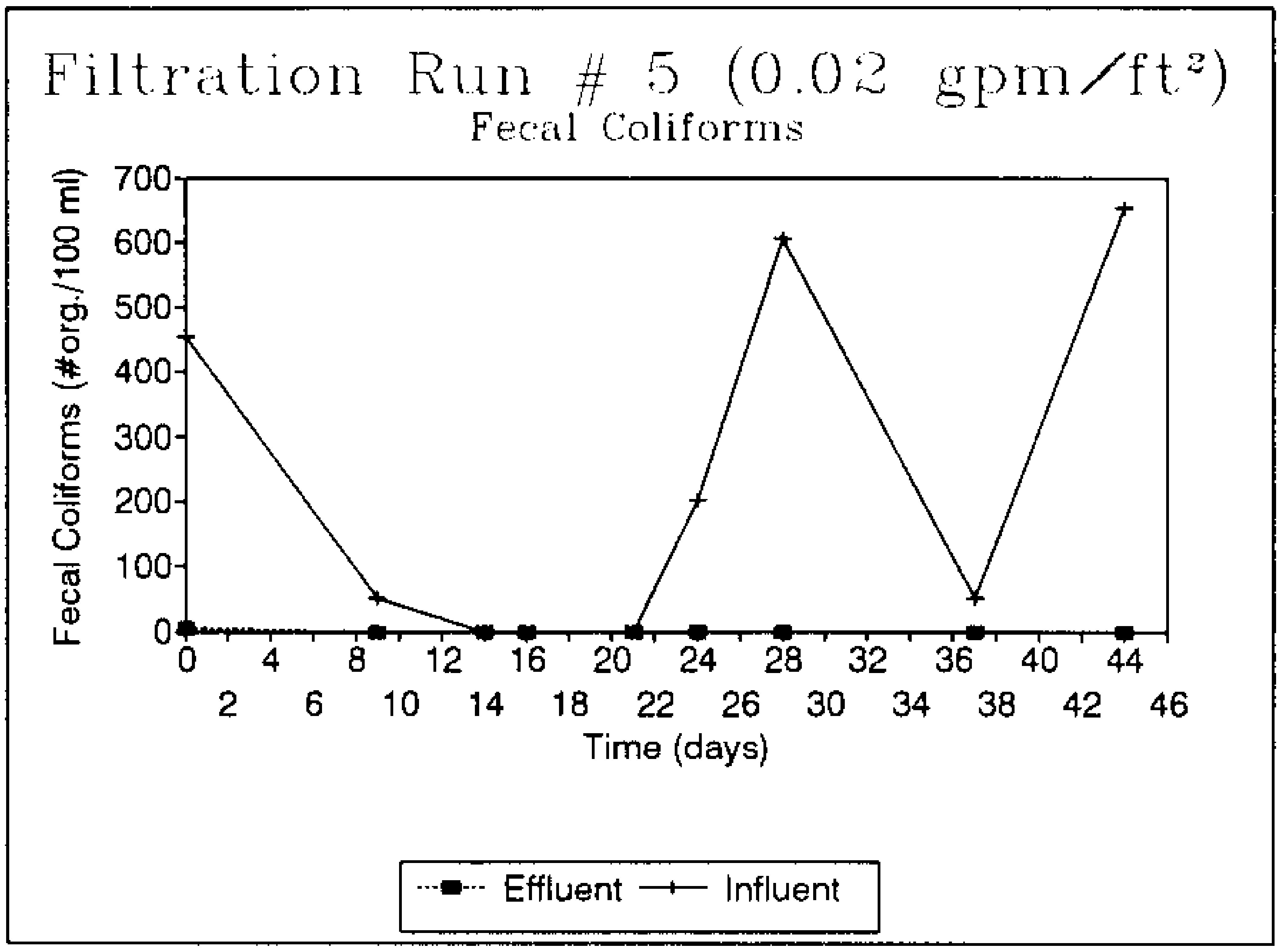

FIG. E-19.- Fecal Coliforms for Filtration Run 5

Table E-1.- Biochemical Oxygen Demand : Day # 1 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	8.50	7.60	8.48	7.60	1	0.0001	250
0.05%	8.50	7.58	8.48	7.60	1	0.0005	100
0.1%	8.50	6.45	8.48	7.60	1	0.0010	1175
0.5%	8.50	7.78	8.48	7.60	1	0.0050	-30
Glucose	8.50	3.68	8.48	7.60	1	0.0200	197.5

Table E-2.- Biochemical Oxygen Demand : Day # 1 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.01%	8.50	7.48	8.48	7.60	1	0.0001	1500
0.05%	8.45	7.40	8.48	7.60	1	0.0005	350
0.1%	8.45	7.18	8.48	7.60	1	0.0010	400
0.5%	8.45	7.70	8.48	7.60	1	0.0050	-25
Glucose	8.50	3.68	8.48	7.60	1	0.0200	197.5

Table E-3.- Biochemical Oxygen Demand : Day # 23 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.23	8.10	9.10	8.18	1	0.0010	200
0.5%	9.25	8.03	9.10	8.18	1	0.0050	60
1%	9.25	7.63	9.10	8.18	1	0.0100	70
5%	9.25	7.80	9.10	8.18	1	0.0500	10.5
Glucose	9.15	3.83	9.10	8.18	1	0.0200	220

Table E-4.- Biochemical Oxygen Demand : Day # 23 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.30	8.33	9.10	8.18	1	0.0010	50
0.5%	9.28	8.25	9.10	8.18	1	0.0050	20
1%	9.25	8.35	9.10	8.18	1	0.0100	-2.5
5%	9.25	8.10	9.10	8.18	1	0.0500	4.5
Glucose	9.15	3.83	9.10	8.18	1	0.0200	220

Table E-5.- Biochemical Oxygen Demand : Day # 44 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.05	8.23	8.93	8.13	1	0.0010	25
0.5%	9.03	8.30	8.93	8.13	1	0.0050	-15
1%	9.08	8.23	8.93	8.13	1	0.0100	5
5%	9.05	8.20	8.93	8.13	1	0.0500	1
Glucose	8.98	4.28	8.93	8.13	1	0.0200	195

Table E-6.- Biochemical Oxygen Demand : Day # 44 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.10	7.73	8.93	8.13	1	0.0010	575
0.5%	9.05	7.95	8.93	8.13	1	0.0050	60
1%	9.05	8.00	8.93	8.13	1	0.0100	25
5%	9.05	8.05	8.93	8.13	1	0.0500	4
Glucose	8.98	4.28	8.93	8.13	1	0.0200	195

Table E-7.- Schmutzdecke Biochemical Oxygen Demand

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.10	7.10	8.93	8.13	1	0.0010	1200
0.5%	9.08	7.80	8.93	8.13	1	0.0050	95
1%	9.05	7.05	8.93	8.13	1	0.0100	120
5%	8.85	5.93	8.93	8.13	1	0.0500	42.5
Glucose	8.98	4.28	8.93	8.13	1	0.0200	195

Table E-8.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.05	4.05	-	
S.A.+P.D.	4.05	8.00	3.95	-	
S.A.+P.D.	0.00	3.96	3.96	-	-
Blank	3.96	8.07	4.11	-	
Blank	3.97	8.06	4.09	-	-
Standard	0.00	3.03	3.03	536.79	
Standard	3.03	6.11	3.08	511.71	524.25
Sch.	0.00	4.08	4.08	1003.34	
Sch.	4.08	8.12	4.04	3010.03	
Sch.	0.00	3.95	3.95	7525.08	3846.15

Table E-9.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	64.00	42.88		
2	65.00	43.55	64.50	43.22

Table E-10.- Schmutzdecke pH

Sample	pH	Average pH
1	8.23	
2	8.02	8.13

Table E-11.- Schmutzdecke Turbidity

Sample	Turbidity (1/100) (NTU)	Turbidity (1/10) (NTU)	Average Turbidity (NTU)
1	5300	3200	
2	5300	3250	4263

Table E-12.- Schmutzdecke Alkalinity

A = 2.5
B = 40.00
C = 18.85

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	37.25	40.20	2.95	0.10009509	73.82	
2	40.20	42.80	2.60	0.10009509	65.06	69.44

Table E-13.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	2331.58	8620.69
2	4444.44	18367.35
Average	3388.01	13494.02

Table E-14.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
119	17.80249	5	17.83336	6174		17.82924	824	
110	18.59218	5	18.62487	6538	6356	18.62105	764	794

Table E-15.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
1E	38.20749	20	38.33147	6199.00		38.31263	942.00		5257.00	
12E	37.50023	20	37.62564	6270.50	6234.75	37.60602	981.00	961.50	5289.50	5273.25

Appendix F: Illustrations for Filtration Run 6

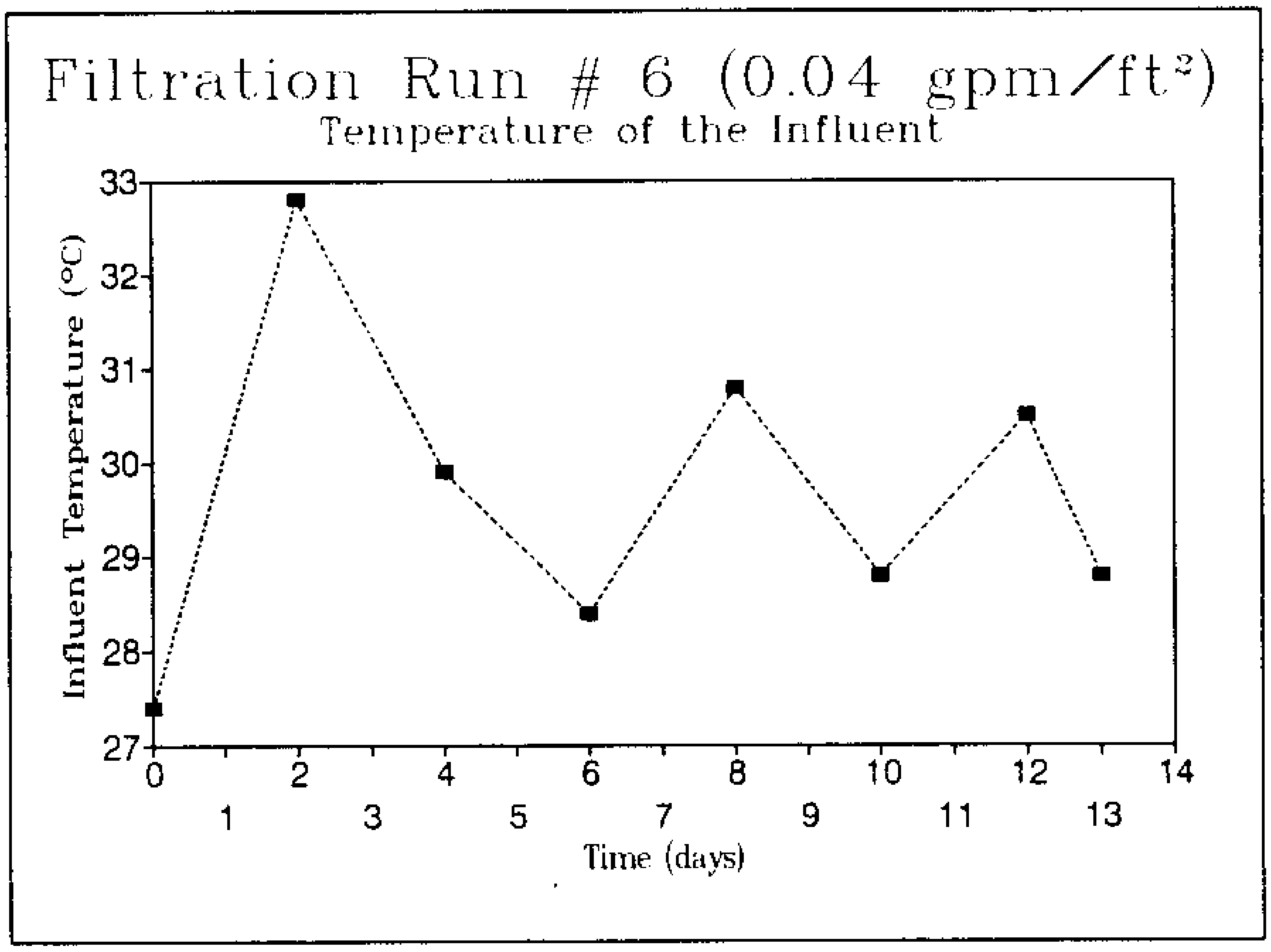

FIG. F-1.- Influent Temperature for Filtration Run 6

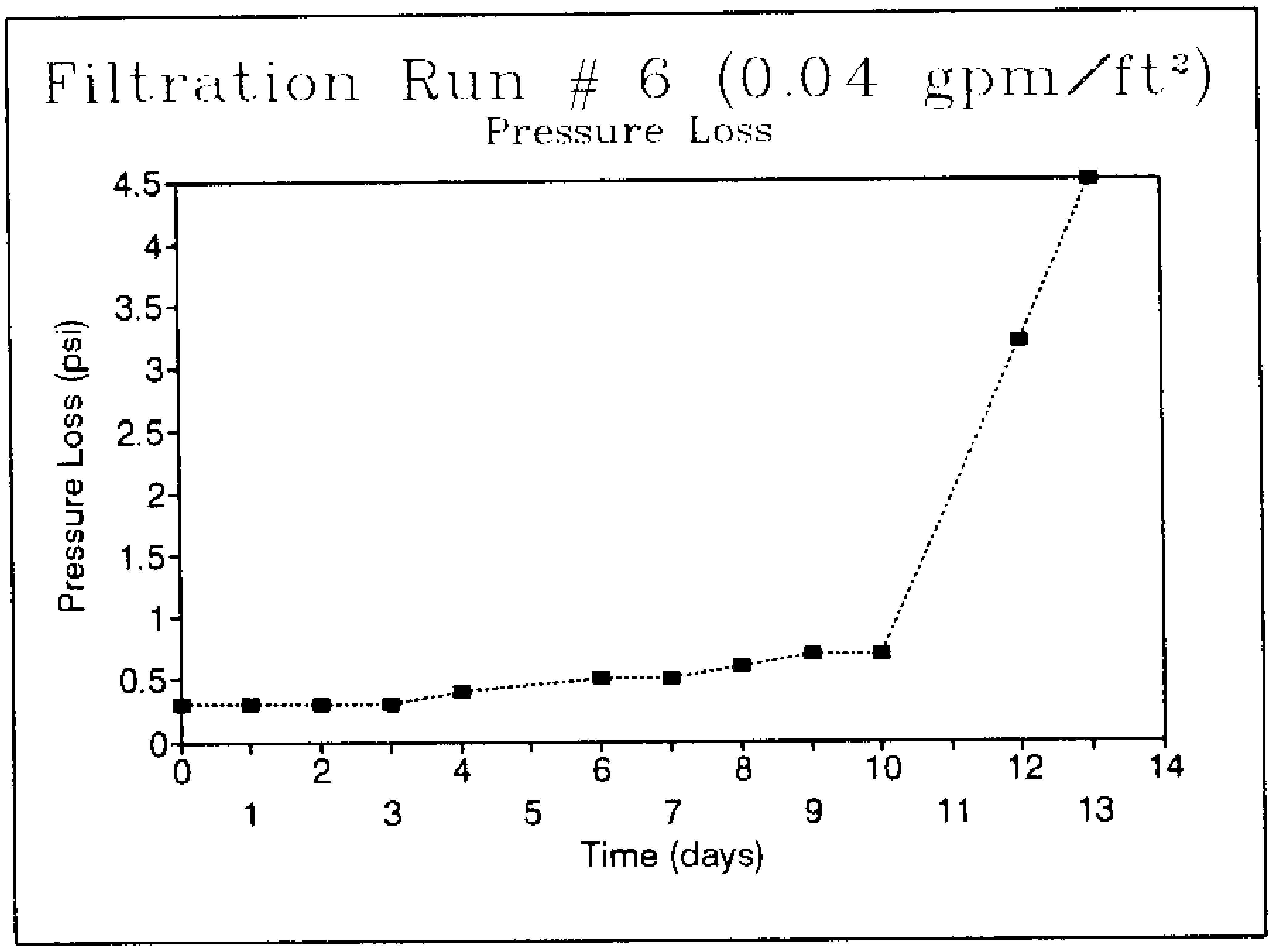

FIG. F-2.- Pressure Loss for Filtration Run 6

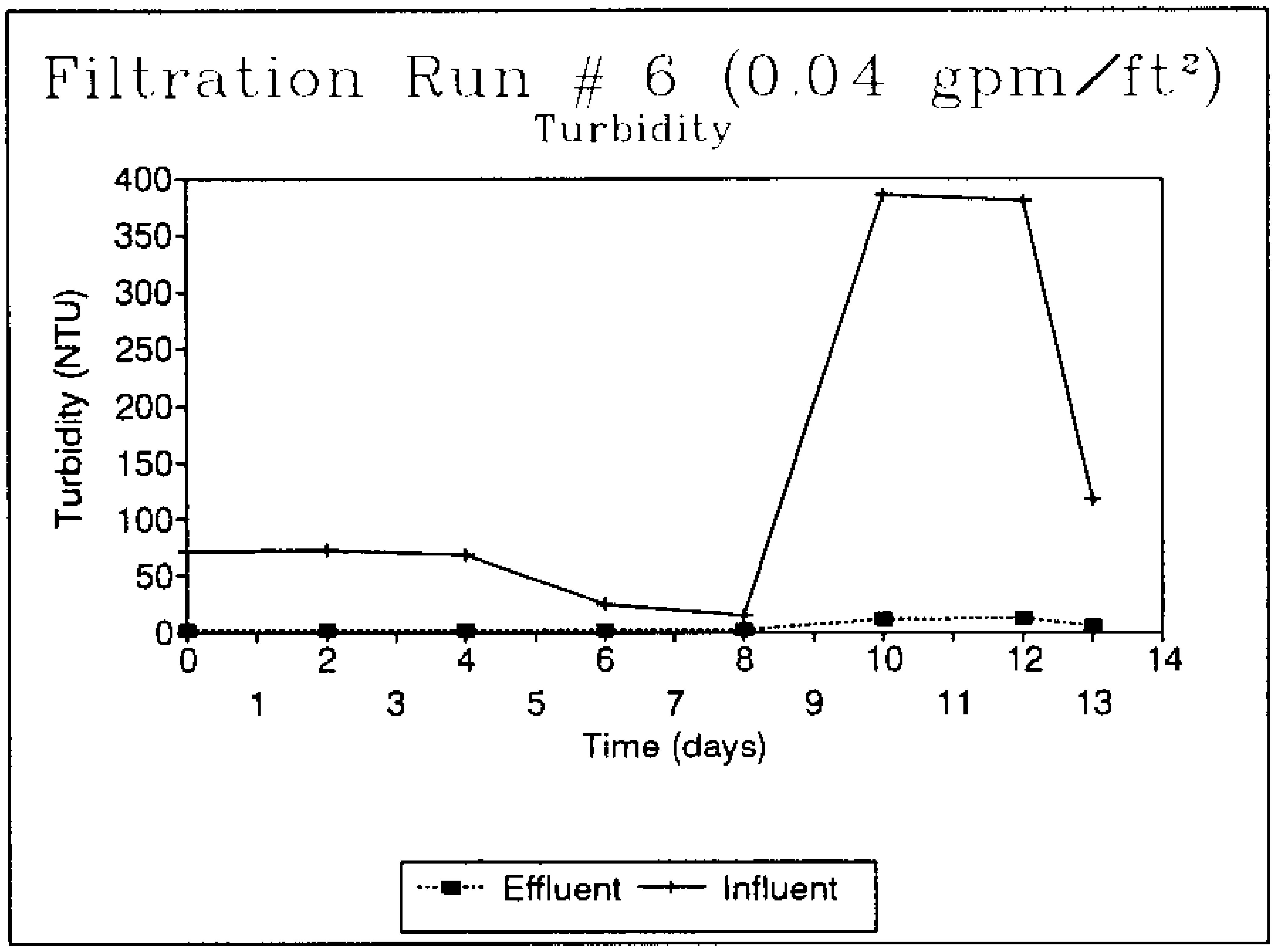

FIG. F-3.- Turbidity for Filtration Run 6

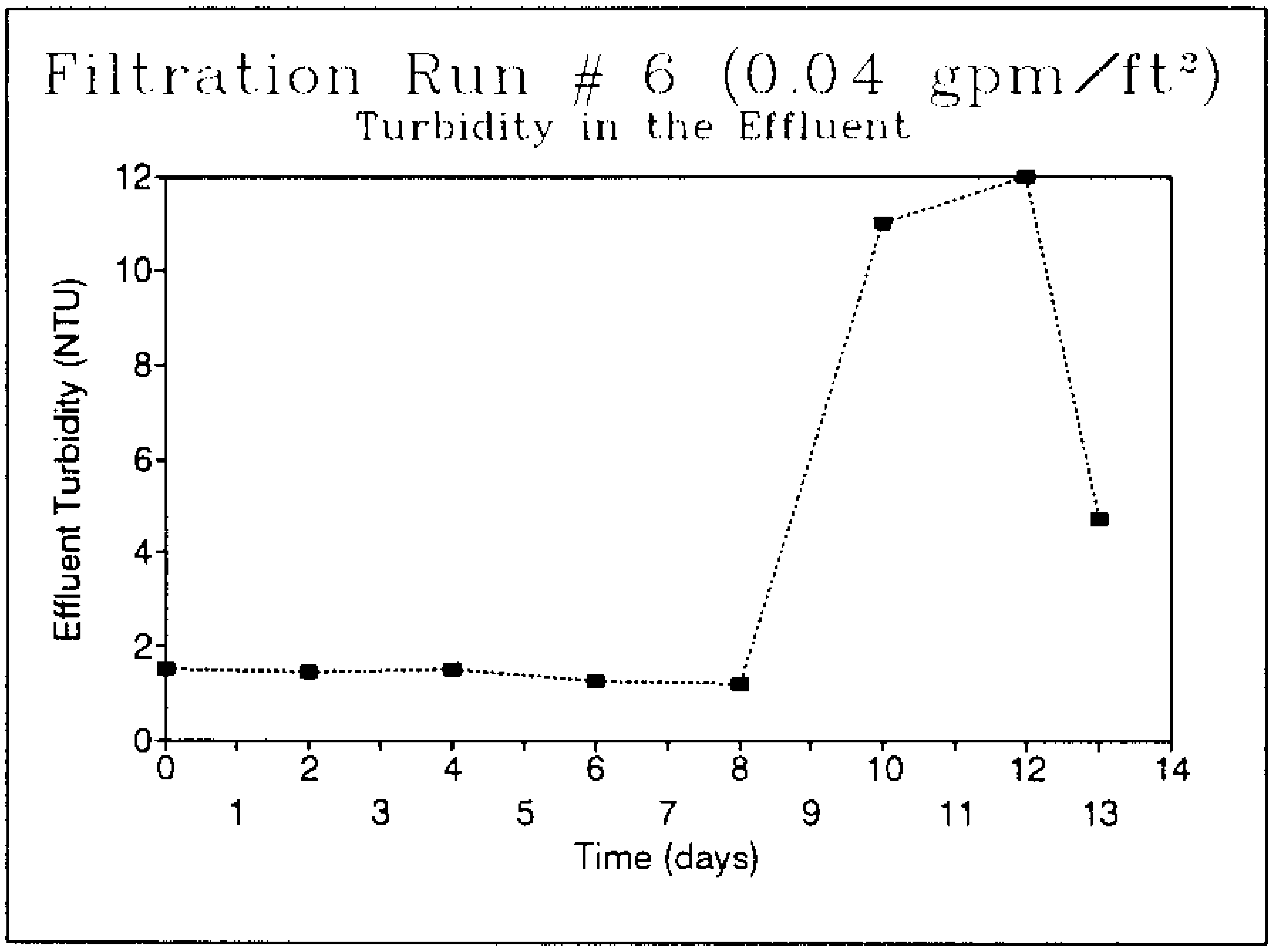

FIG. F-4.- Effluent Turbidity for Filtration Run 6

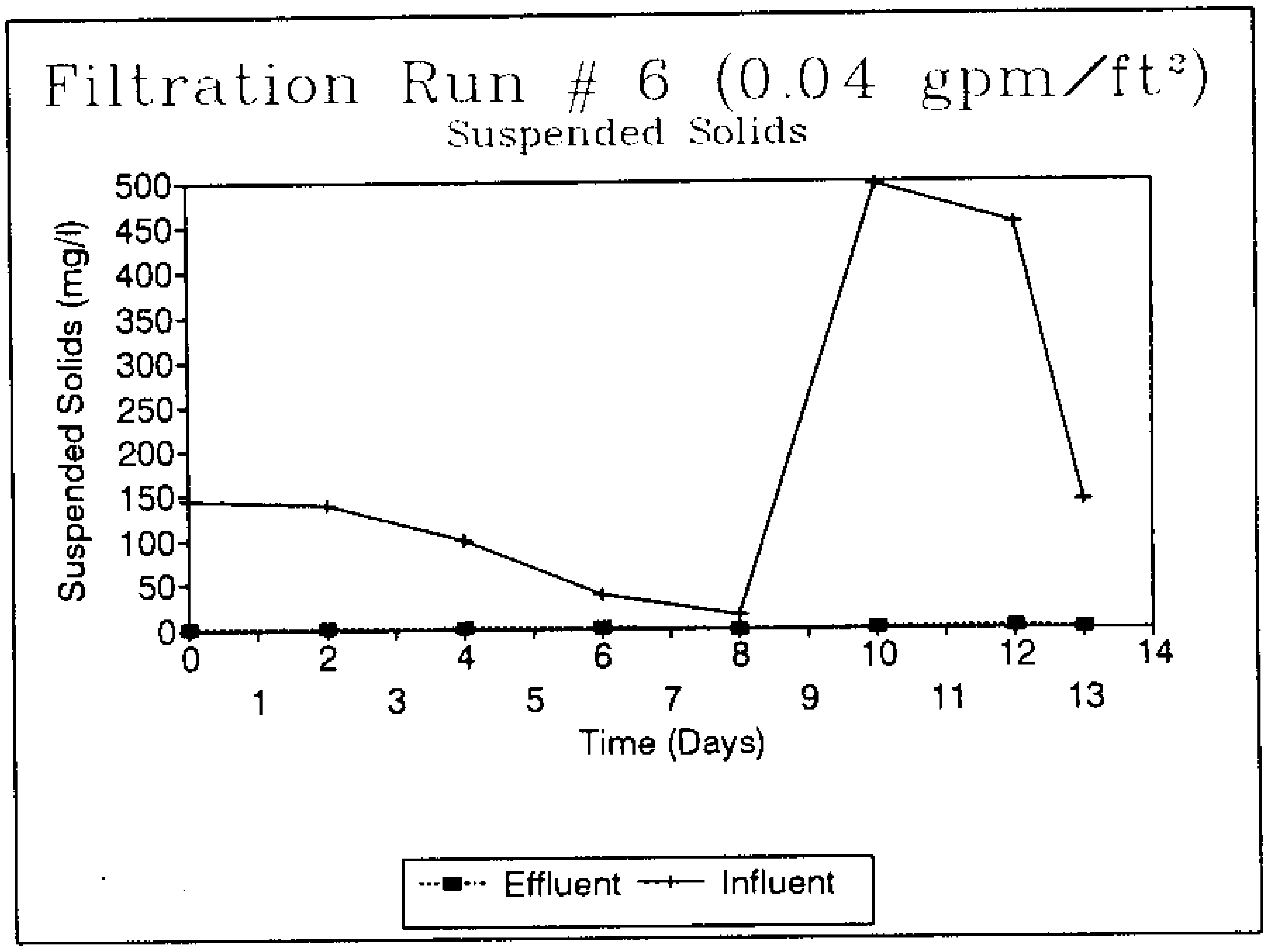

FIG. F-5.- Suspended Solids for Filtration Run 6

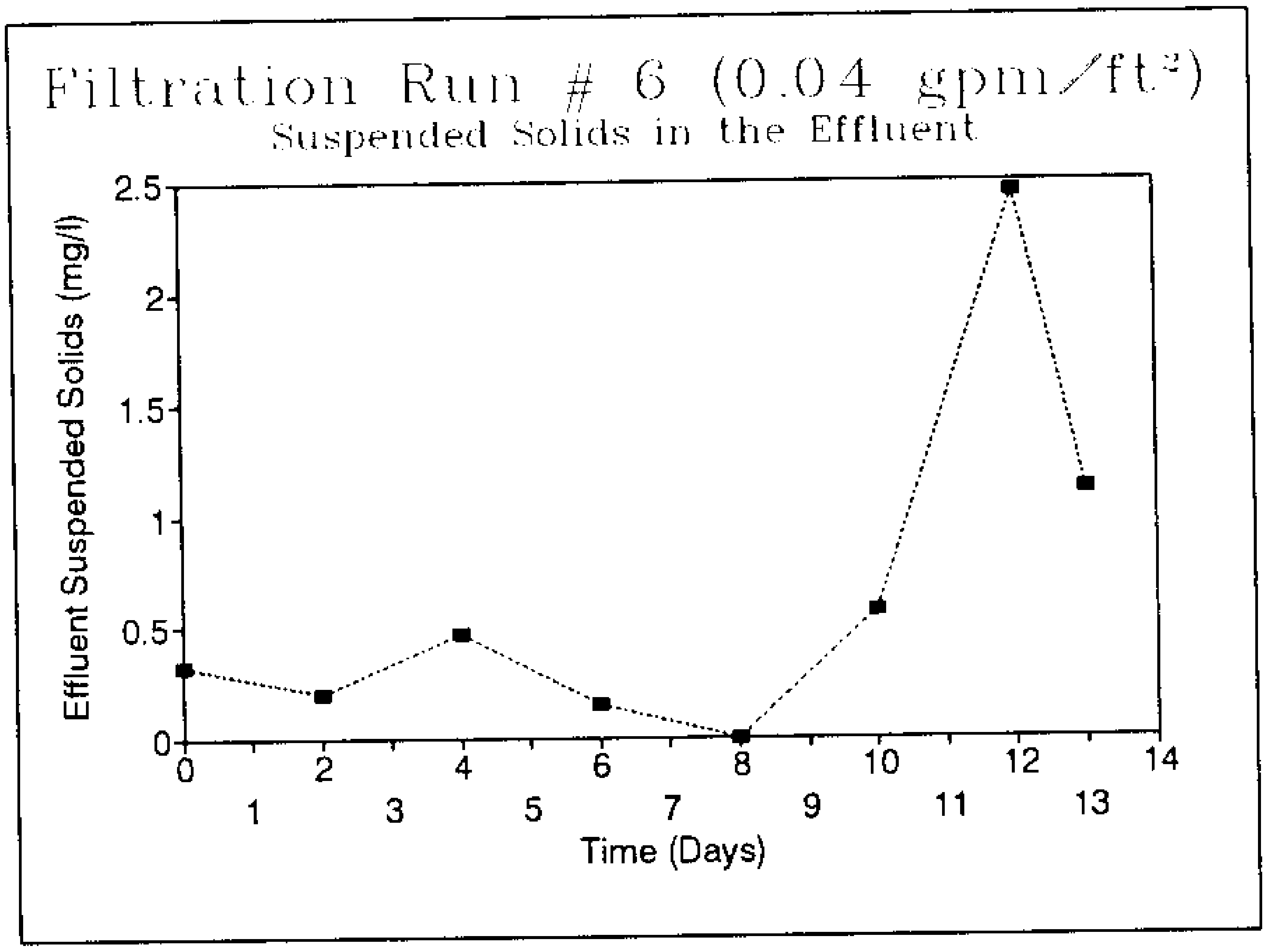

FIG. F-6.- Effluent Suspended Solids for Filtration Run 6

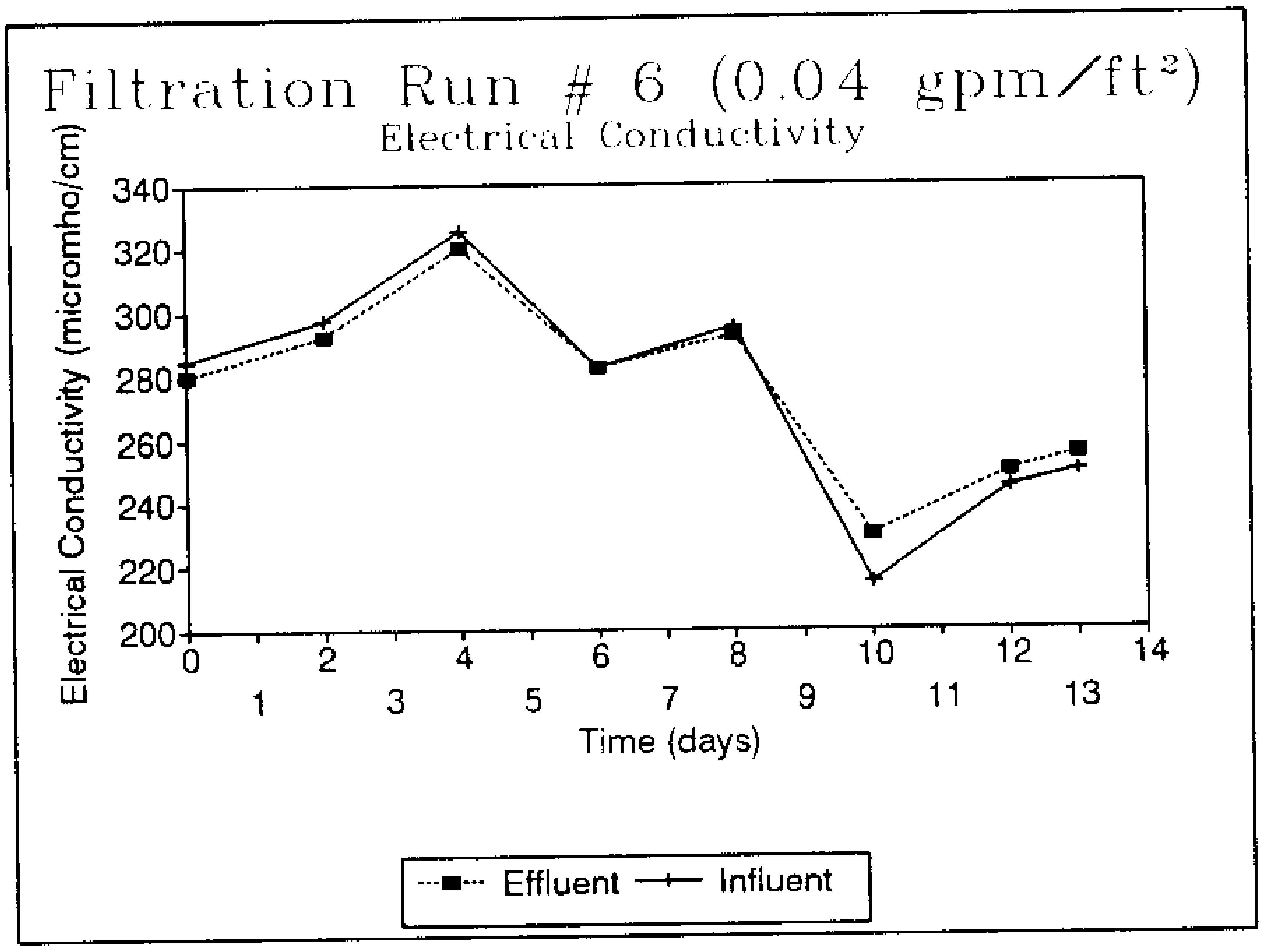

FIG. F-7.- Electrical Conductivity for Filtration Run 6

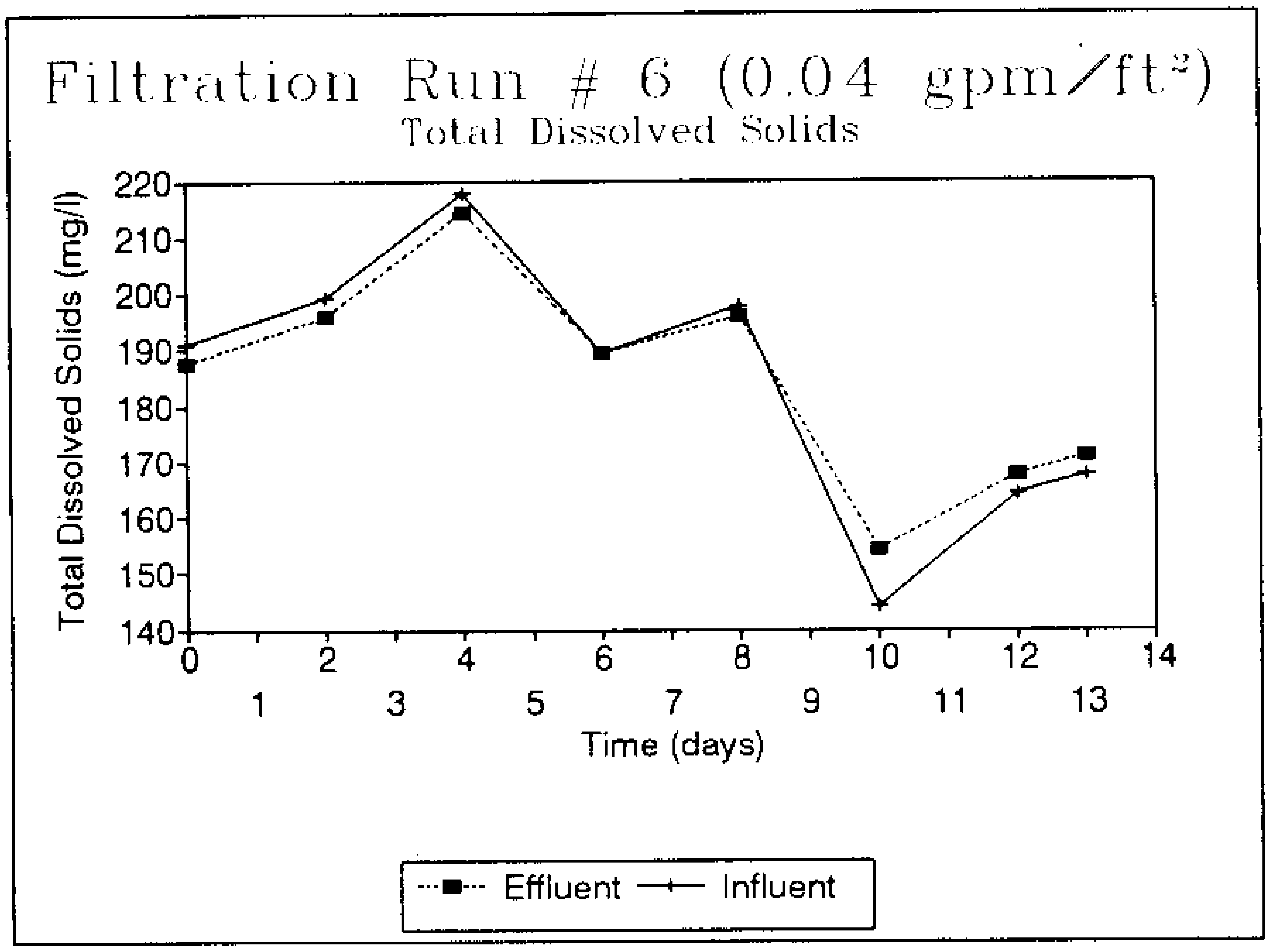

FIG. F-8.- Total Dissolved Solids for Filtration Run 6

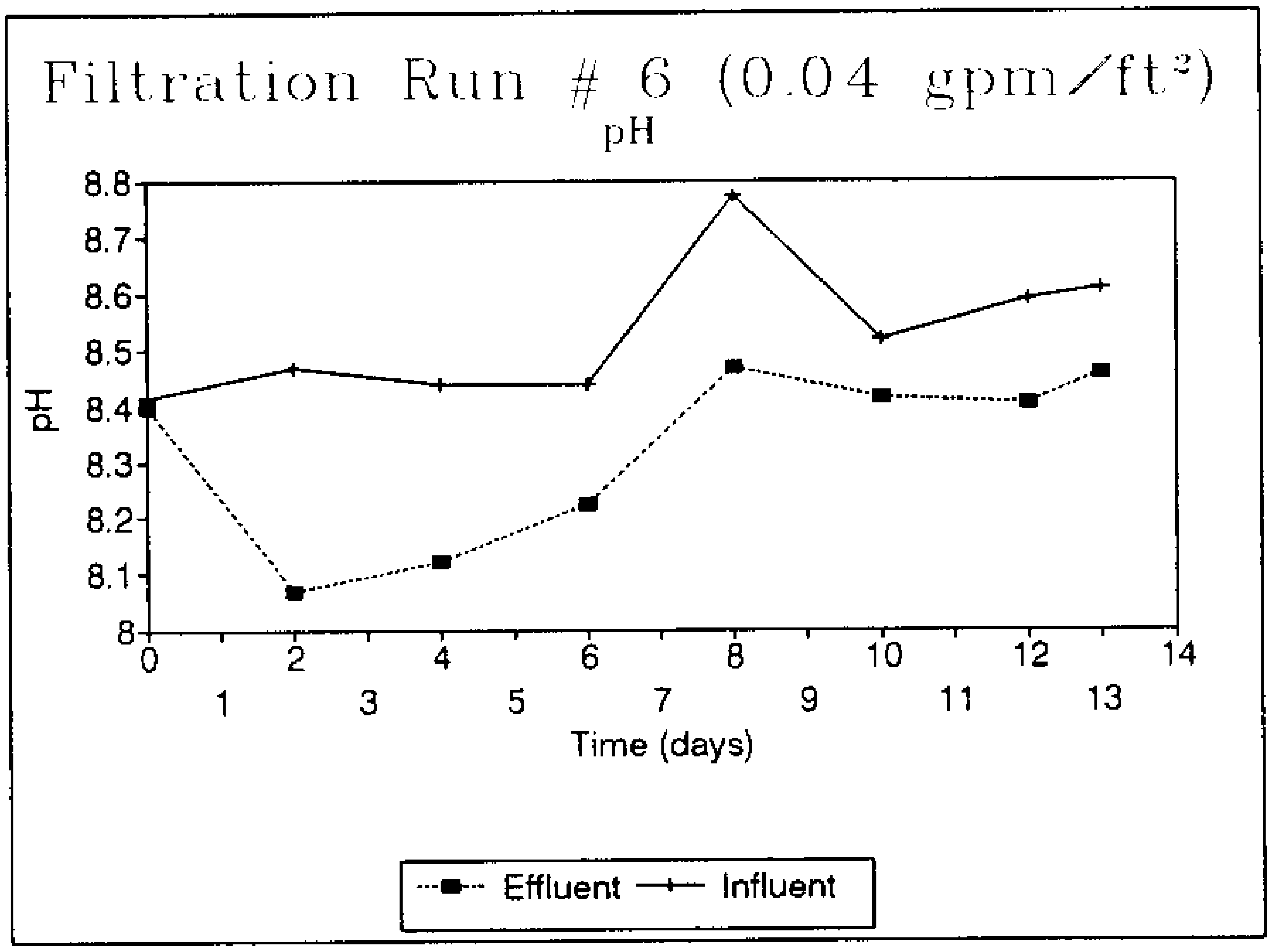

FIG. F-9.- pH for Filtration Run 6

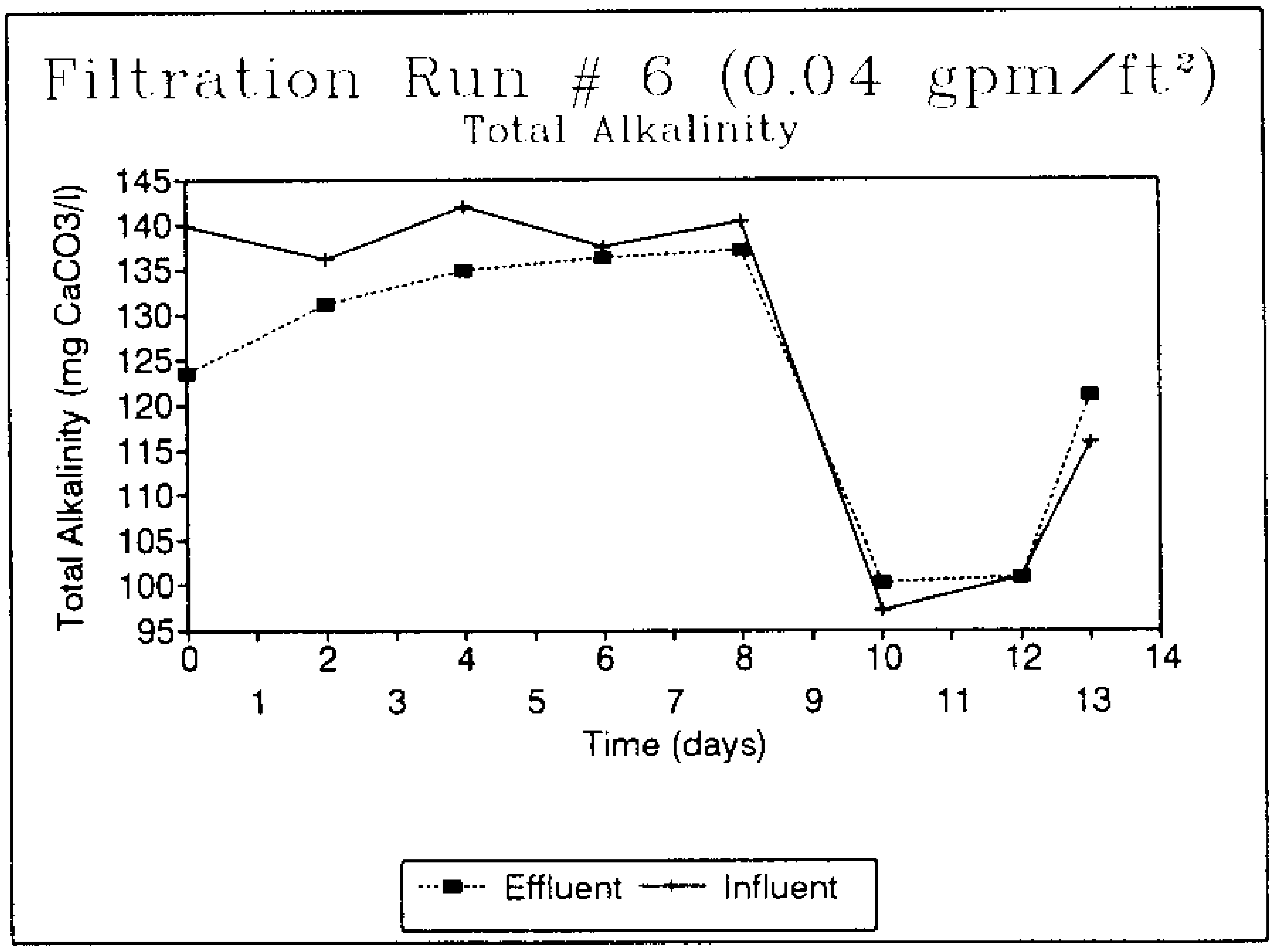

FIG. F-10.- Total Alkalinity for Filtration Run 6

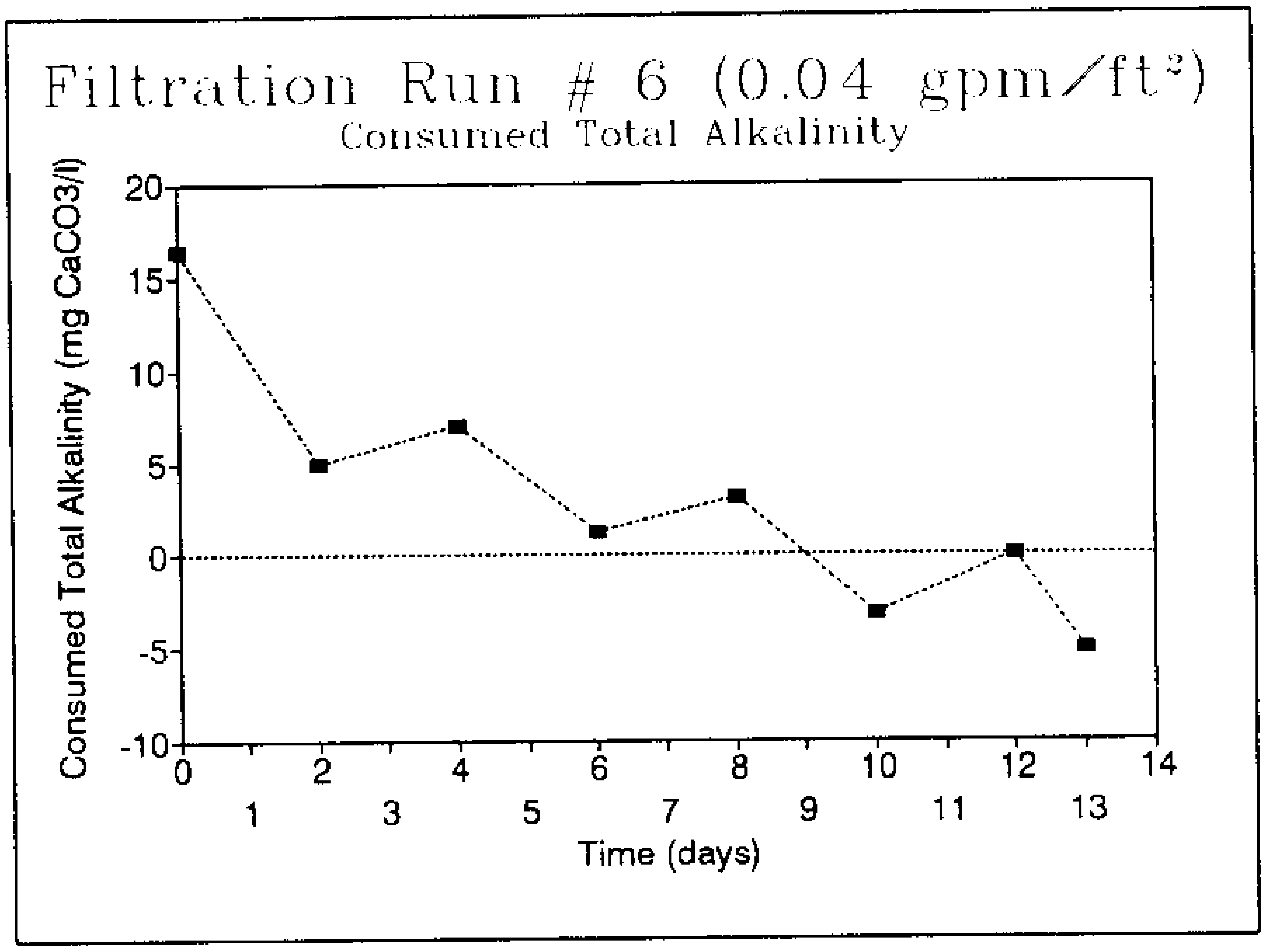

FIG. F-11.- Consumed Total Alkalinity for Filtration Run 6

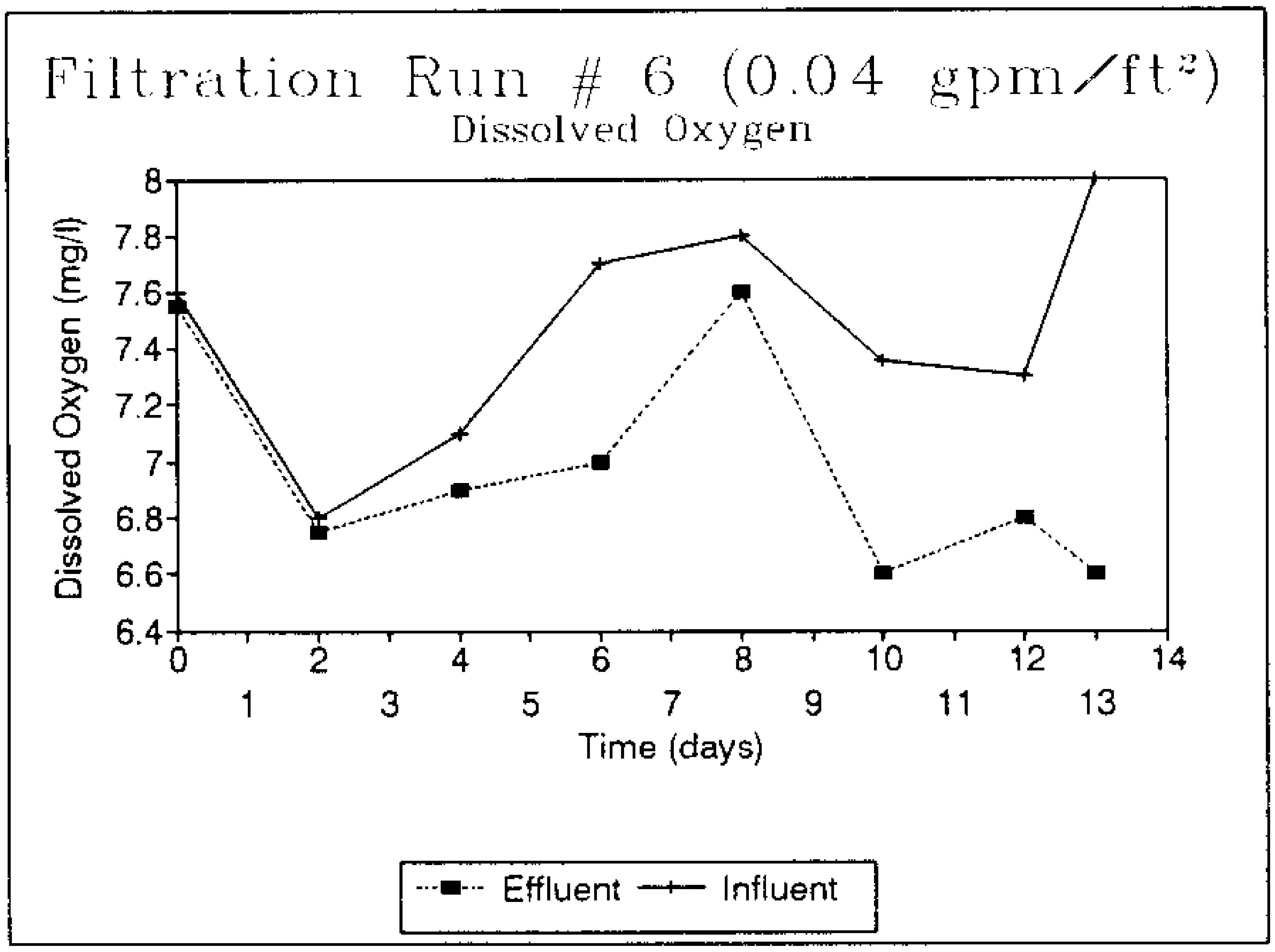

FIG. F-12.- Dissolved Oxygen for Filtration Run 6

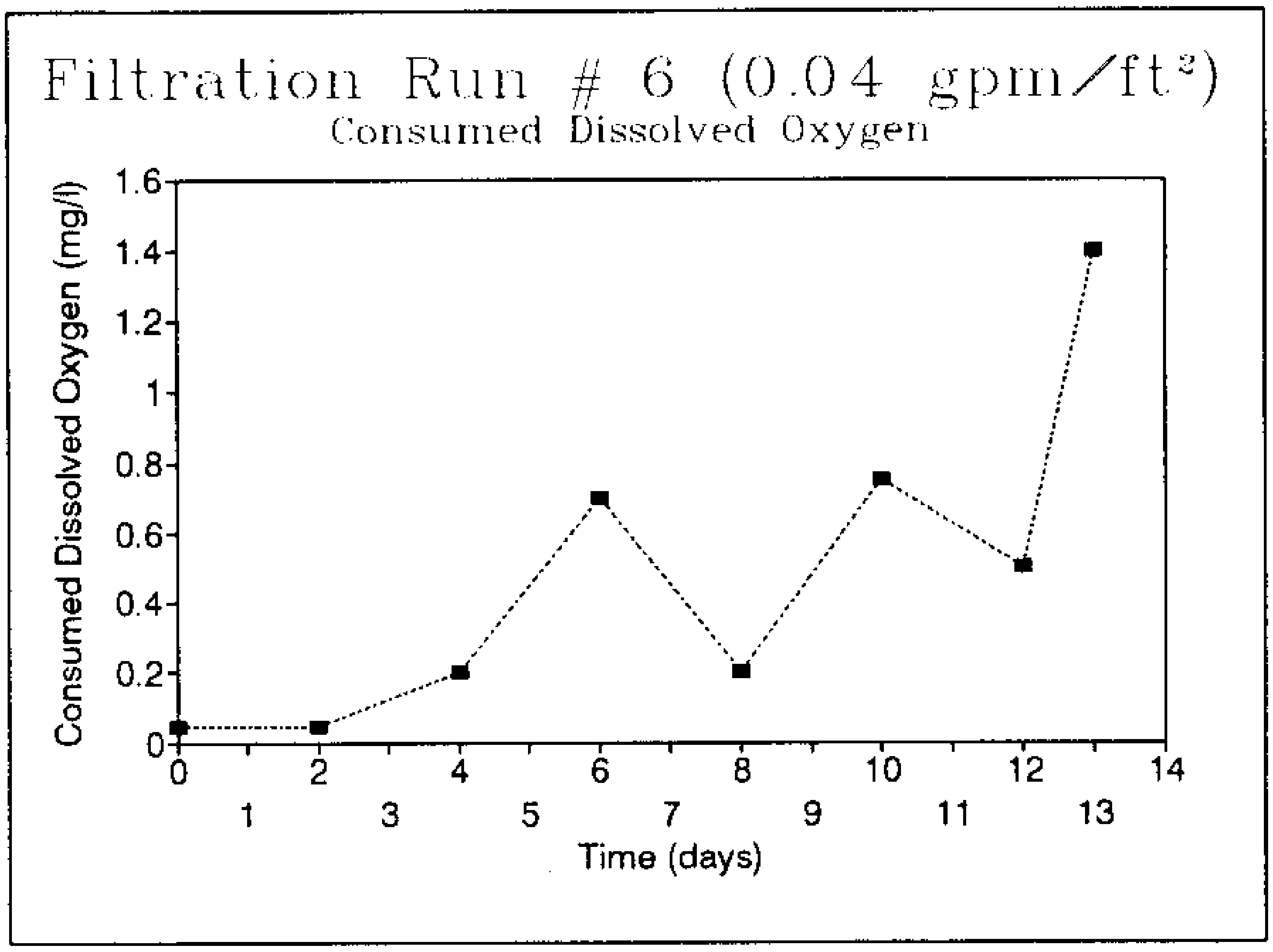

FIG. F-13.- Consumed Dissolved Oxygen for Filtration Run 6

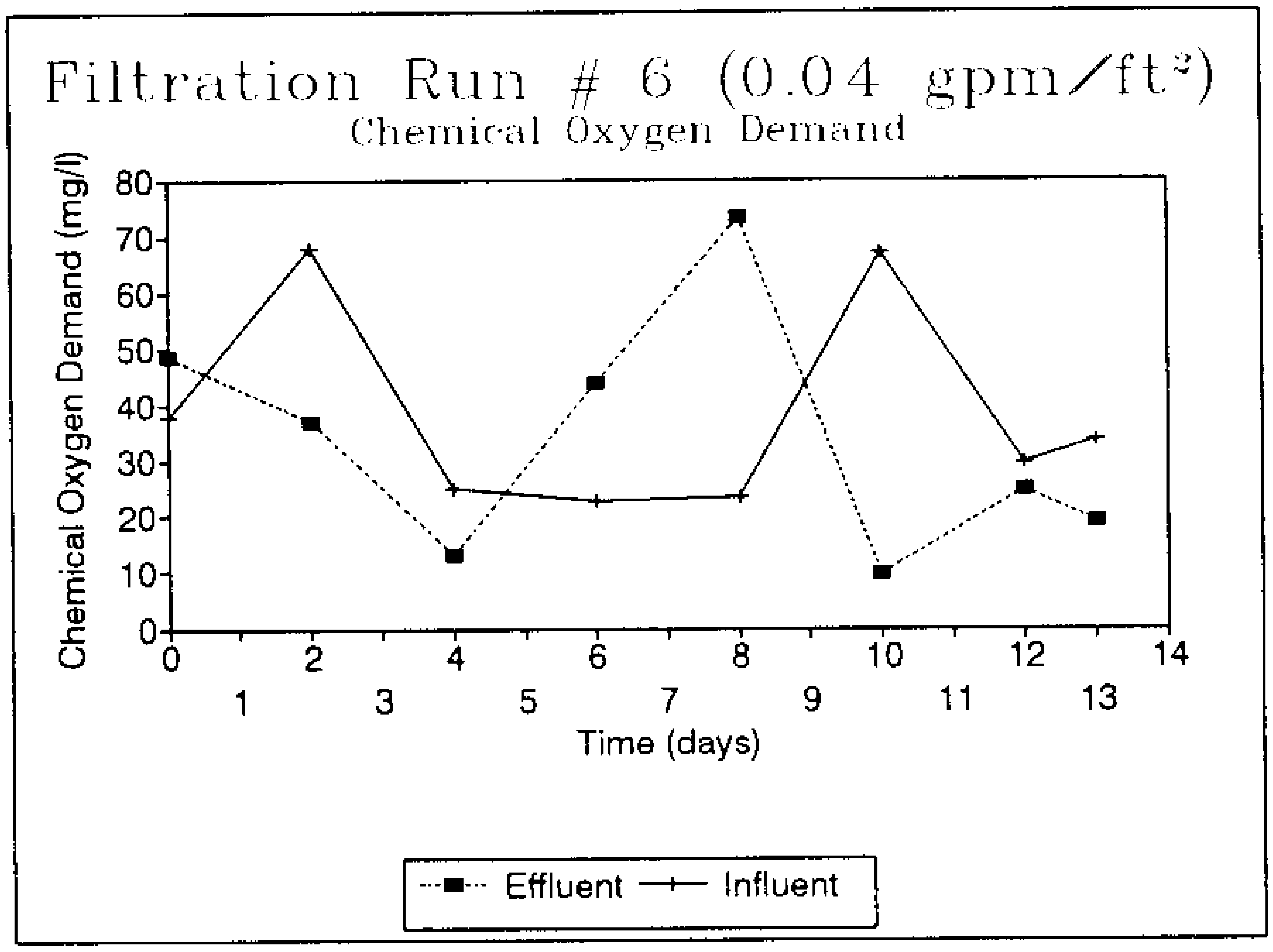

FIG. F-14.- Chemical Oxygen Demand (COD) for Filtration Run 6

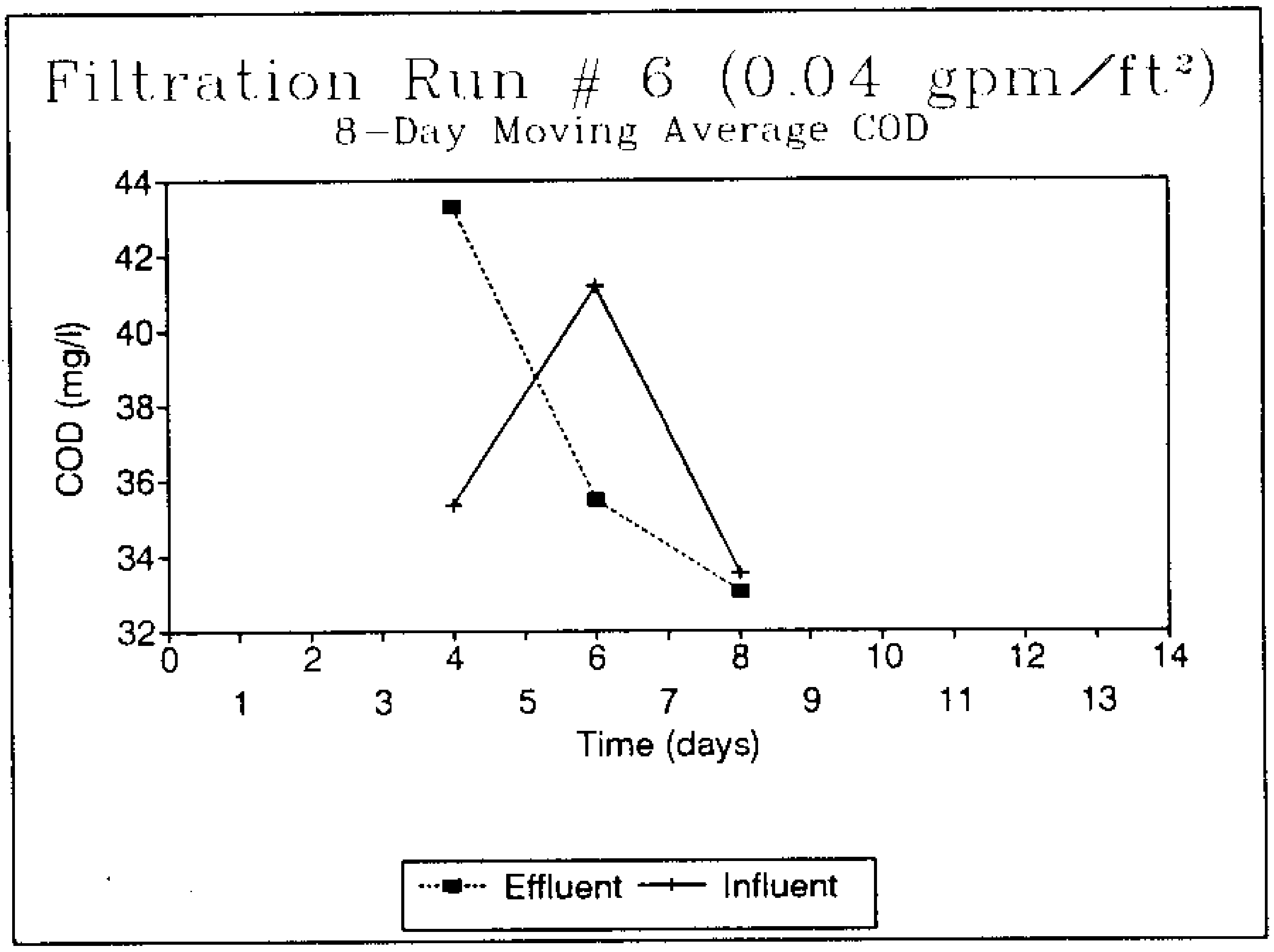

FIG. F-15.- 8-Day Moving Average COD for Filtration Run 6

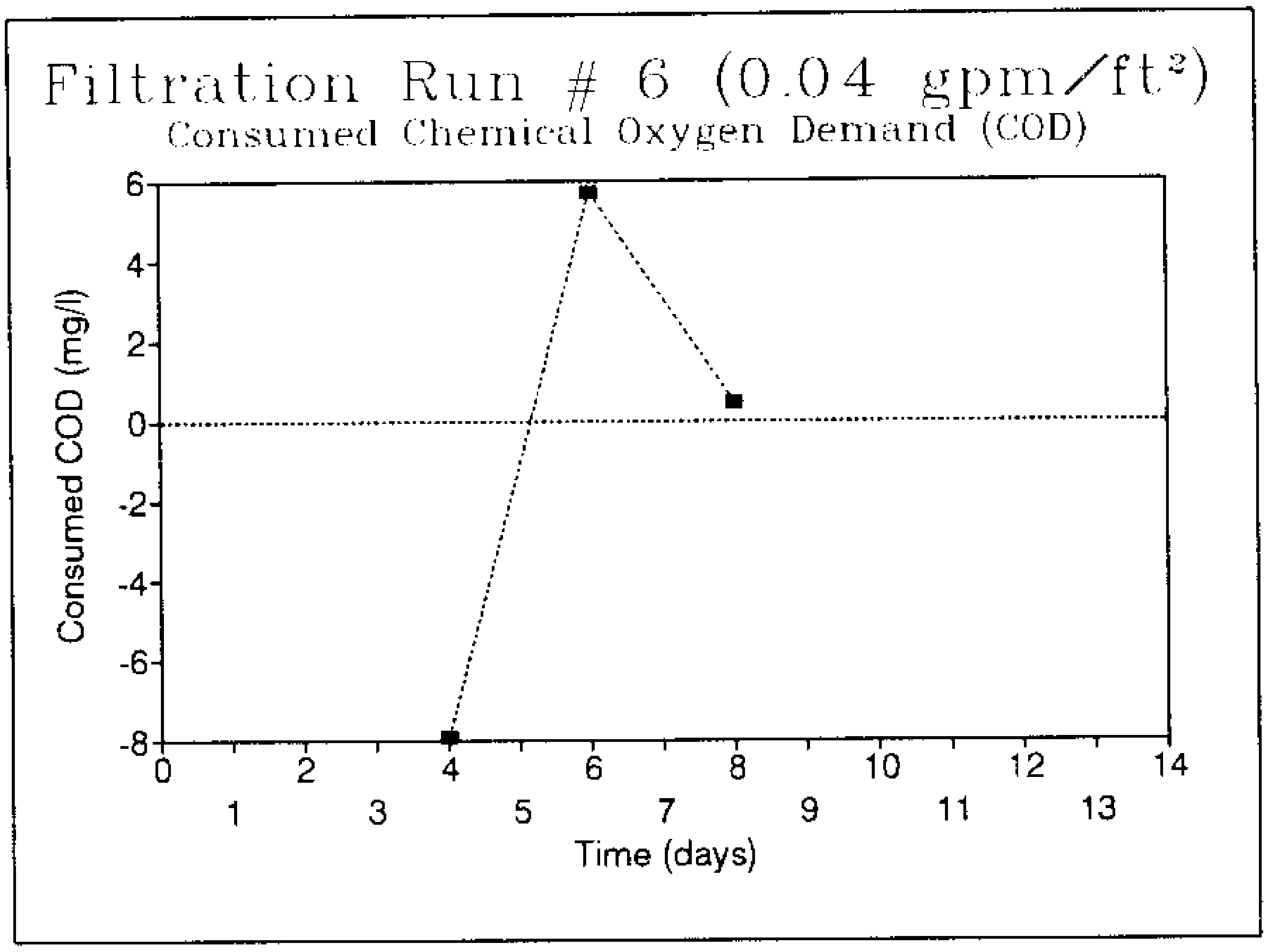

FIG. F-16.- Consumed COD for Filtration Run 6

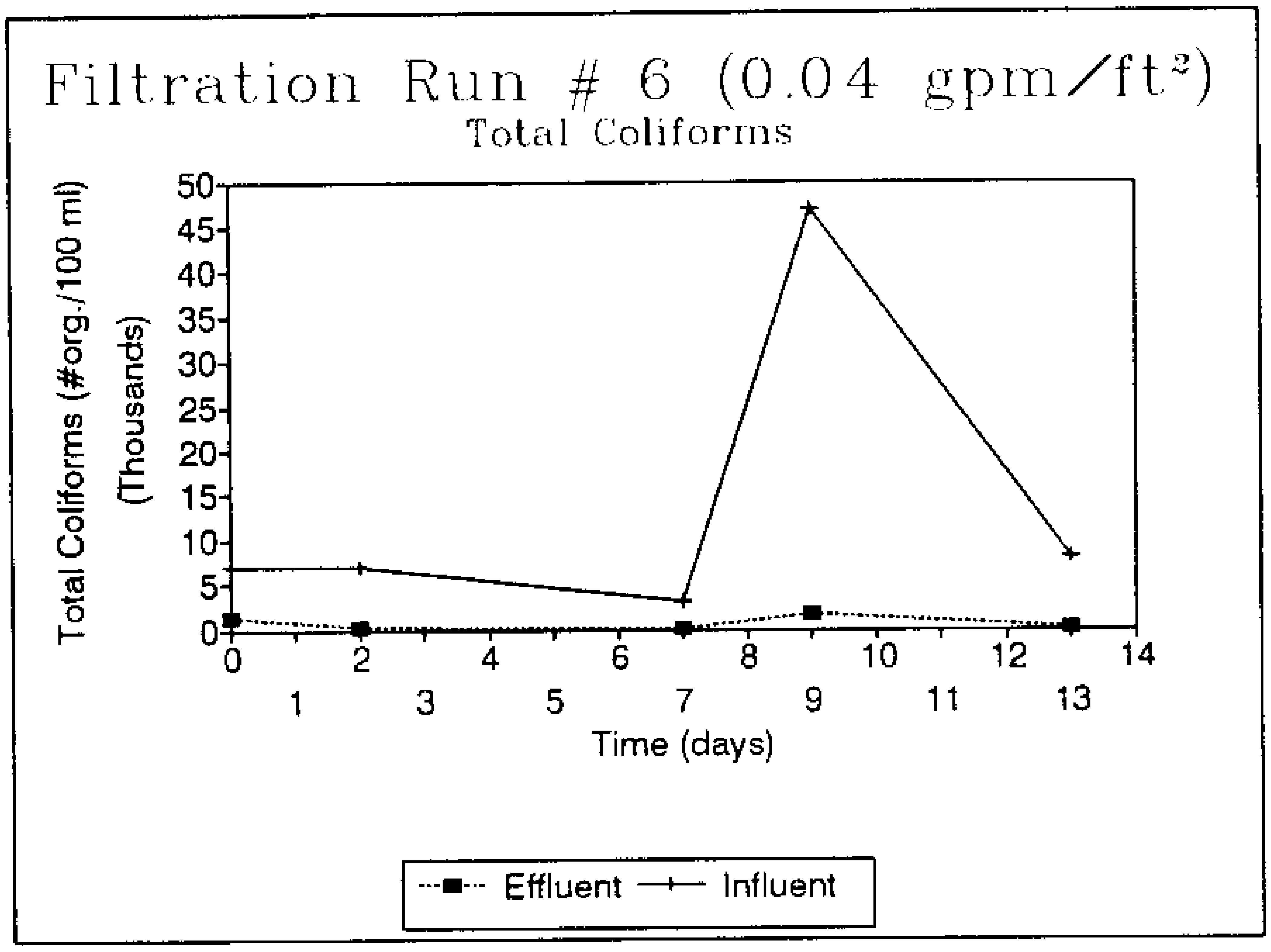

FIG. F-17.- Total Coliforms for Filtration Run 6

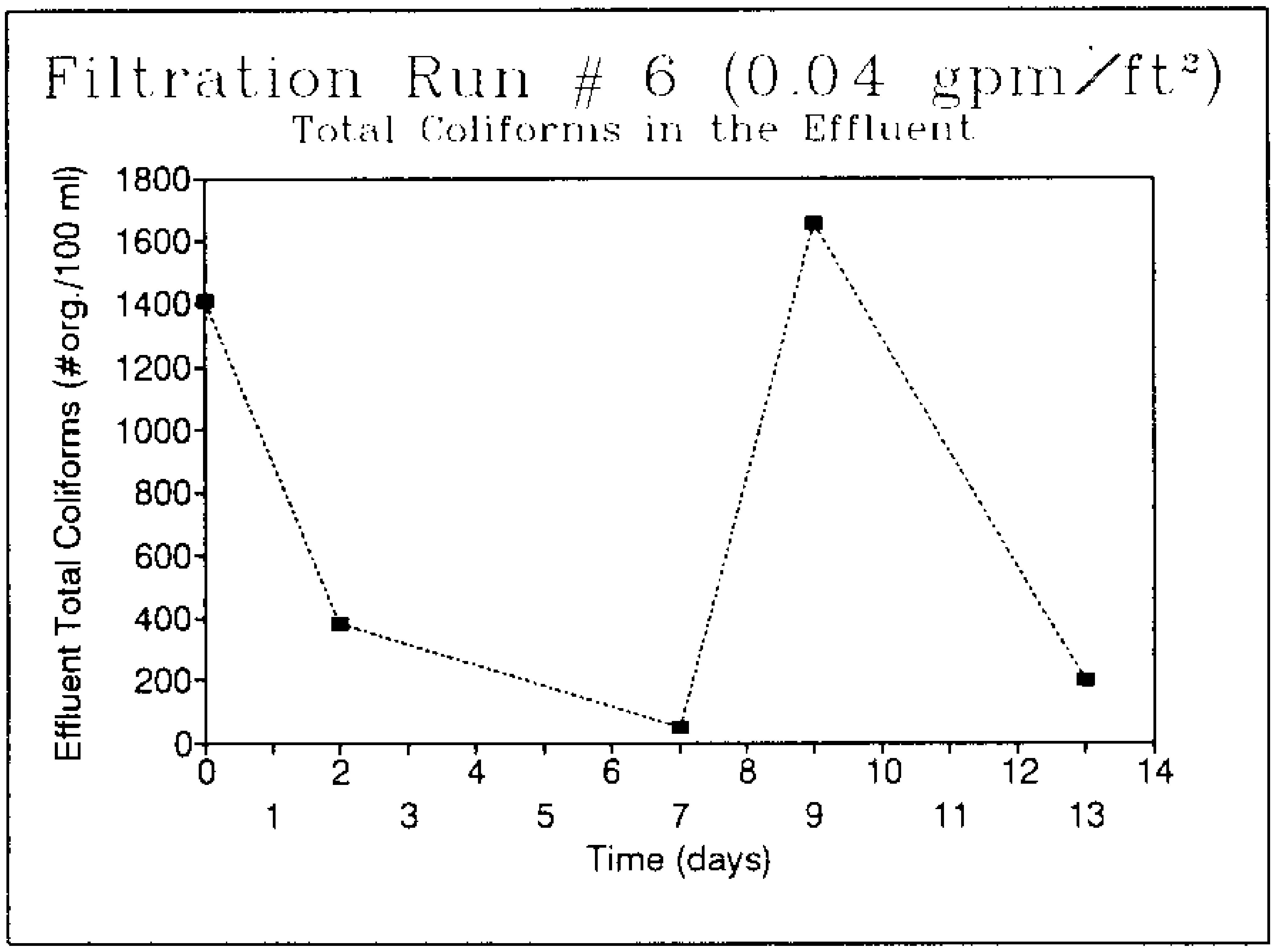

FIG. F-18.- Effluent Total Coliforms for Filtration Run 6

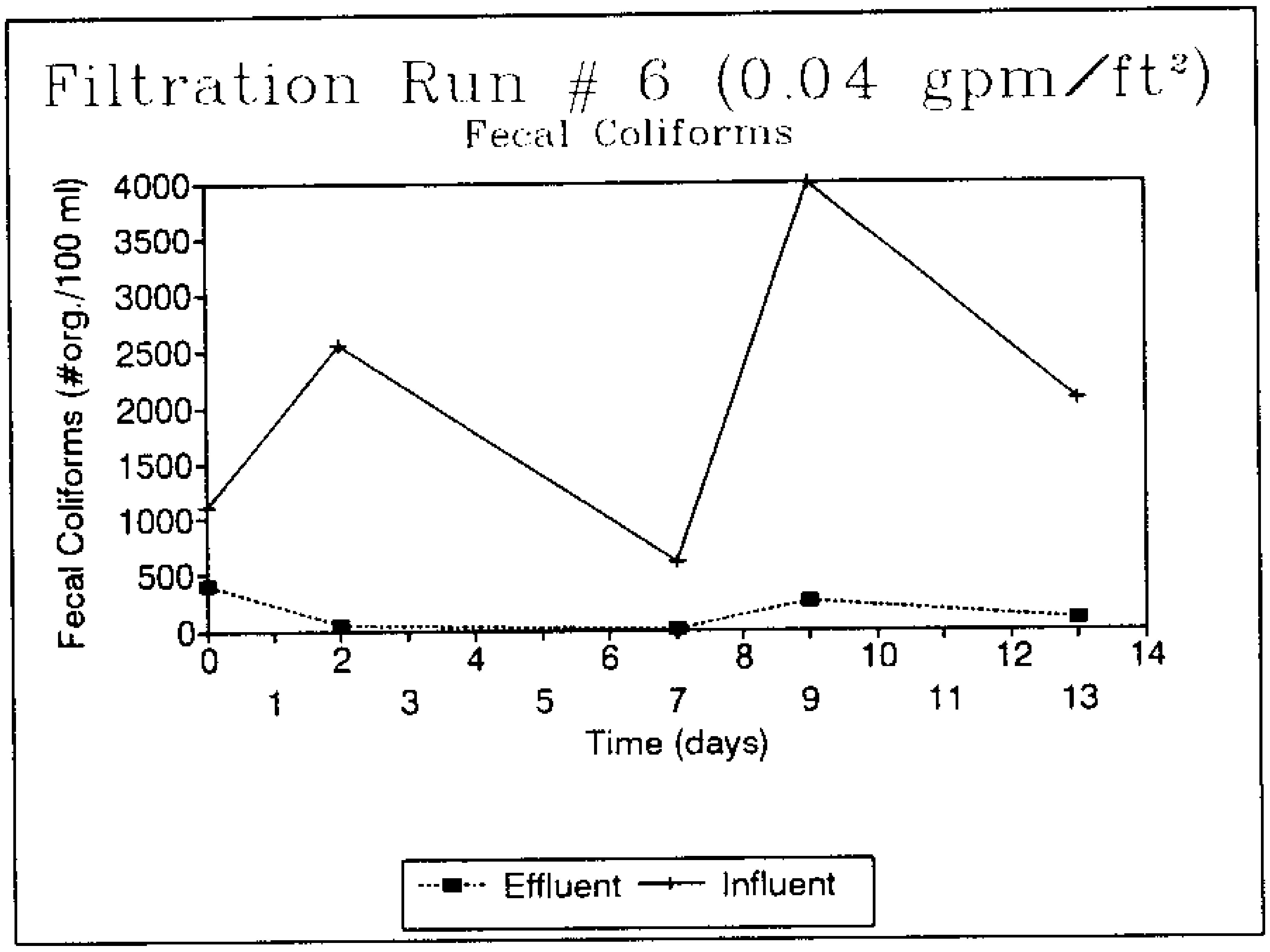

FIG. F-19.- Fecal Coliforms for Filtration Run 6

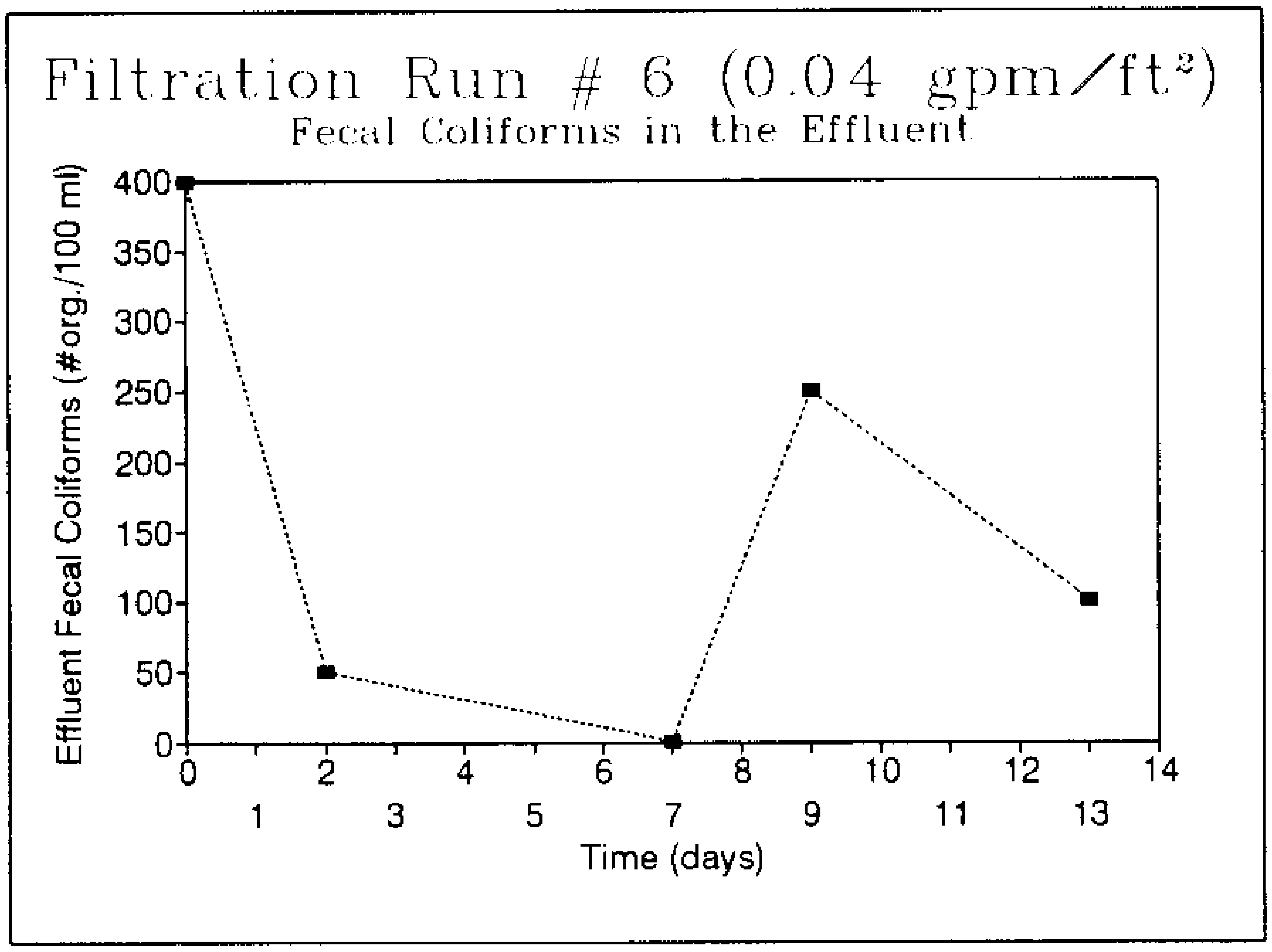

Figure F-20 : Effluent Fecal Coliforms for Filtration Run 6

Table F-1.- Biochemical Oxygen Demand: Day # 0 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.43	8.40	9.33	8.38	1	0.0010	75
0.5%	9.45	8.13	9.33	8.38	1	0.0050	75
1%	9.43	8.38	9.33	8.38	1	0.0100	10
5%	9.43	8.13	9.33	8.38	1	0.0500	7
Glucose	9.40	4.60	9.33	8.38	1	0.0200	192.5

Table F-2.- Biochemical Oxygen Demand: Day # 0 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	9.50	6.48	9.33	8.38	1	0.0010	2075
0.5%	9.40	7.50	9.33	8.38	1	0.0050	190
1%	9.35	8.35	9.33	8.38	1	0.0100	5
5%	9.40	8.35	9.33	8.38	1	0.0500	2
Glucose	9.40	4.60	9.33	8.38	1	0.0200	192.5

Table F-3.- Biochemical Oxygen Demand: Day # 13 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.55	7.68	8.60	7.68	1	0.0010	-50
0.5%	8.35	7.60	8.60	7.68	1	0.0050	-35
1%	8.28	7.43	8.60	7.68	1	0.0100	-7.5
5%	8.30	7.25	8.60	7.68	1	0.0500	2.5
Glucose	8.65	3.78	8.60	7.68	1	0.0200	197.5

Table F-4.- Biochemical Oxygen Demand: Day # 13 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.53	7.38	8.60	7.68	1	0.0010	225
0.5%	8.43	7.40	8.60	7.68	1	0.0050	20
1%	8.35	7.33	8.60	7.68	1	0.0100	10
5%	8.33	7.13	8.60	7.68	1	0.0500	5.5
Glucose	8.65	3.78	8.60	7.68	1	0.0200	197.5

Table F-5.- Schmutzdecke Biochemical Oxygen Demand

$BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P$

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.43	7.33	8.60	7.68	1	0.0010	175
0.5%	8.48	7.13	8.60	7.68	1	0.0050	85
1%	8.53	6.80	8.60	7.68	1	0.0100	80
5%	8.23	4.55	8.60	7.68	1	0.0500	55
Glucose	8.65	3.78	8.60	7.68	1	0.0200	197.5

Table F-6.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.25	4.25	-	
S.A.+P.D.	4.25	8.50	4.25	-	
S.A.+P.D.	0.00	4.15	4.15	-	-
Blank	4.15	8.40	4.25	-	
Blank	0.00	4.23	4.23	-	
Blank	4.23	8.50	4.27	-	-
Standard	0.00	3.12	3.12	535.97	
Standard	3.12	6.33	3.21	493.28	514.62
Sch.1/100	0.00	4.11	4.11	6640.32	
Sch.1/100	4.11	8.21	4.10	7114.62	
Sch.1/10	0.00	3.68	3.68	2703.56	
Sch.1/10	3.68	7.32	3.64	2893.28	4837.94

Table F-7.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (μmho/cm)	TDS (mg/l)	Average Conductivity (μmho/cm)	Average TDS (mg/l)
1	135.00	90.45		
2	130.00	87.10	132.50	88.78

Table F-8.- Schmutzdecke pH

Sample	pH	Average pH
1	8.41	
2	8.38	8.40

Table F-9.- Schmutzdecke Turbidity

Sample	Turbidity (NTU)	Average Turbidity (NTU)
1	28000	
2	28000	28000

Table F-10.- Schmutzdecke Alkalinity

A = 2.5024
B = 40.00
C = 18.55

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	36.60	53.80	17.20	0.10181152	437.79	
2	3.80	20.35	16.55	0.10181152	421.25	429.52

Table F-11.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	21212.12	40404.04
2	29292.93	40404.04
Average	25252.52	40404.04

Table F-12.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
0	15.70927	2	15.80474	47735		15.79619	4275	
19	16.77581	2	16.87673	50460	49097.5	16.86807	4330	4302.5

Table F-13.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
1E	38.20597	20	39.19668	49535.50		39.07062	6303.00		43232.50	
19E	38.01094	20	39.00366	49636.00	49585.75	38.87290	6538.00	6420.50	43098.00	43165.25

Appendix G: Illustrations for Filtration Run 7

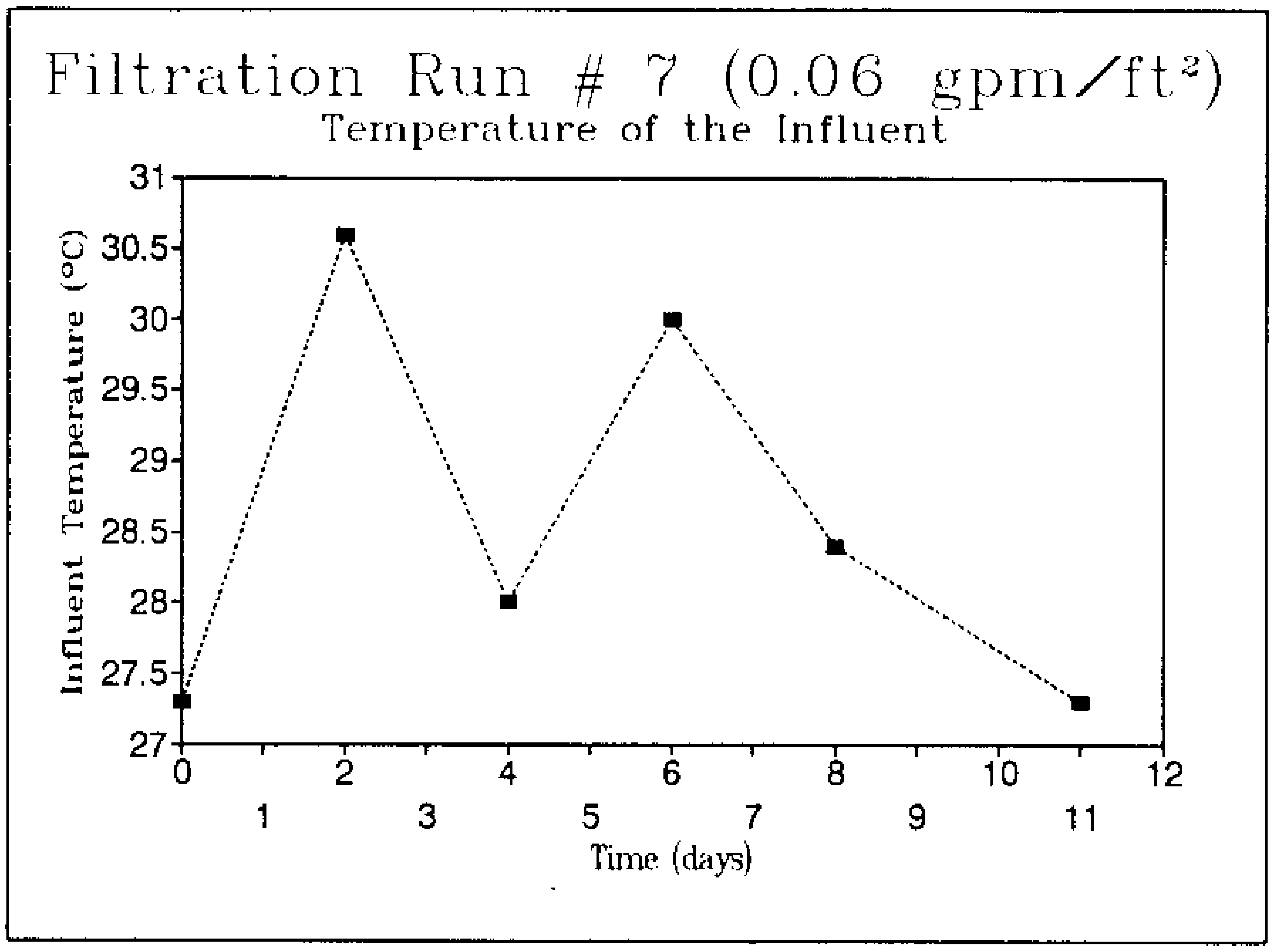

FIG. G-1.- Influent Temperature for Filtration Run 7

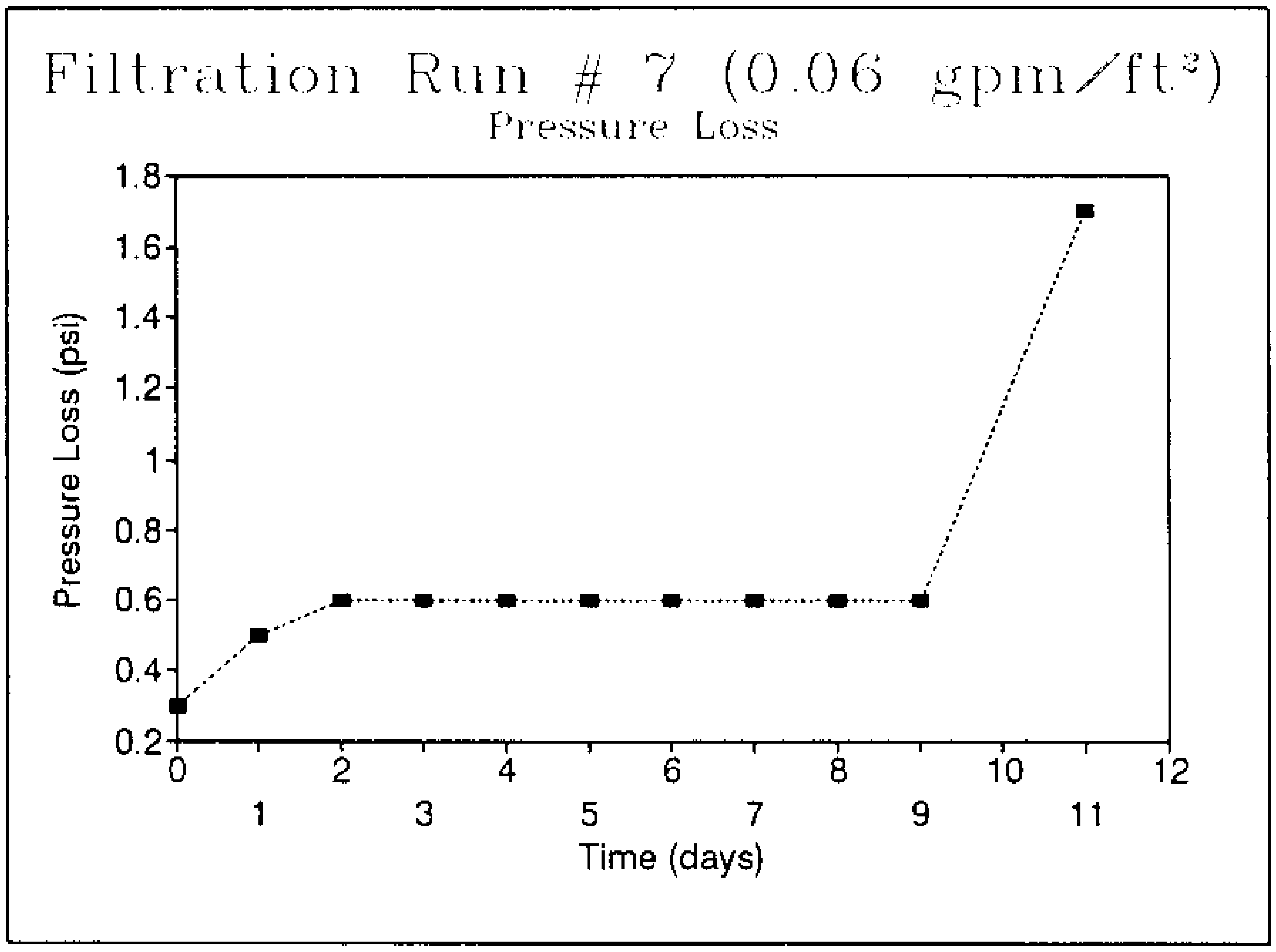

FIG. G-2.- Pressure Loss for Filtration Run 7

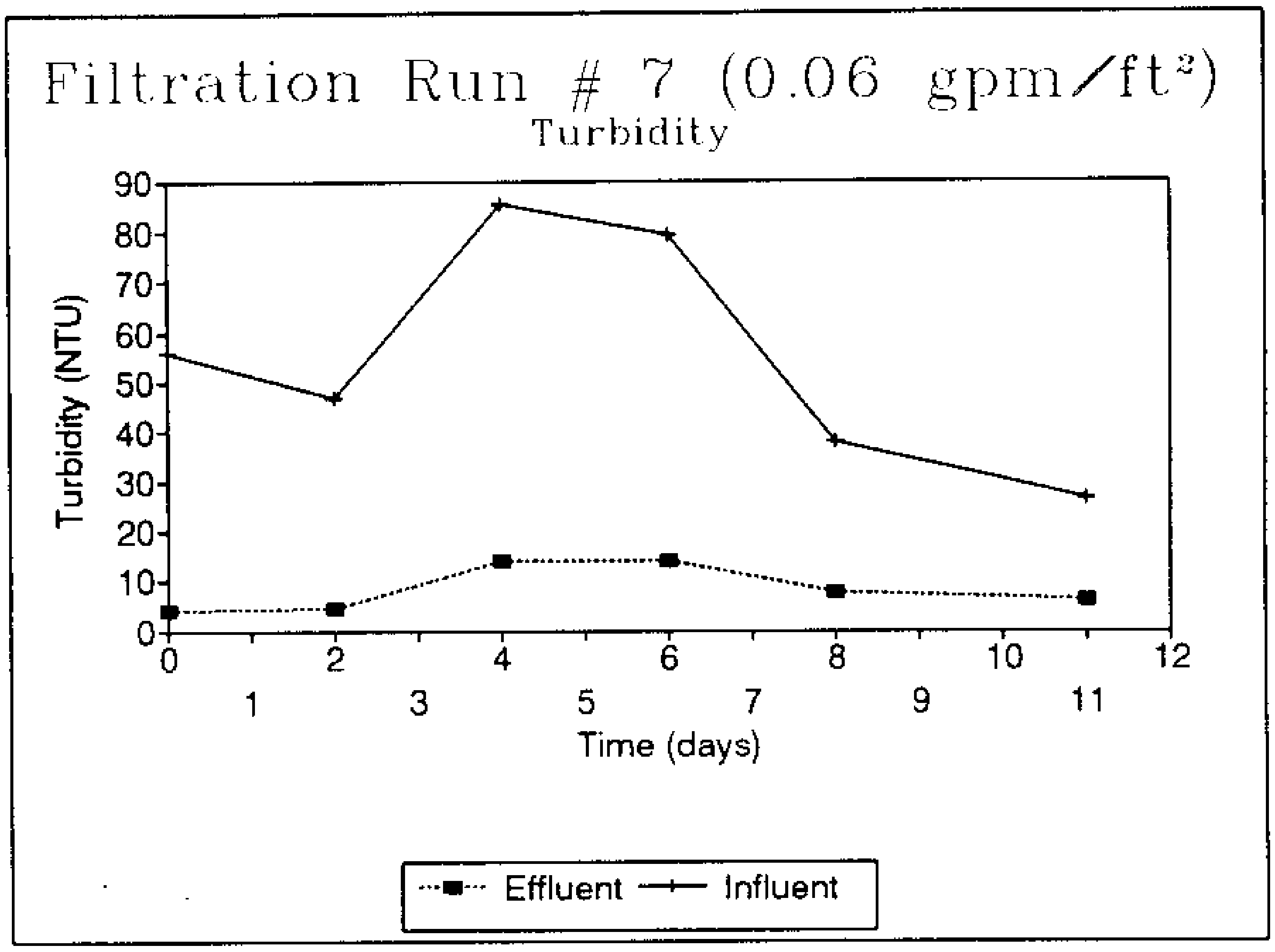

FIG. G-3.- Turbidity for Filtration Run 7

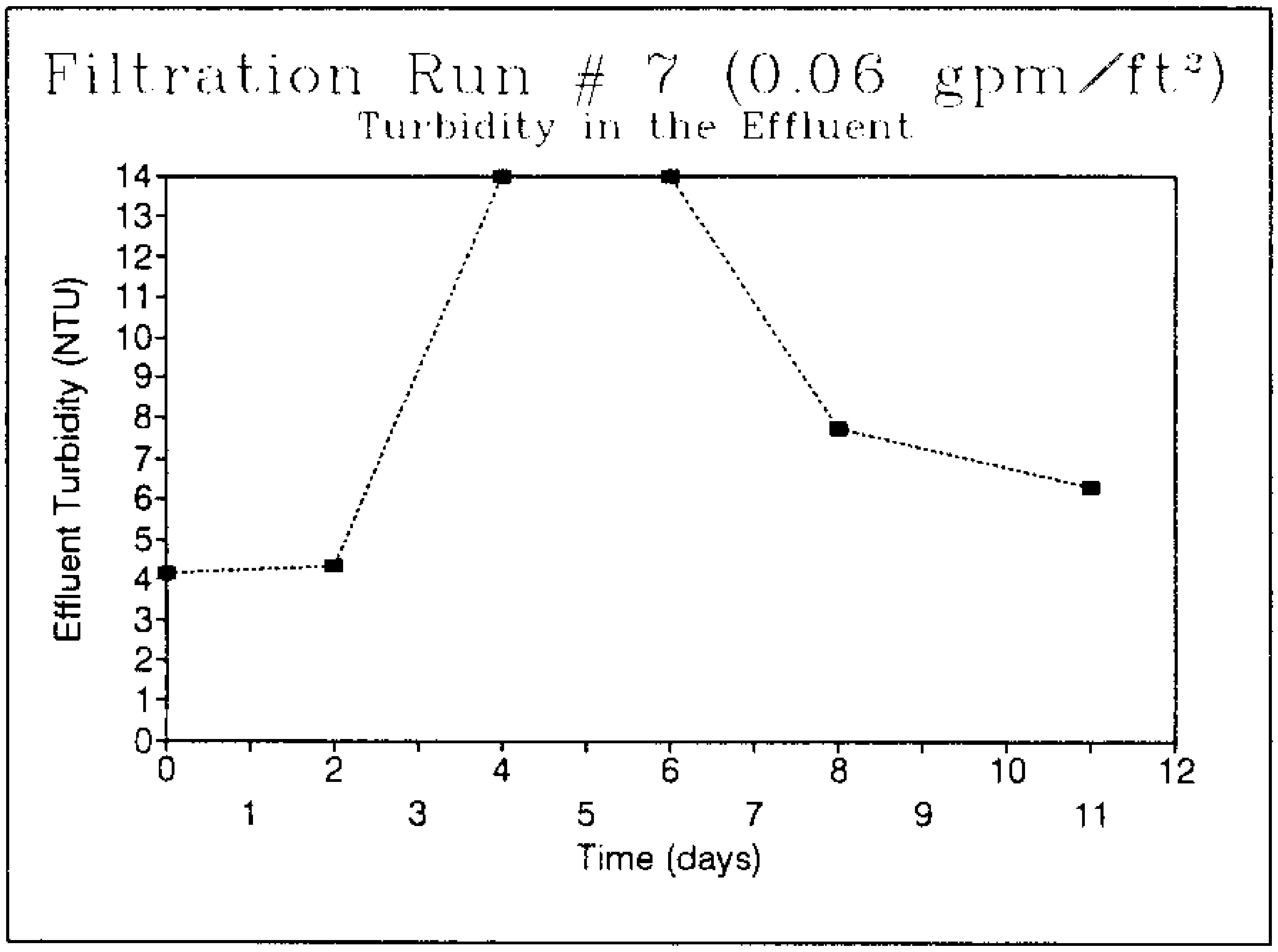

FIG. G-4.- Effluent Turbidity for Filtration Run 7

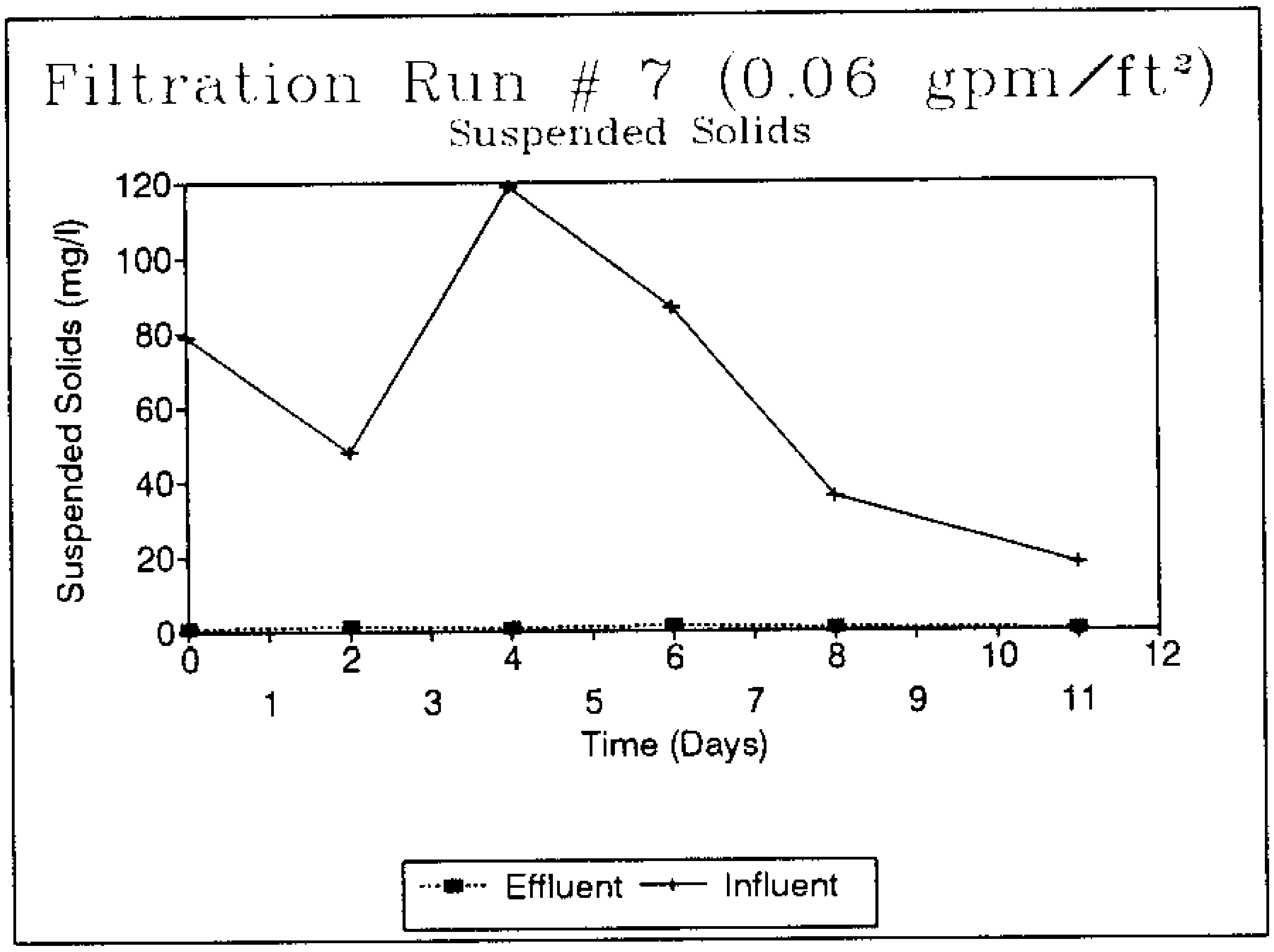

FIG. G-5.- Suspended Solids for Filtration Run 7

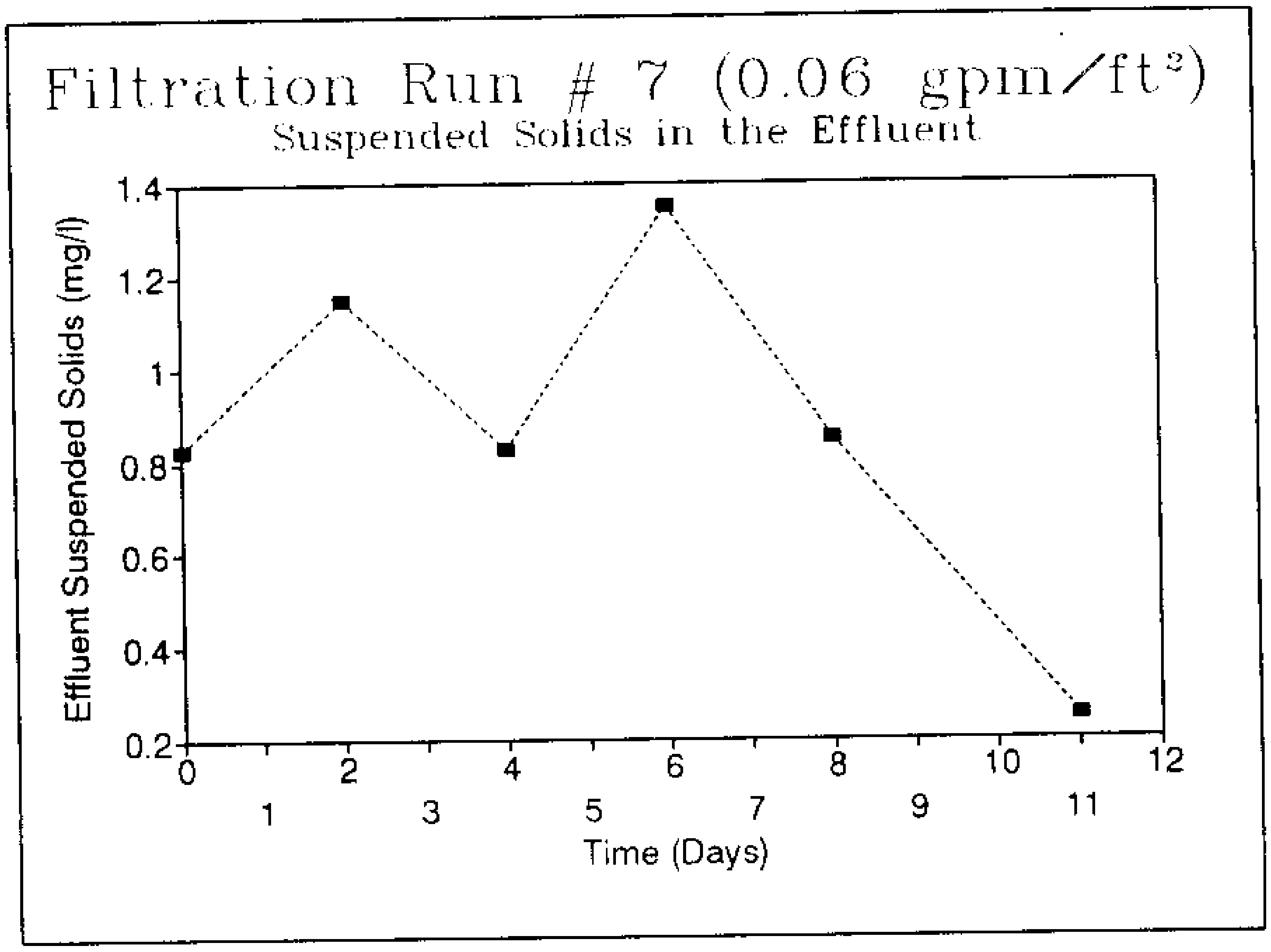

FIG. G-6.- Effluent Suspended Solids for Filtration Run 7

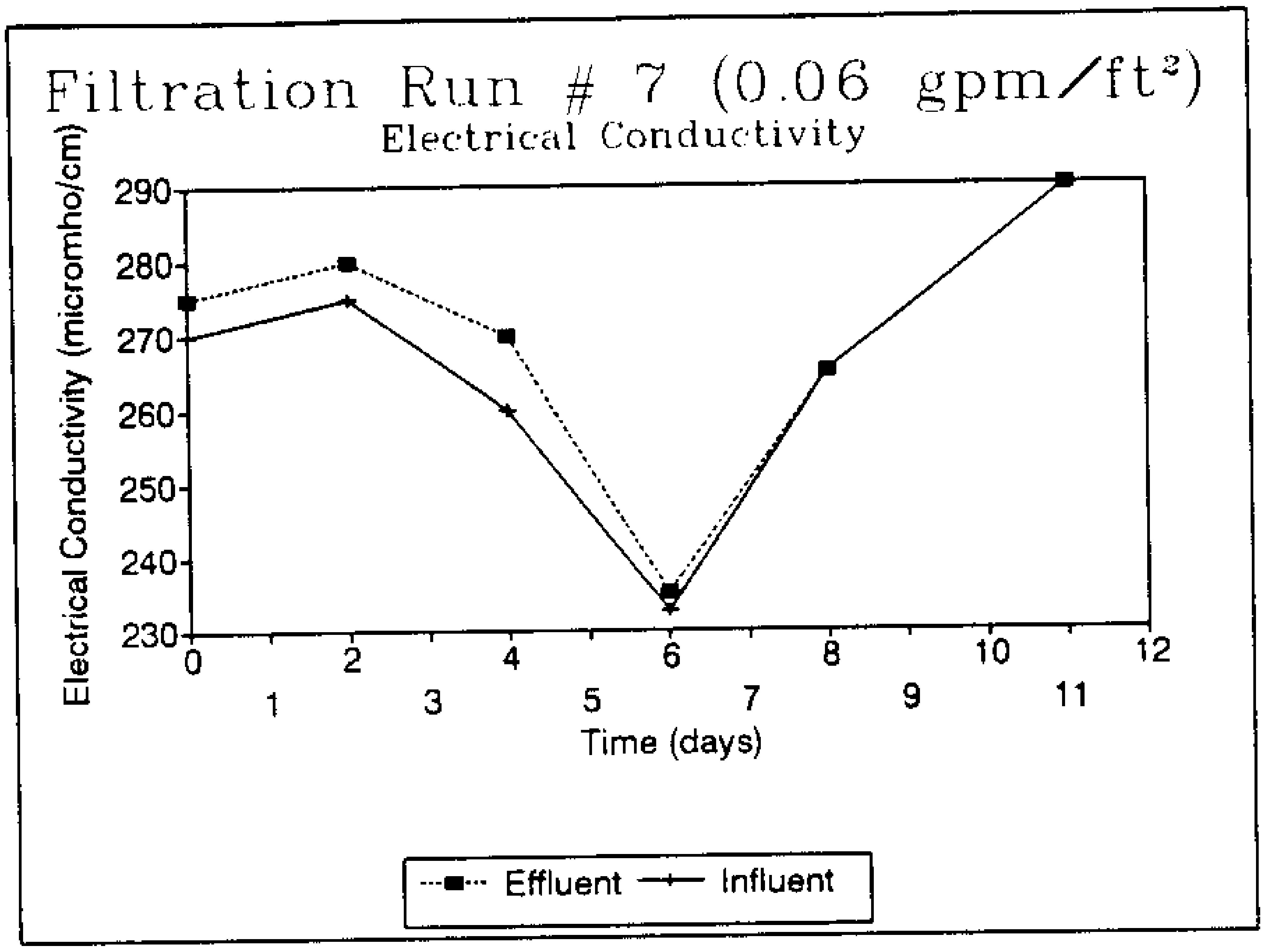

FIG. G-7.- Electrical Conductivity for Filtration Run 7

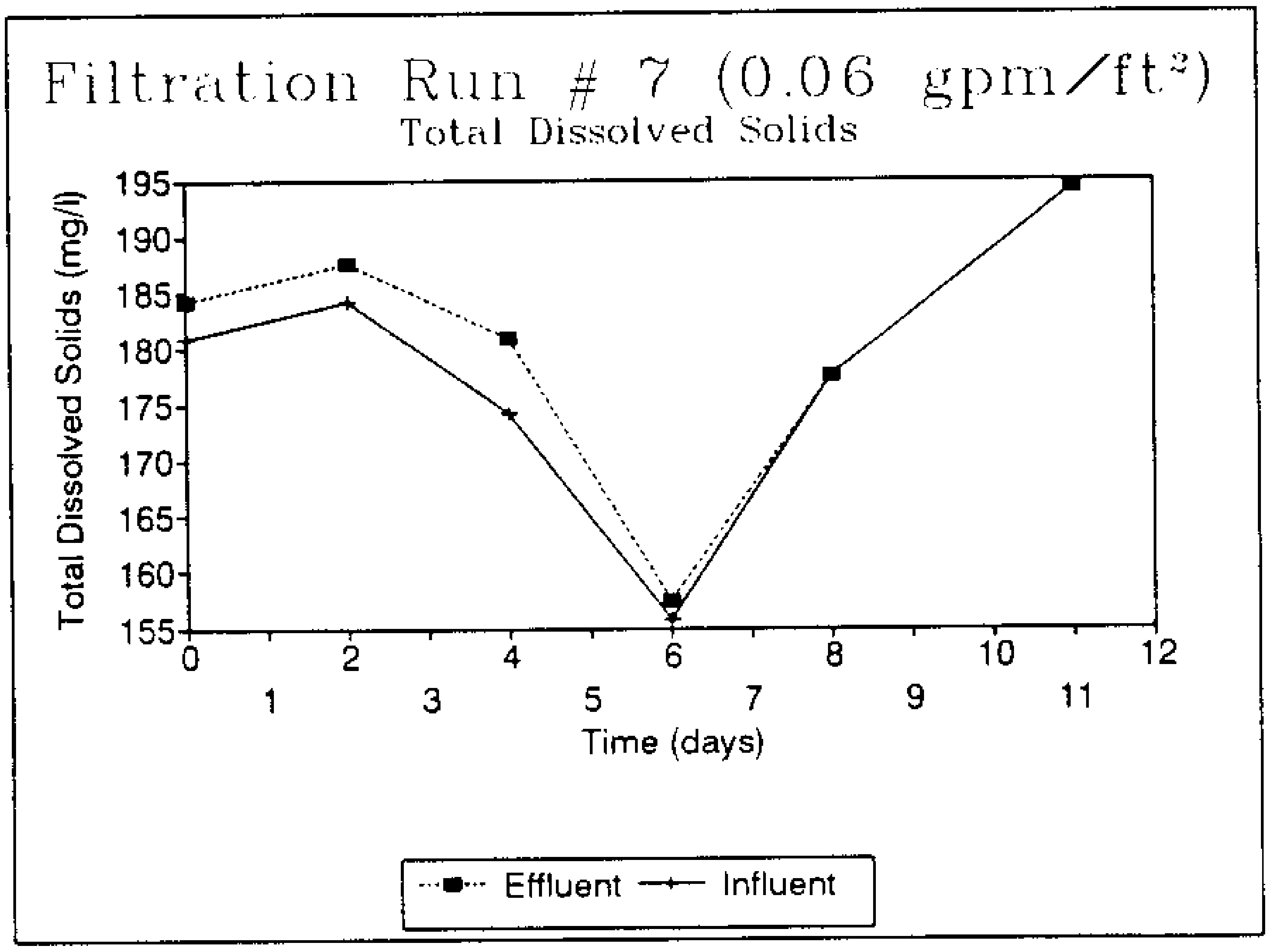

FIG. G-8.- Total Dissolved Solids for Filtration Run 7

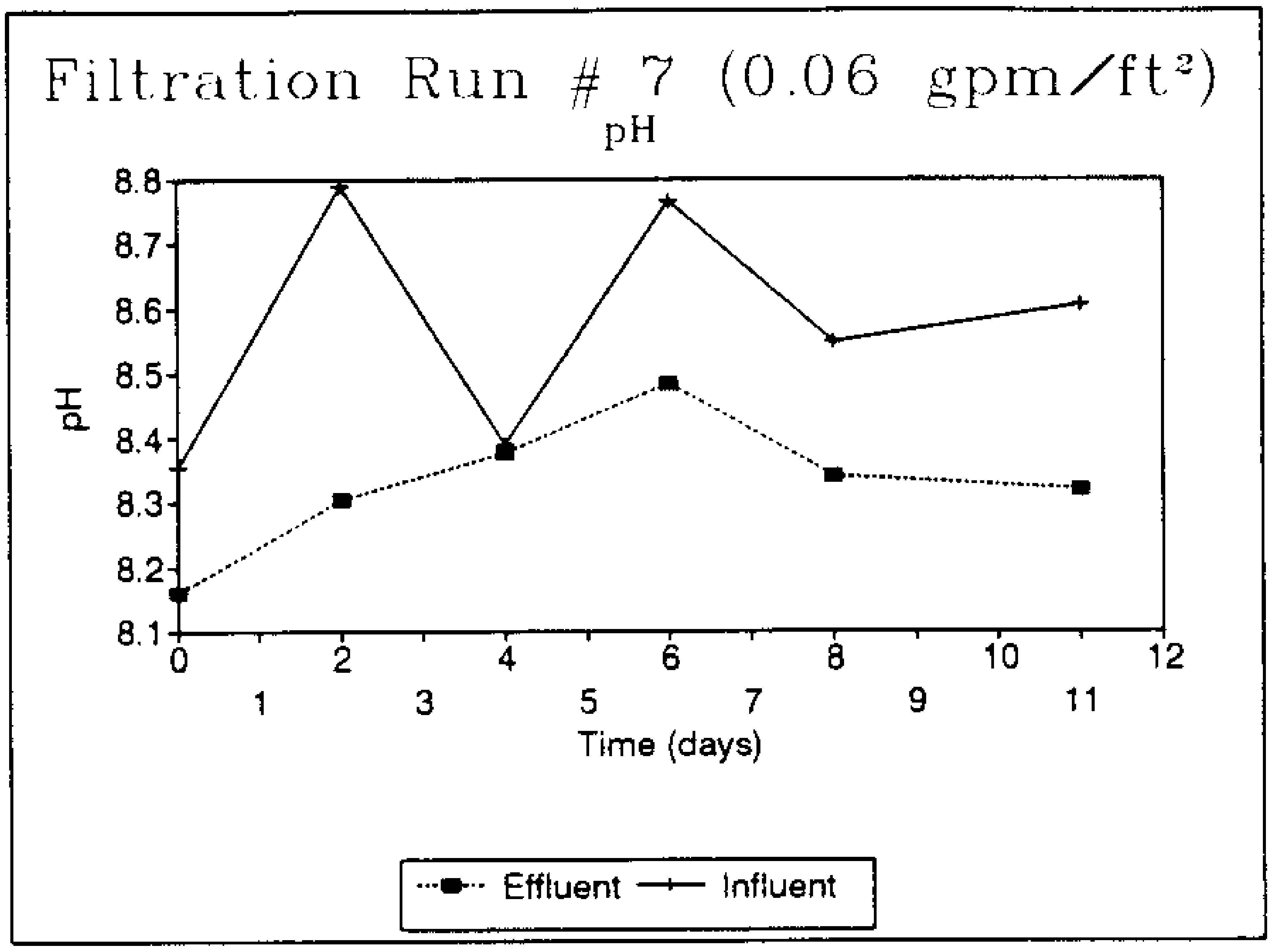

FIG. G-9.- pH for Filtration Run 7

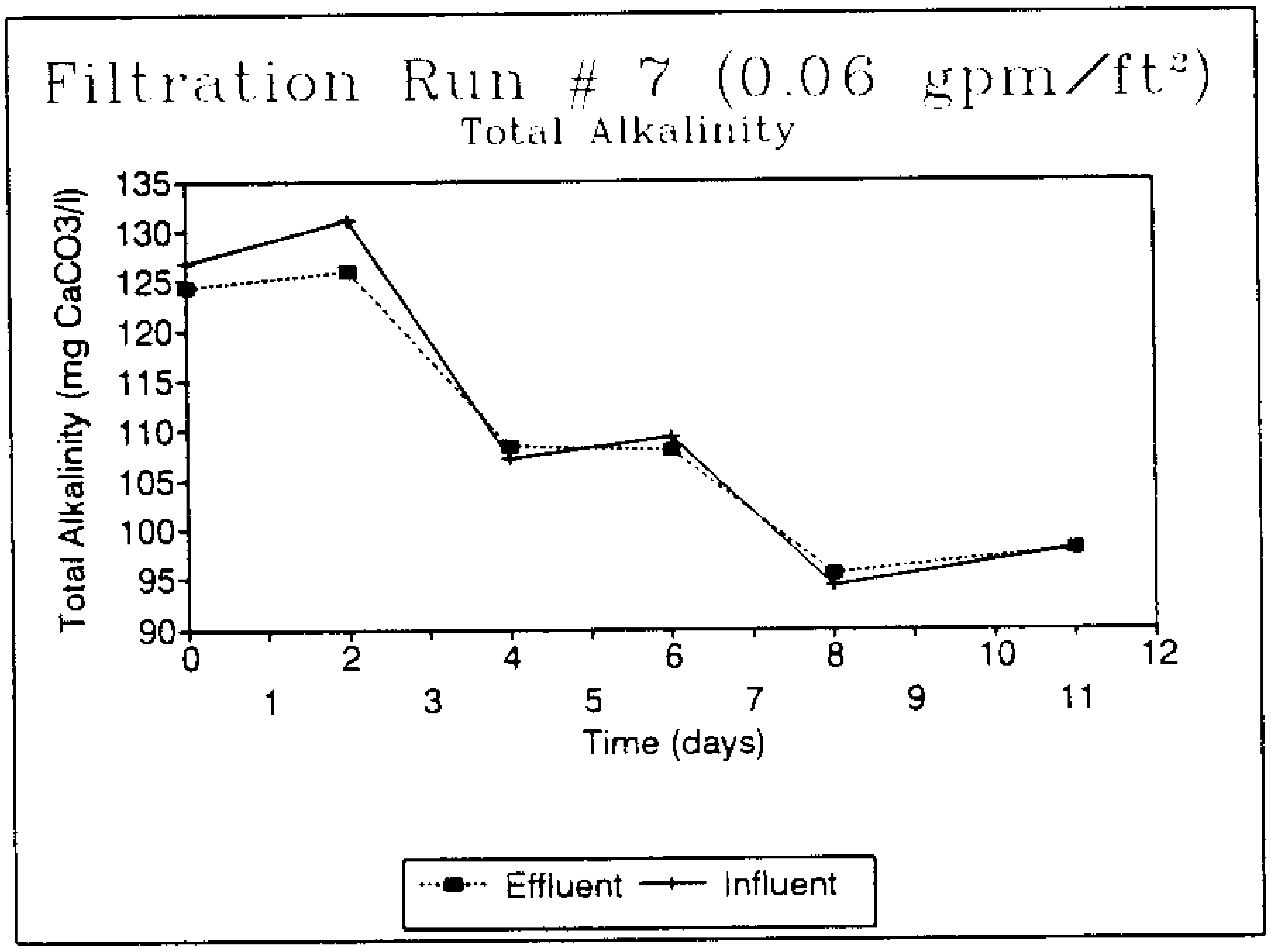

FIG. G-10.- Total Alkalinity for Filtration Run 7

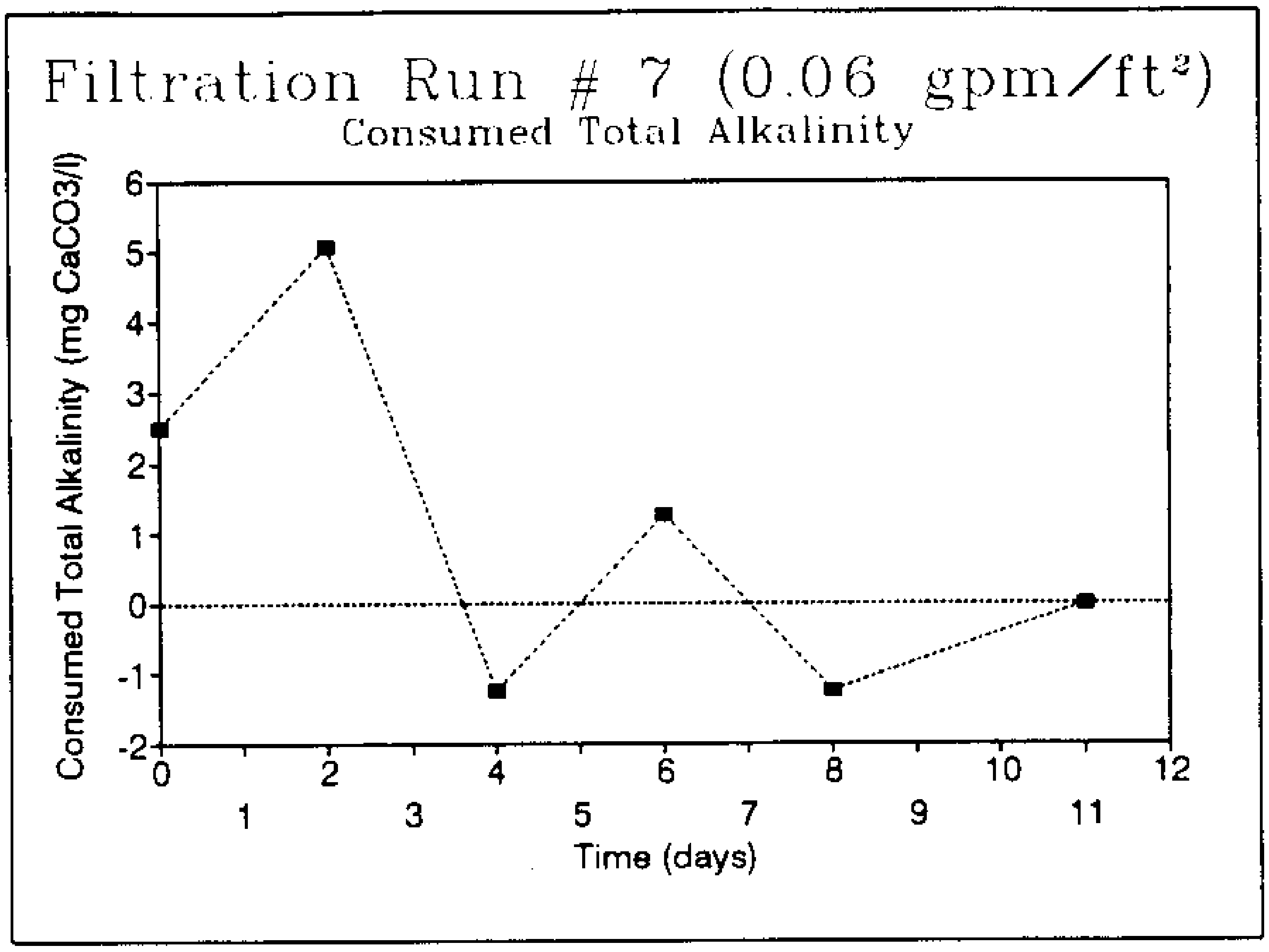

FIG. G-11.- Consumed Total Alkalinity for Filtration Run 7

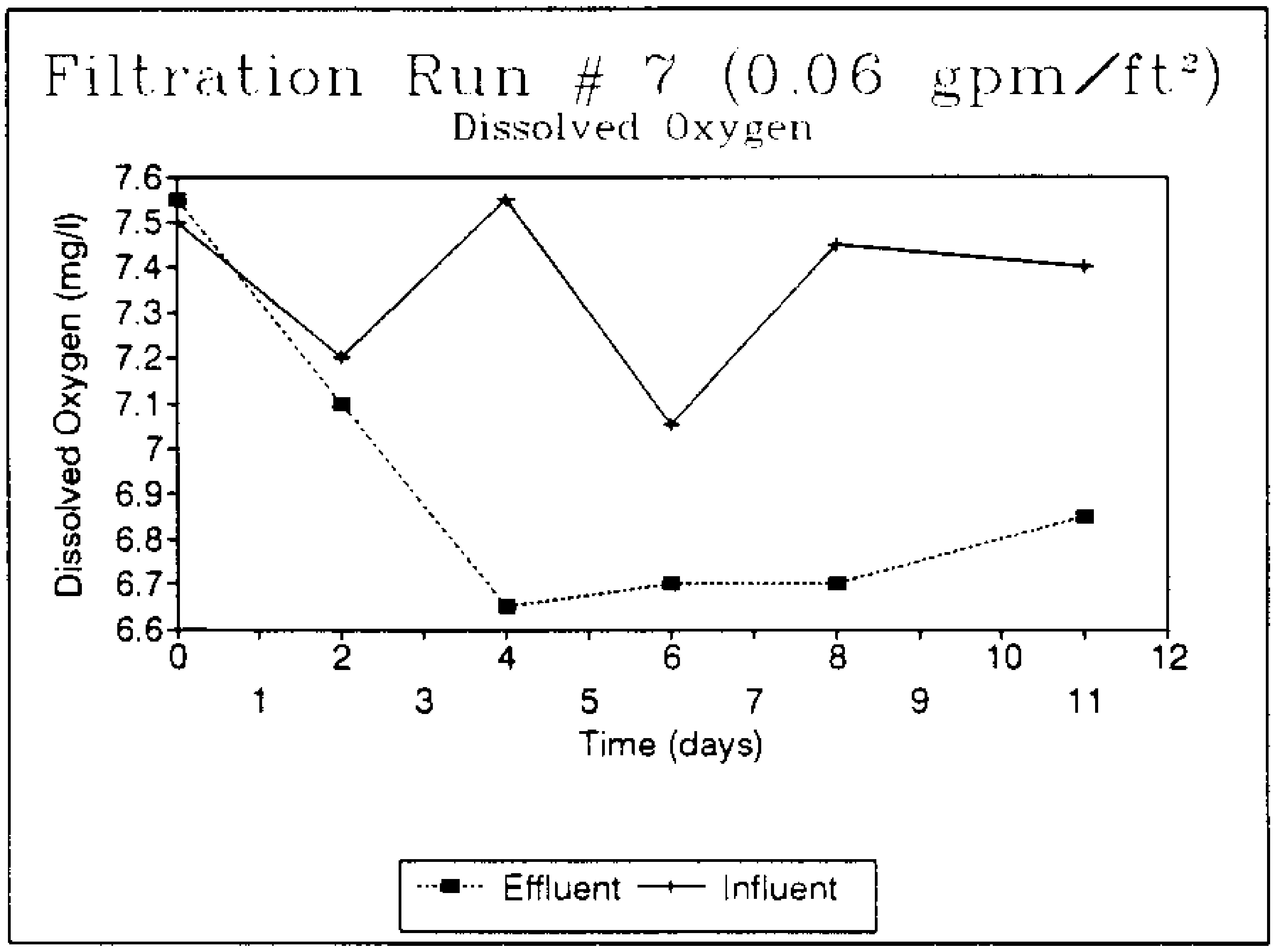

FIG. G-12.- Dissolved Oxygen for Filtration Run 7

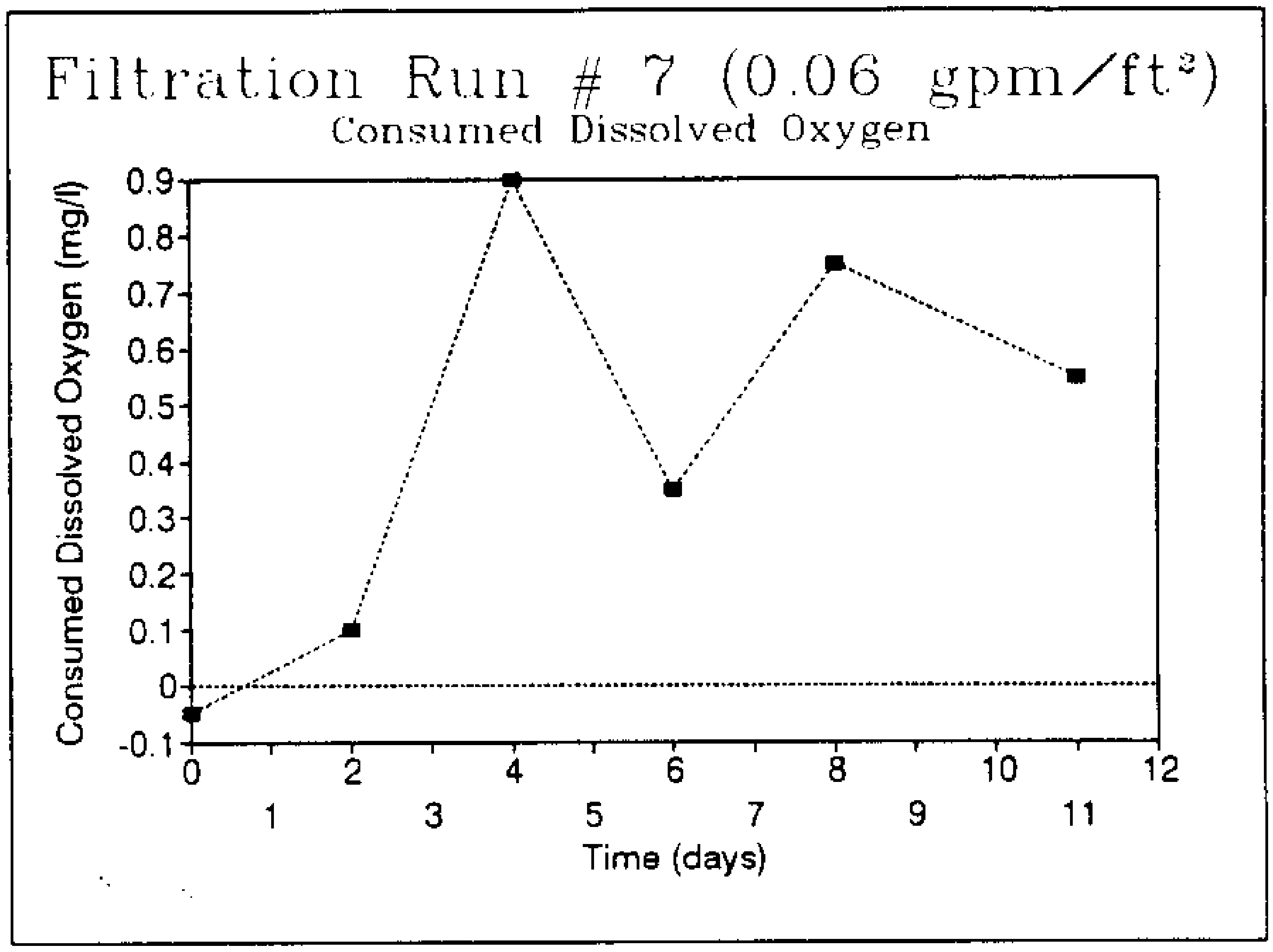

FIG. G-13.- Consumed Dissolved Oxygen for Filtration Run 7

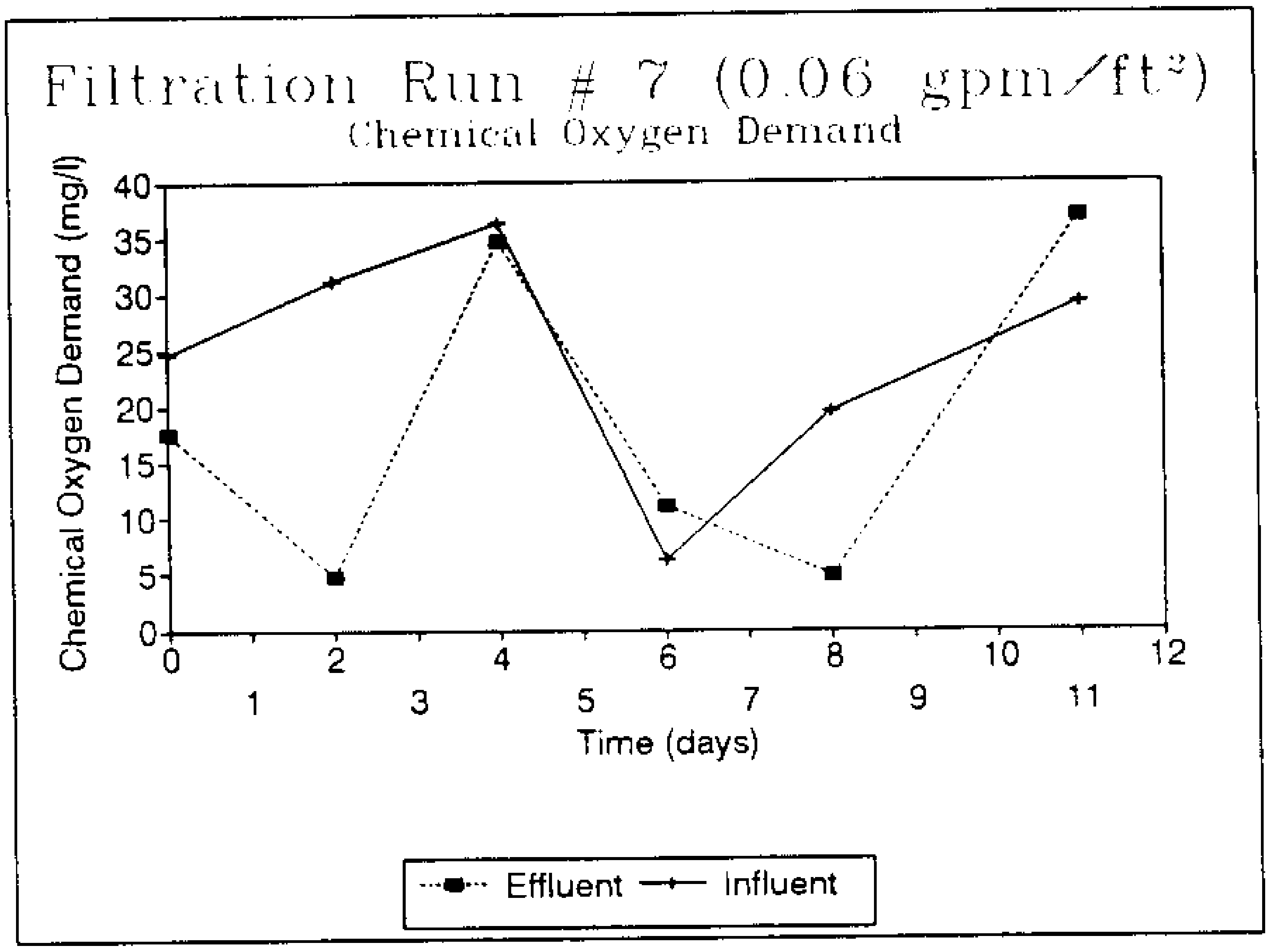

FIG. G-14.- Chemical Oxygen Demand (COD) for Filtration Run 7

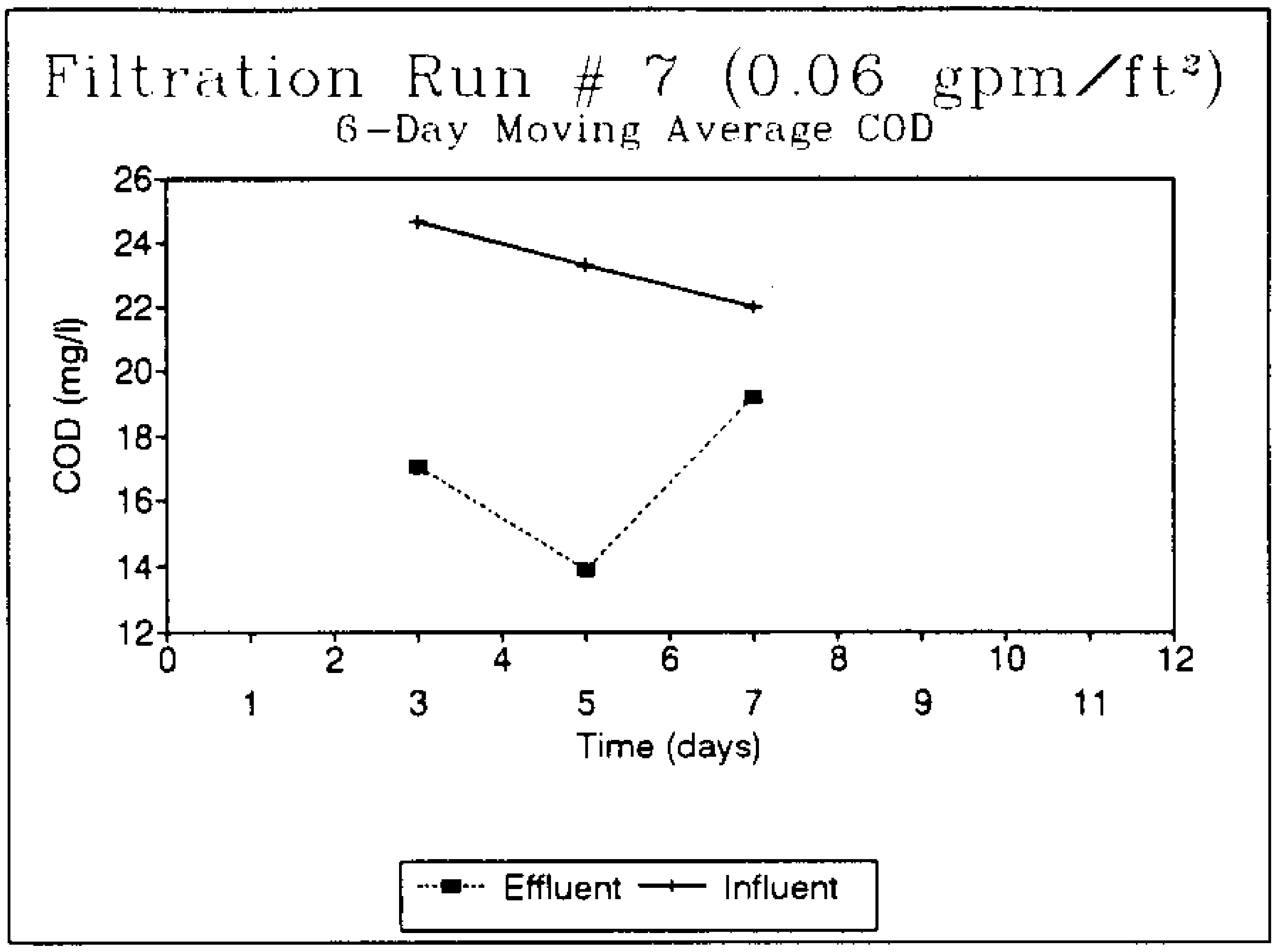

FIG. G-15.- 6-Day Moving Average COD for Filtration Run 7

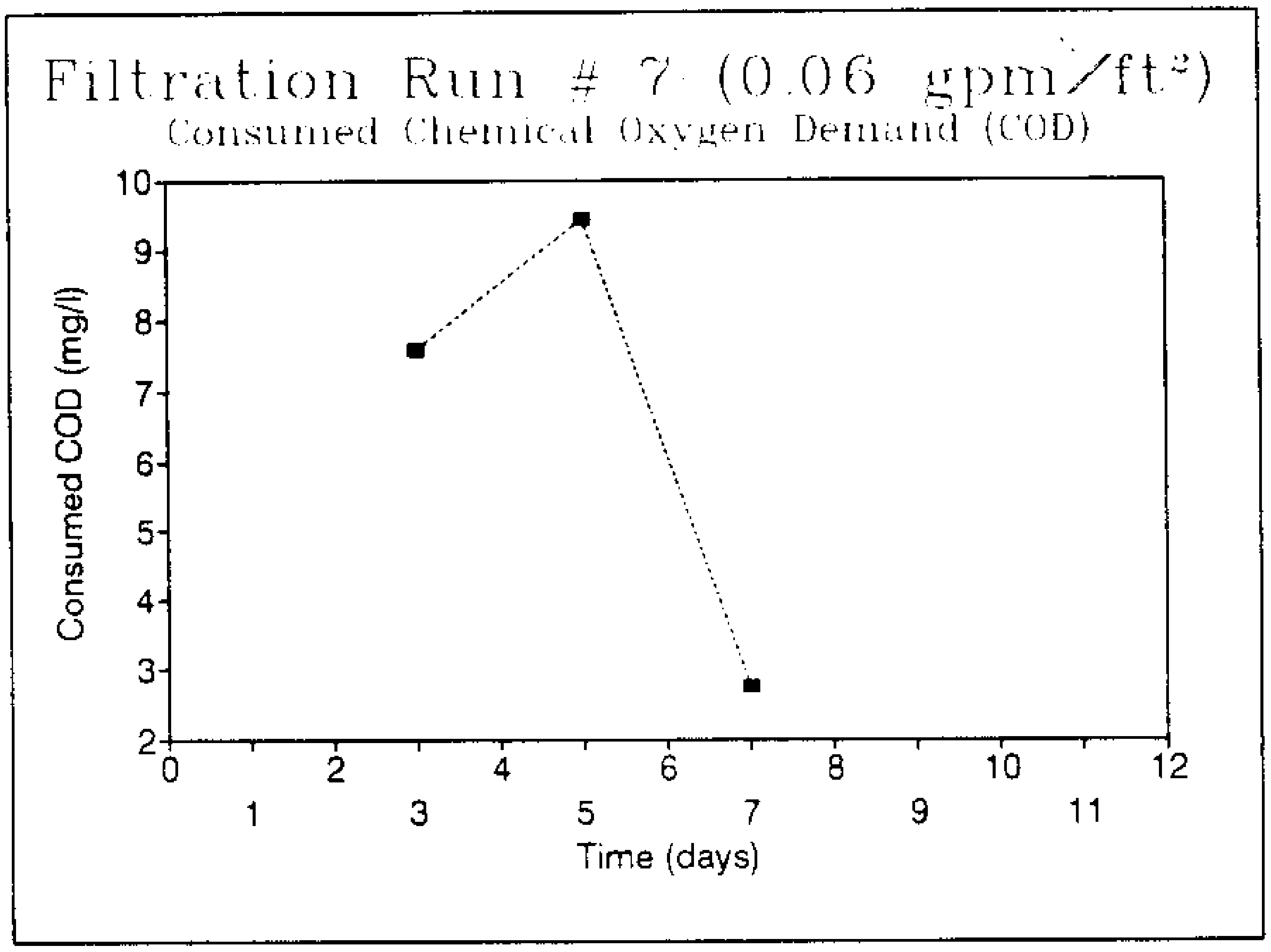

FIG. G-16.- Consumed COD for Filtration Run 7

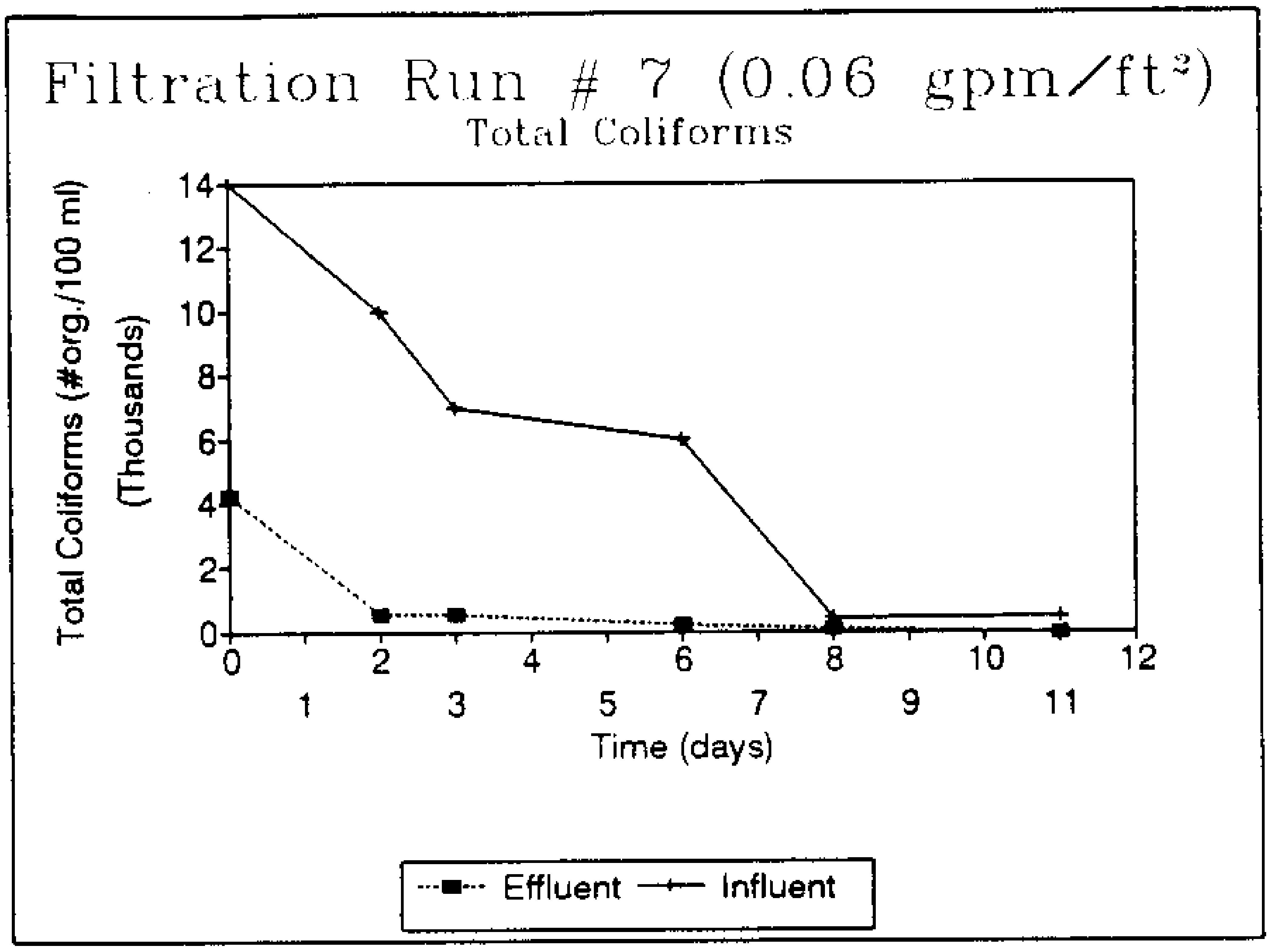

FIG. G-17.- Total Coliforms for Filtration Run 7

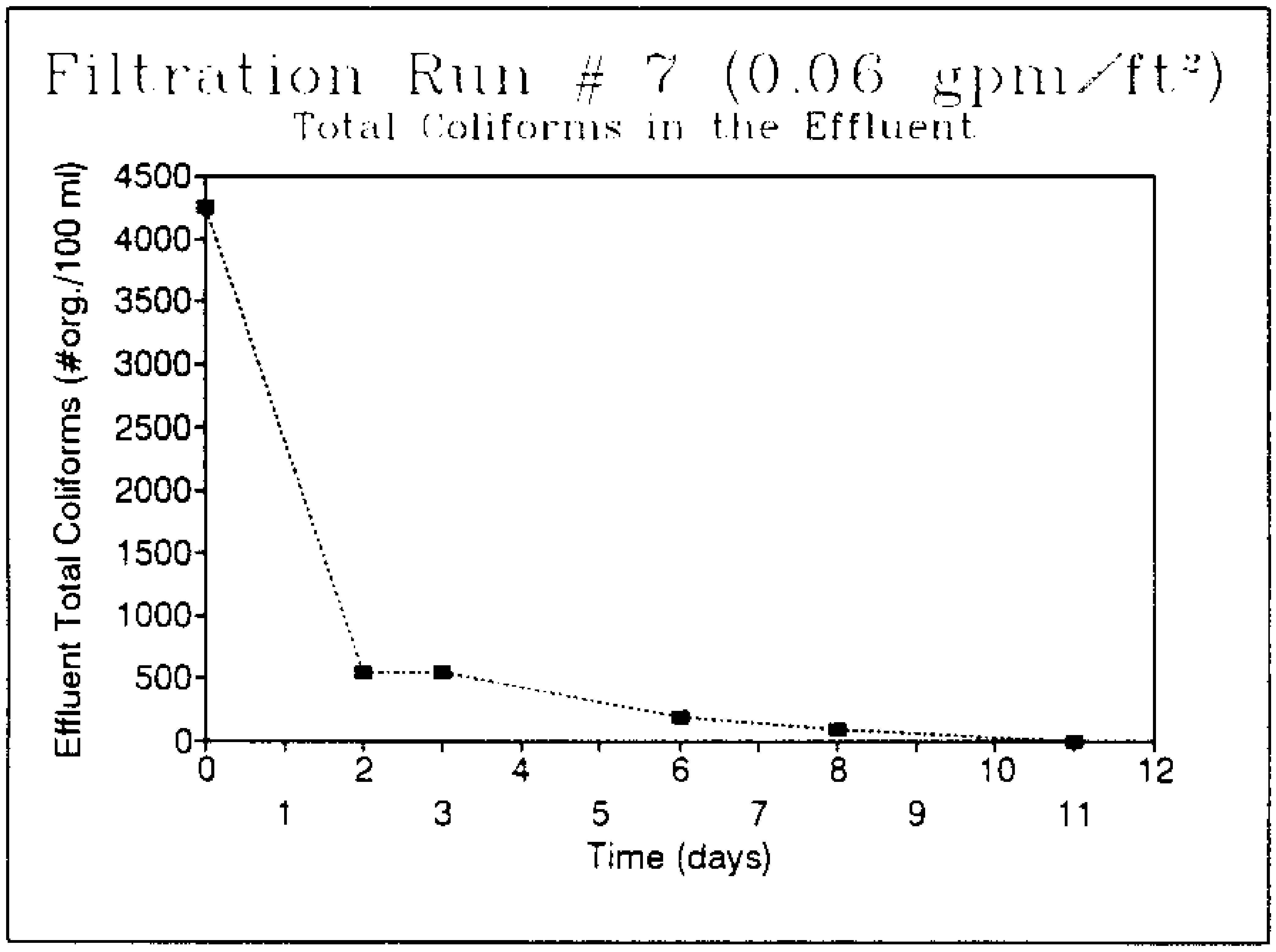

FIG. G-18.- Effluent Total Coliforms for Filtration Run 7

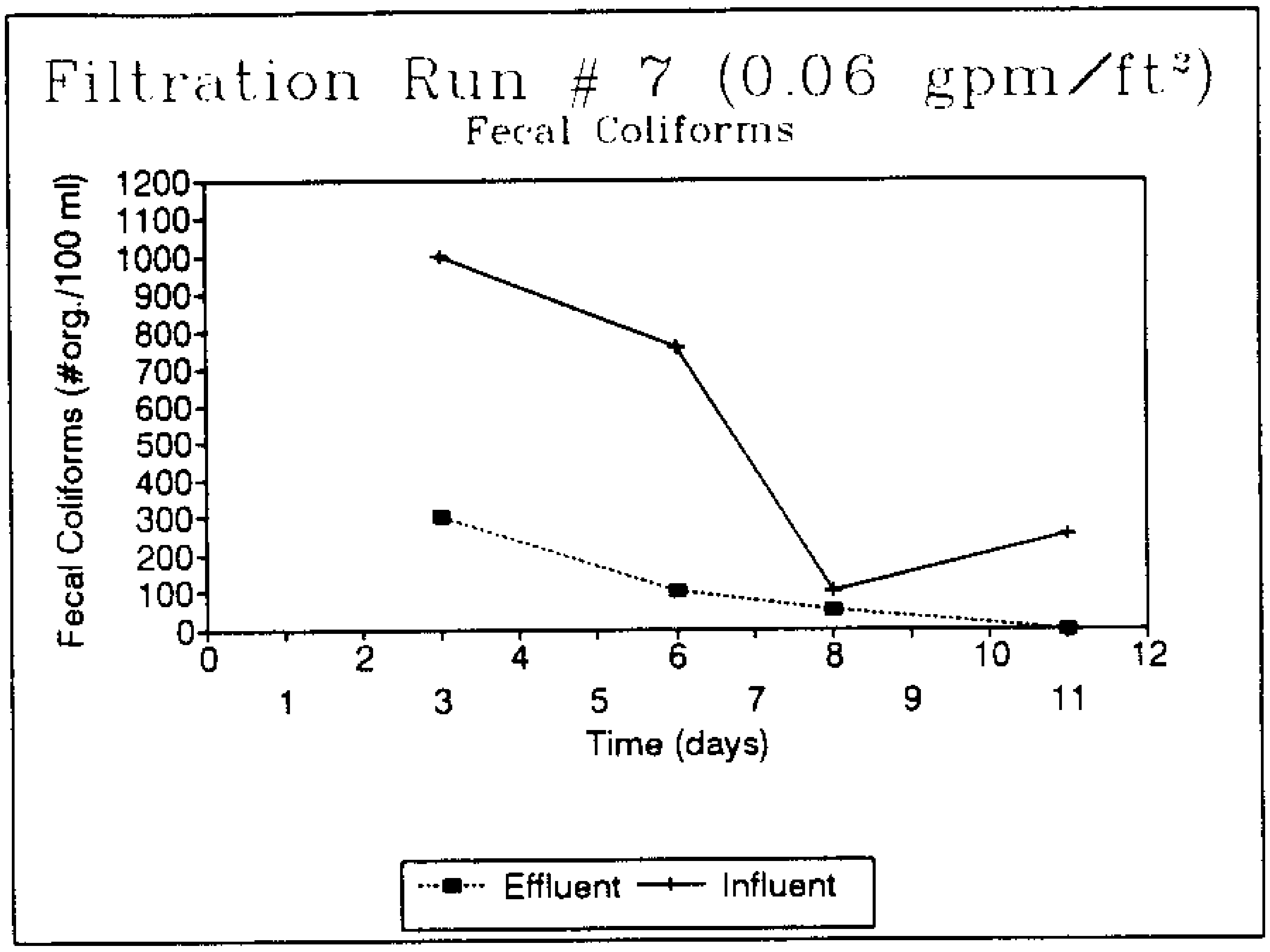

FIG. G-19.- Fecal Coliforms for Filtration Run 7

Table G-1.- Biochemical Oxygen Demand: Day # 0 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.00	7.85	8.15	7.95	1	0.0010	-50
0.5%	7.95	7.85	8.15	7.95	1	0.0050	-20
1%	7.93	7.73	8.15	7.95	1	0.0100	0
5%	7.90	7.78	8.15	7.95	1	0.0500	-1.5
Glucose	8.08	4.35	8.15	7.95	1	0.0200	176.25

Table G-2.- Biochemical Oxygen Demand: Day # 0 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	7.85	7.83	8.15	7.95	1	0.0010	-175
0.5%	7.85	7.65	8.15	7.95	1	0.0050	0
1%	7.80	7.35	8.15	7.95	1	0.0100	25
5%	7.80	7.65	8.15	7.95	1	0.0500	-1
Glucose	8.08	4.35	8.15	7.95	1	0.0200	176.25

Table G-3.- Biochemical Oxygen Demand: Day # 8 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.38	7.83	8.30	7.85	1	0.0010	100
0.5%	8.35	7.75	8.30	7.85	1	0.0050	30
1%	8.35	7.88	8.30	7.85	1	0.0100	2.5
5%	8.35	7.88	8.30	7.85	1	0.0500	0.5
Glucose	8.35	3.98	8.30	7.85	1	0.0200	196.25

Table G-4.- Biochemical Oxygen Demand: Day # 8 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.35	7.93	8.30	7.85	1	0.0010	-25
0.5%	8.35	7.95	8.30	7.85	1	0.0050	-10
1%	8.35	7.93	8.30	7.85	1	0.0100	-2.5
5%	8.35	7.90	8.30	7.85	1	0.0500	0
Glucose	8.35	3.98	8.30	7.85	1	0.0200	196.25

Table G-5.- Biochemical Oxygen Demand: Day # 11 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.35	7.75	8.33	7.73	1	0.0010	0
0.5%	8.35	7.85	8.33	7.73	1	0.0050	-20
1%	8.33	7.63	8.33	7.73	1	0.0100	10
5%	8.35	7.48	8.33	7.73	1	0.0500	5.5
Glucose	8.35	3.63	8.33	7.73	1	0.0200	206.25

Table G-6.- Biochemical Oxygen Demand: Day # 11 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.35	7.88	8.33	7.73	1	0.0010	-125
0.5%	8.35	8.00	8.33	7.73	1	0.0050	-50
1%	8.33	7.80	8.33	7.73	1	0.0100	-7.5
5%	8.30	7.80	8.33	7.73	1	0.0500	-2
Glucose	8.35	3.63	8.33	7.73	1	0.0200	206.25

Table G-7.- Schmutzdecke Biochemical Oxygen Demand

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.30	7.80	8.33	7.73	1	0.0010	-100
0.5%	8.30	7.60	8.33	7.73	1	0.0050	20
1%	8.30	7.45	8.33	7.73	1	0.0100	25
5%	8.20	5.83	8.33	7.73	1	0.0500	35.5
Glucose	8.35	3.63	8.33	7.73	1	0.0200	206.25

Table G-8.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.32	4.32	-	
S.A.+P.D.	4.32	8.69	4.37	-	
S.A.+P.D.	0.00	4.36	4.36	-	-
Blank	4.36	8.66	4.30	-	
Blank	0.00	4.36	4.36	-	
Blank	4.36	8.73	4.37	-	-
Standard	0.00	3.35	3.35	456.70	
Standard	3.35	6.54	3.19	530.27	493.49
Sch.1/100	0.00	4.28	4.28	2911.88	
Sch.1/100	4.28	8.50	4.22	5670.50	
Sch.1/10	0.00	4.06	4.06	1302.68	
Sch.1/10	4.06	8.10	4.04	1394.64	2819.92

Table G-9.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	96.50	64.66		
2	94.50	63.32	95.50	63.99

Table G-10.- Schmutzdecke pH

Sample	pH	Average pH
1	8.43	
2	8.45	8.44

Table G-11.- Schmutzdecke Turbidity

Sample	Turbidity (NTU)	Average Turbidity (NTU)
1	22000	
2	21000	21500

Table G-12.- Schmutzdecke Alkalinity

A = 2.5022
B = 40.00
C = 18.55

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	33.95	42.25	8.30	0.10180339	211.24	
2	35.00	43.15	8.15	0.10180339	207.42	209.33

Table G-13.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	10101.01	20202.02
2	10000.00	30000.00
Average	10050.51	25101.01

Table G-14.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
148	15.48862	5	15.62772	27820		15.61068	3408	
5	14.50155	5	14.63807	27304	27562	14.62067	3480	3444

Table G-15.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
6E	37.65219	20	38.17596	26188.50		38.11811	2892.50		23296.00	
26	36.96170	20	37.49329	26579.50	26384	37.42715	3307.00	3099.75	23272.50	23284.25

Appendix H: Illustrations for Filtration Run 8

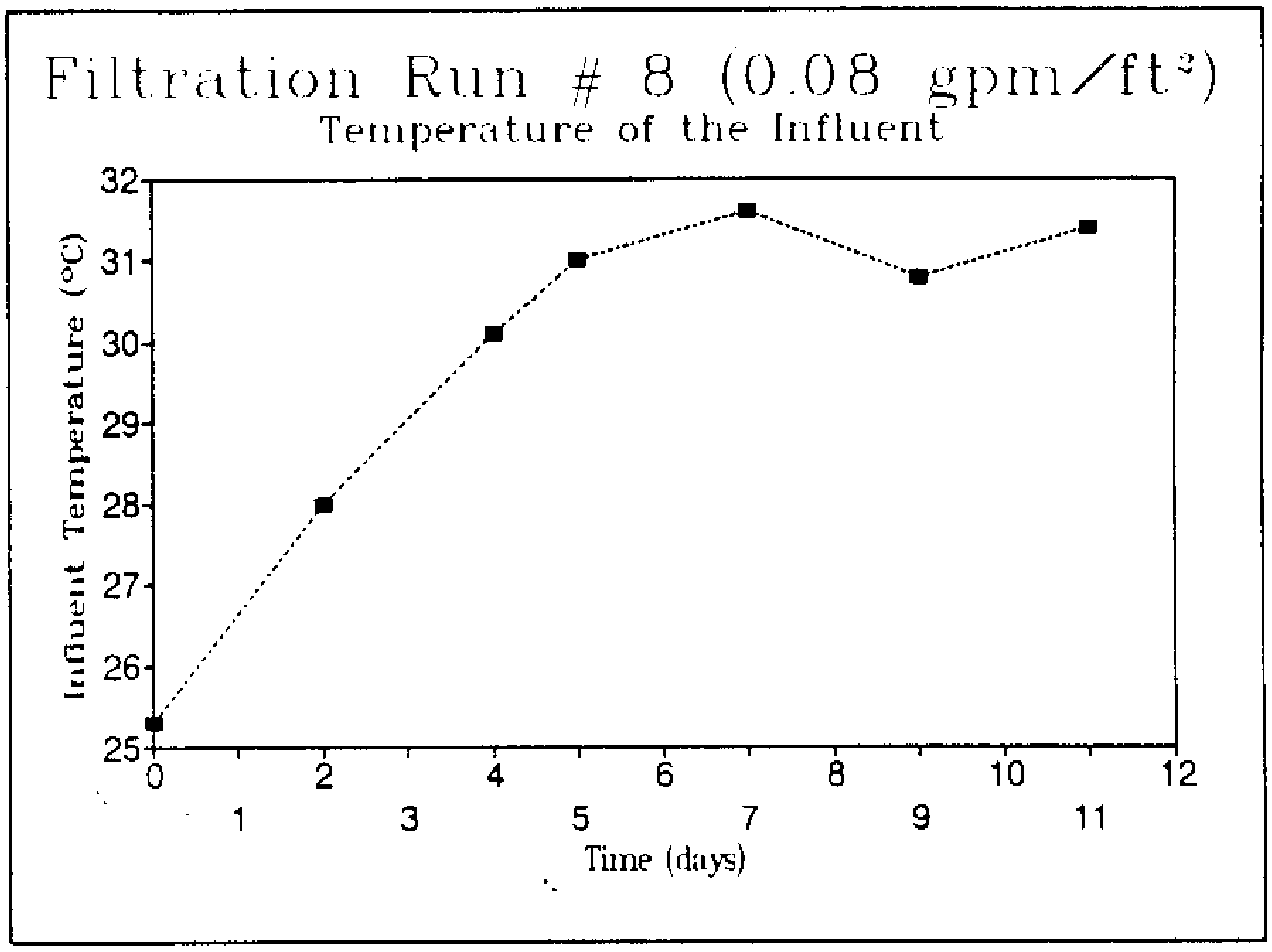

FIG. H-1.- Influent Temperature for Filtration Run 8

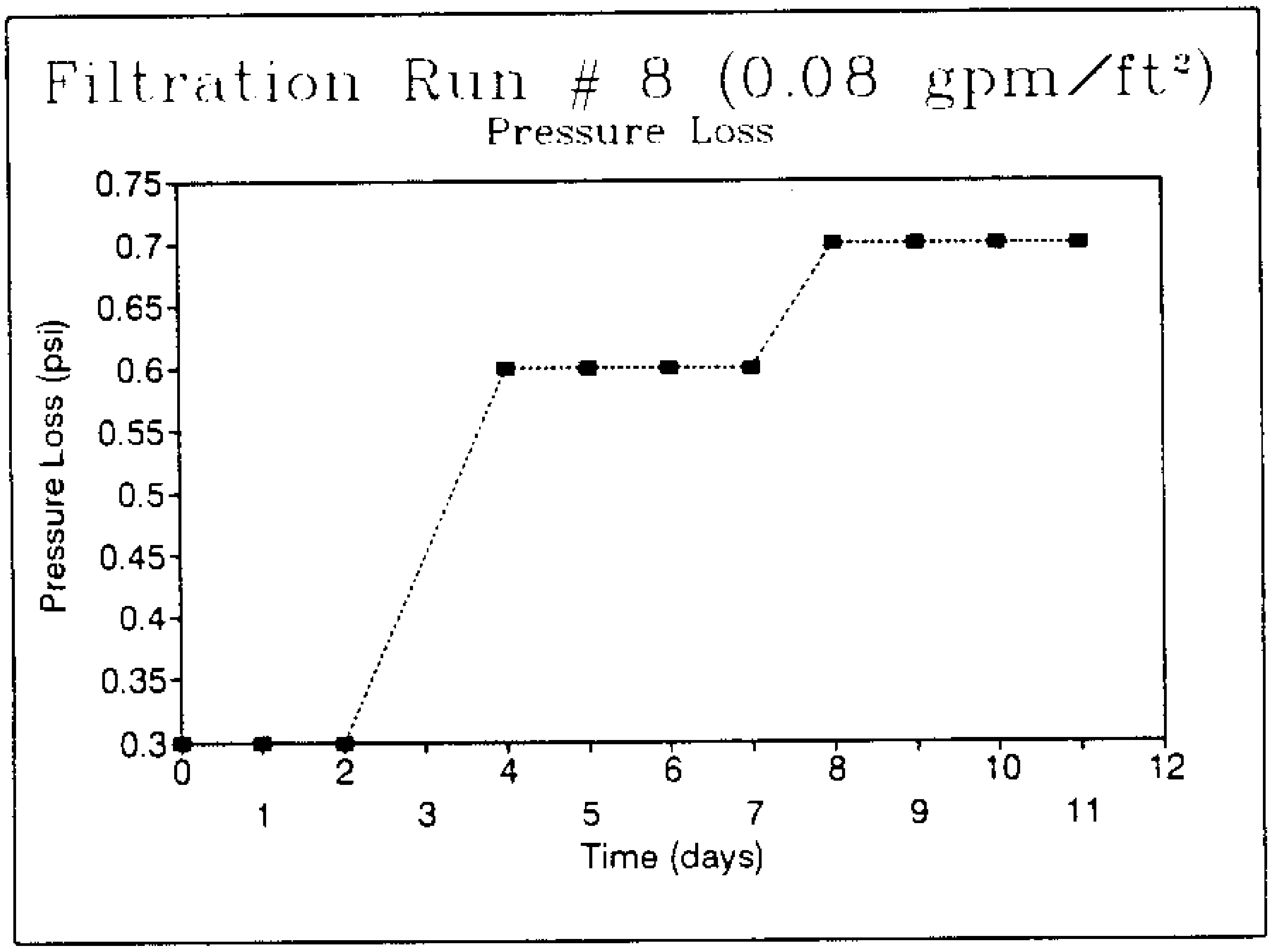

FIG. H-2.- Pressure Loss for Filtration Run 8

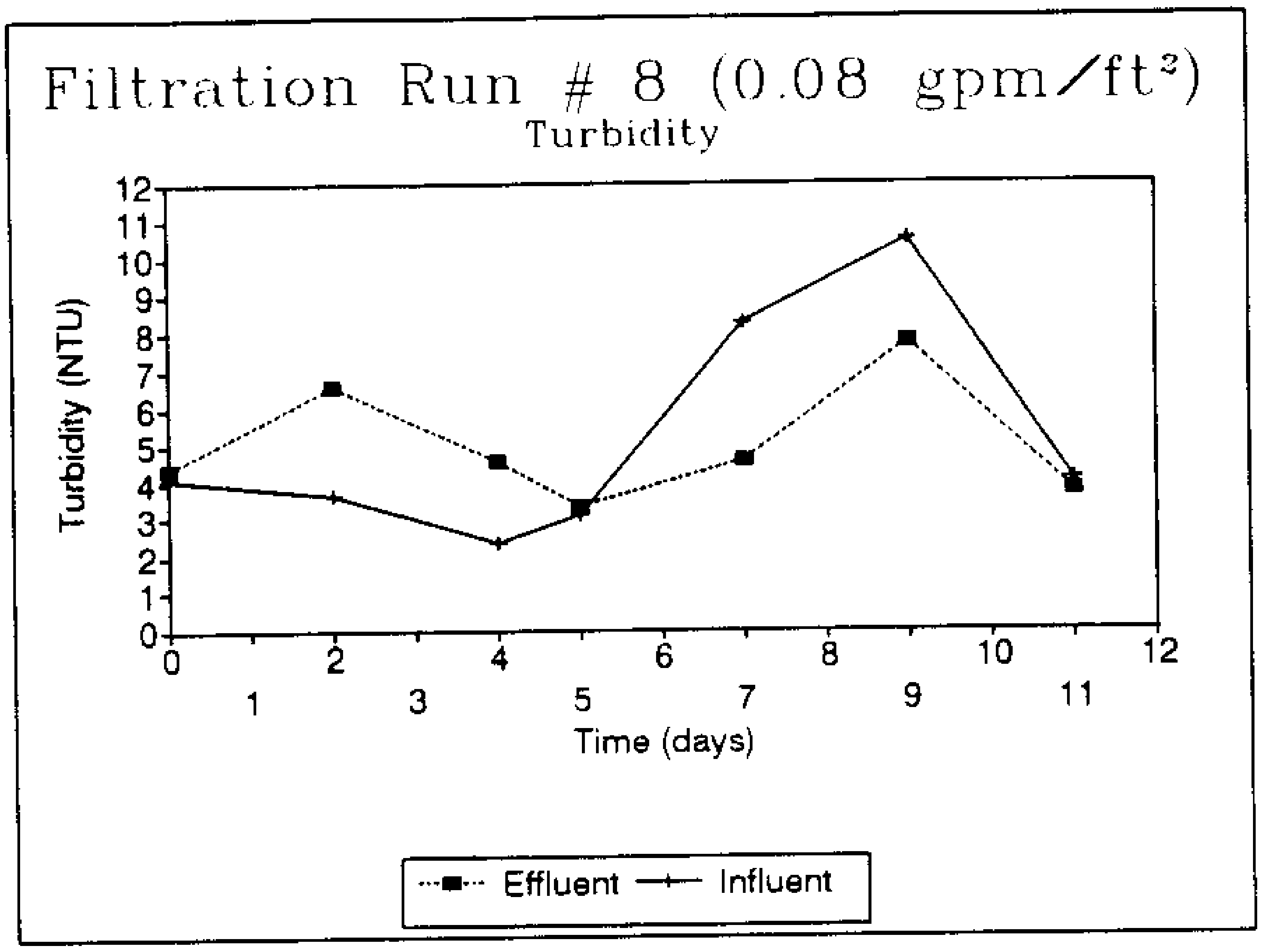

FIG. H-3.- Turbidity for Filtration Run 8

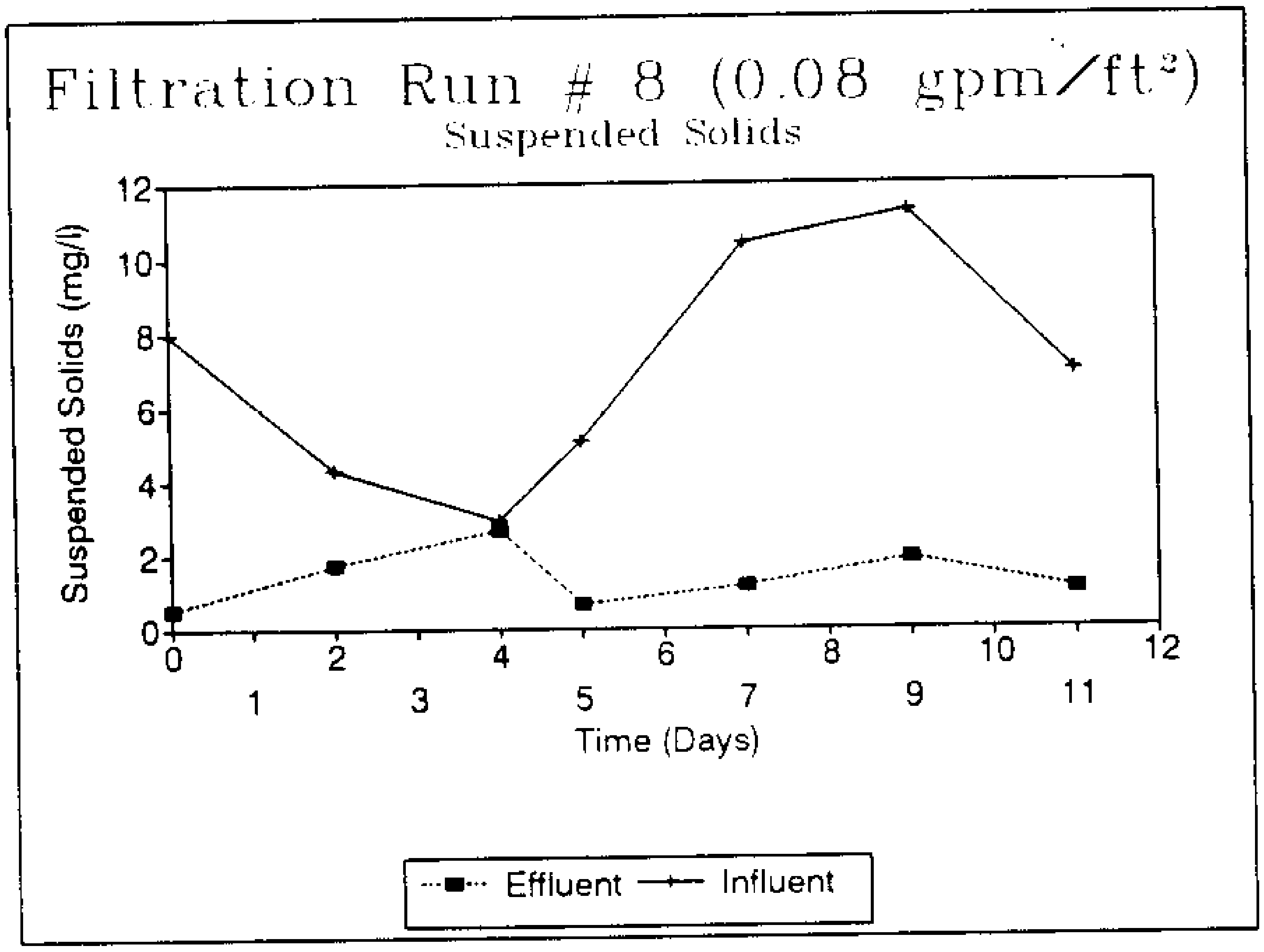

FIG. H-4.- Suspended Solids for Filtration Run 8

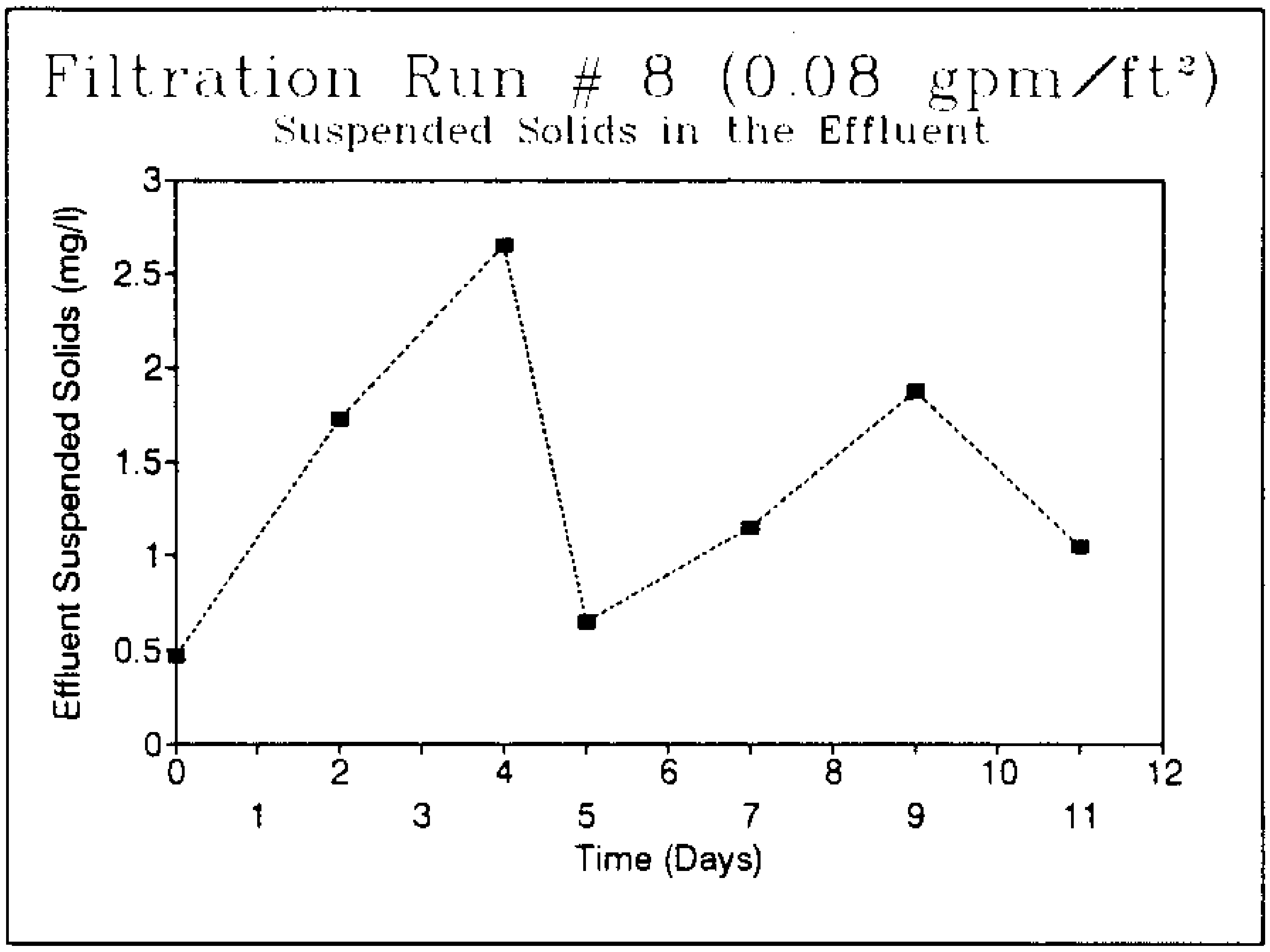

FIG. H-5.- Effluent Suspended Solids for Filtration Run 8

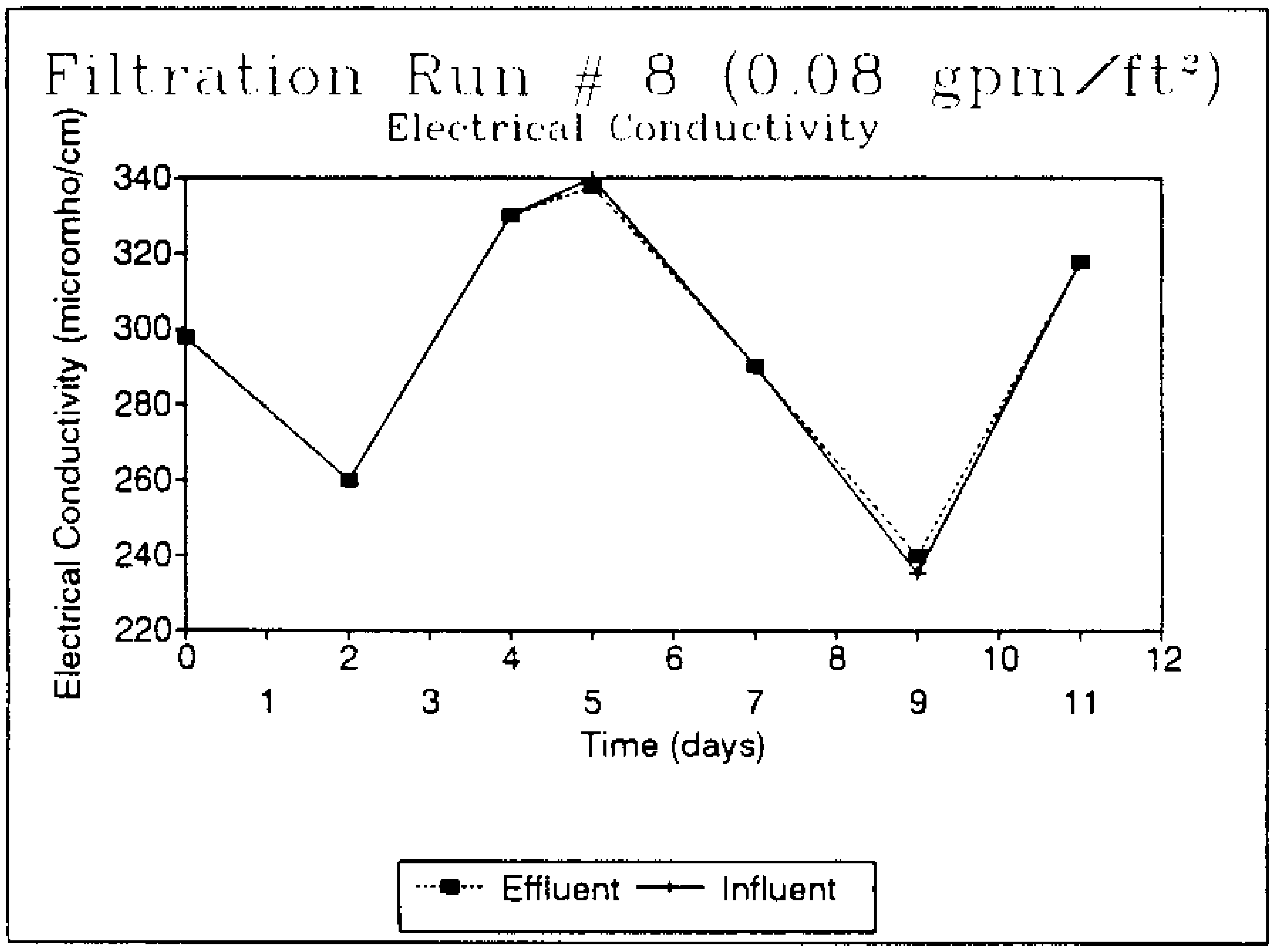

FIG. H-6.- Electrical Conductivity for Filtration Run 8

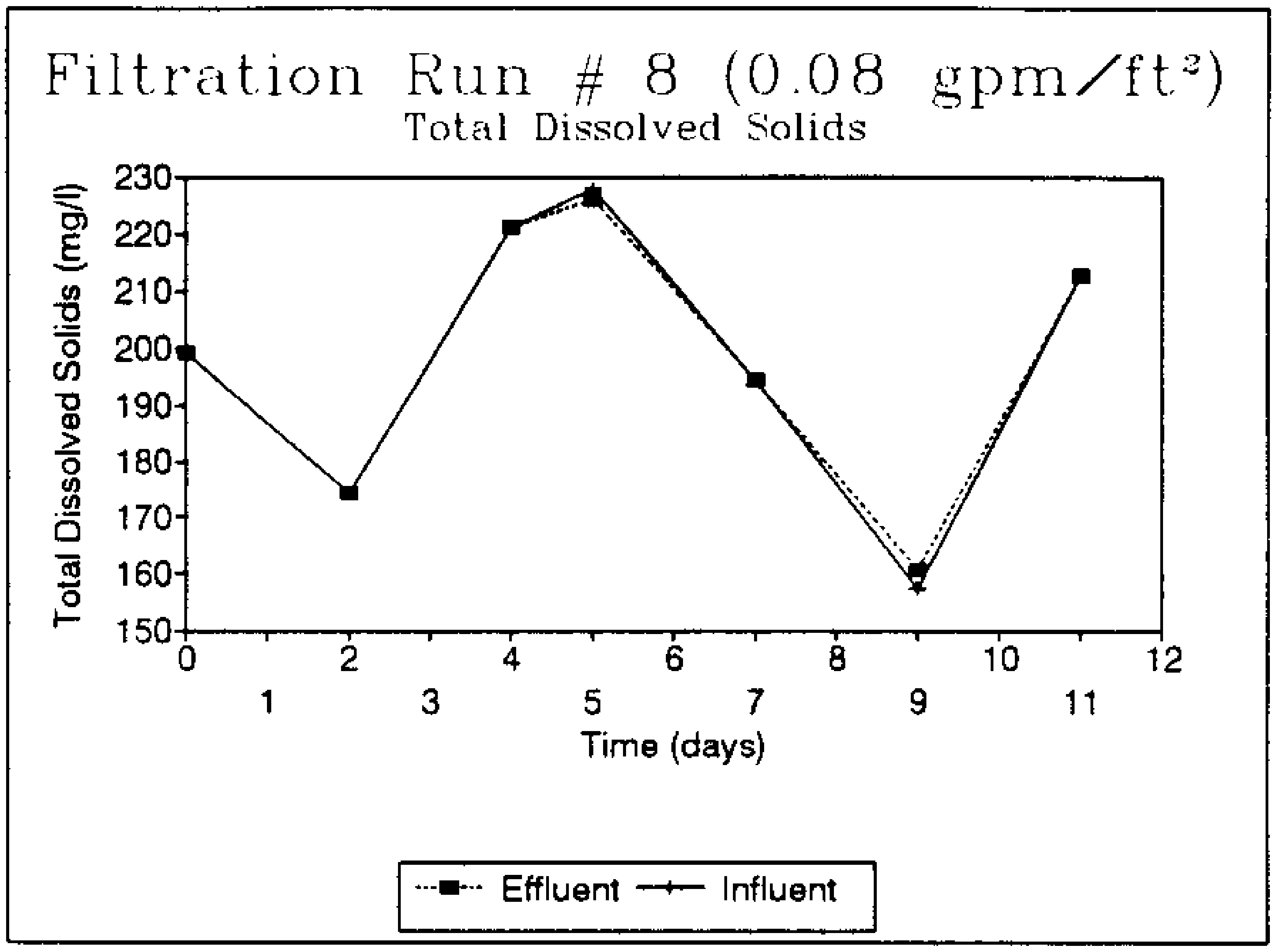

FIG. H-7.- Total Dissolved Solids for Filtration Run 8

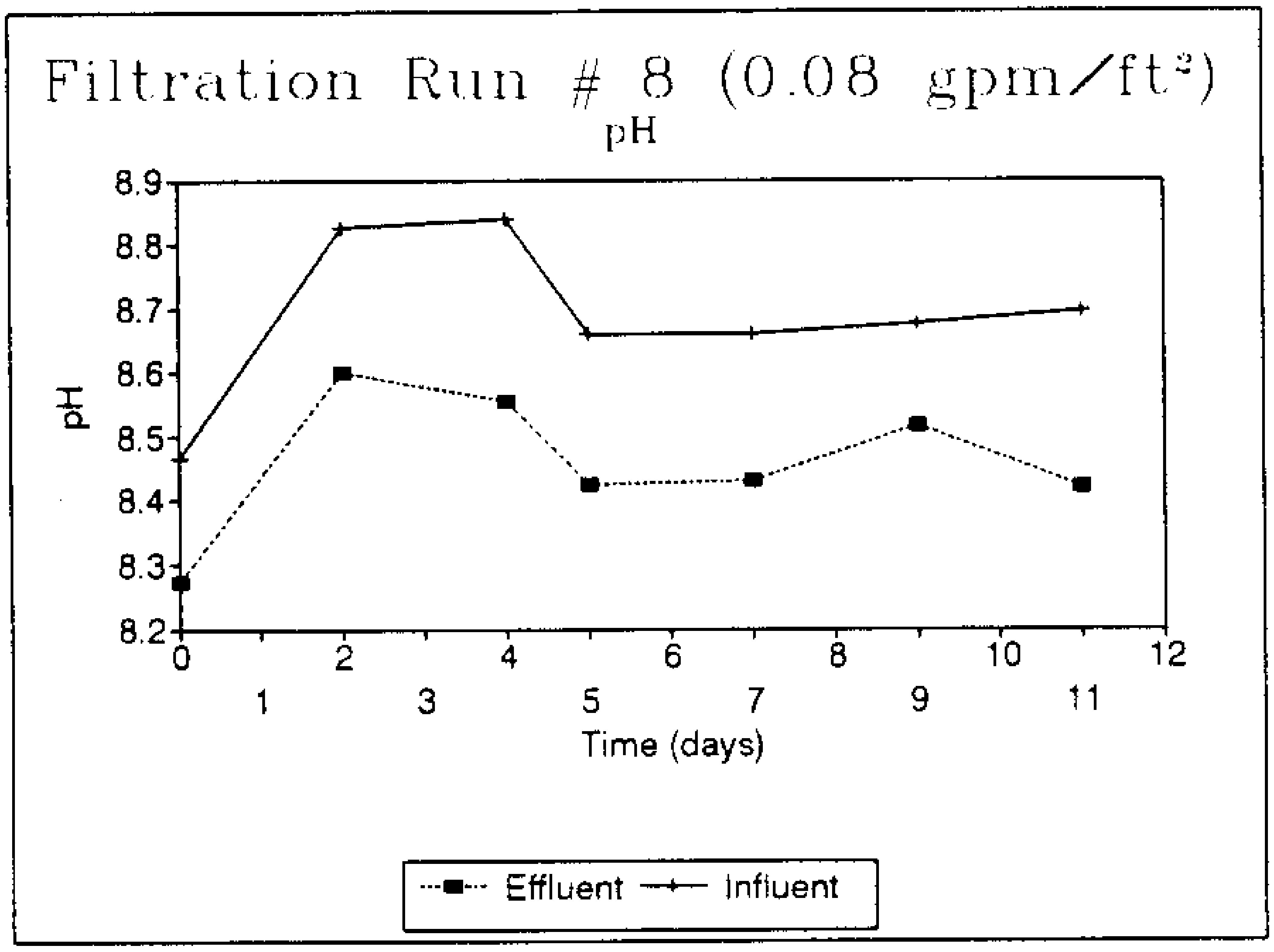

FIG. H-8.- pH for Filtration Run 8

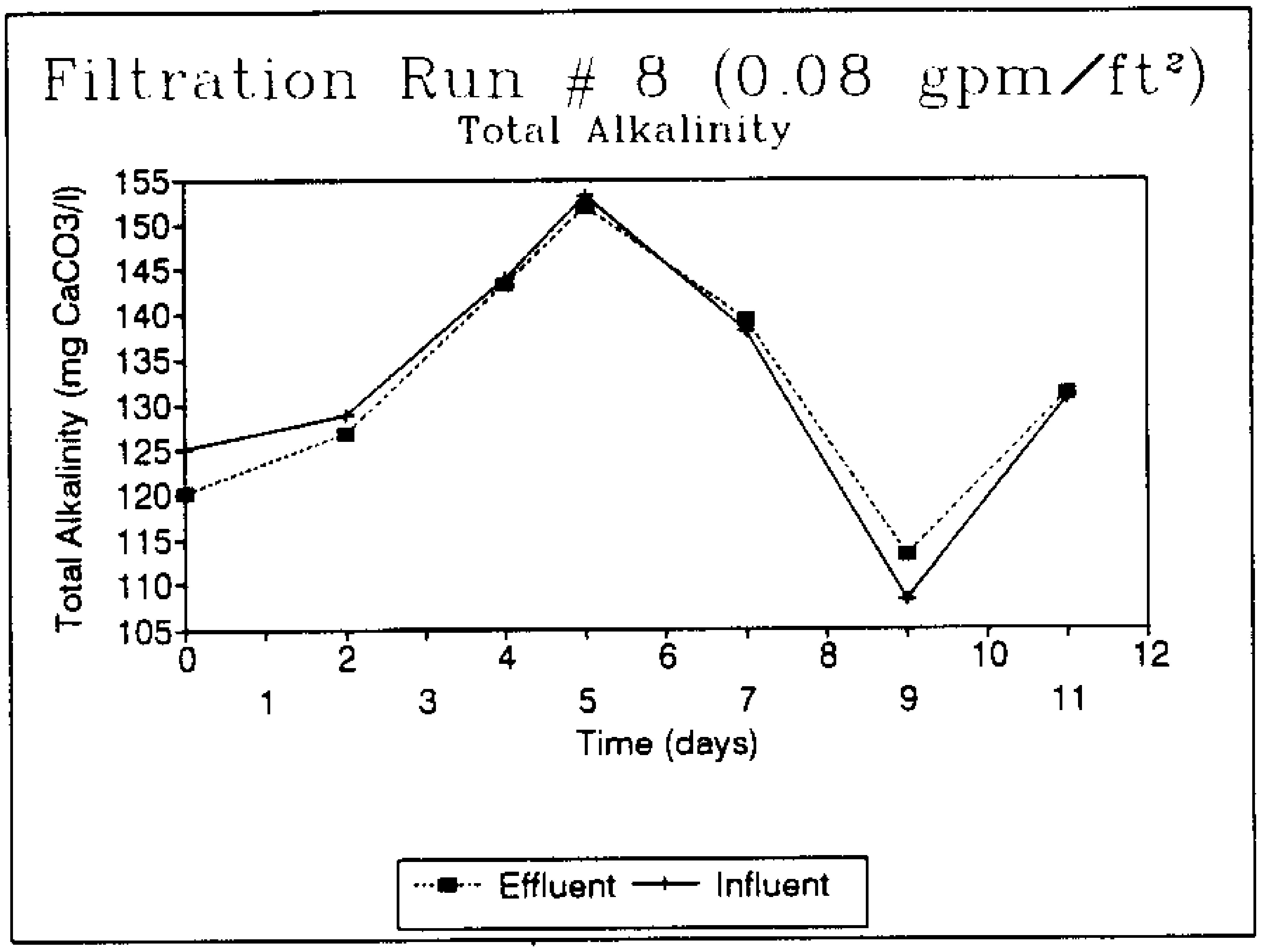

FIG. H-9.- Total Alkalinity for Filtration Run 8

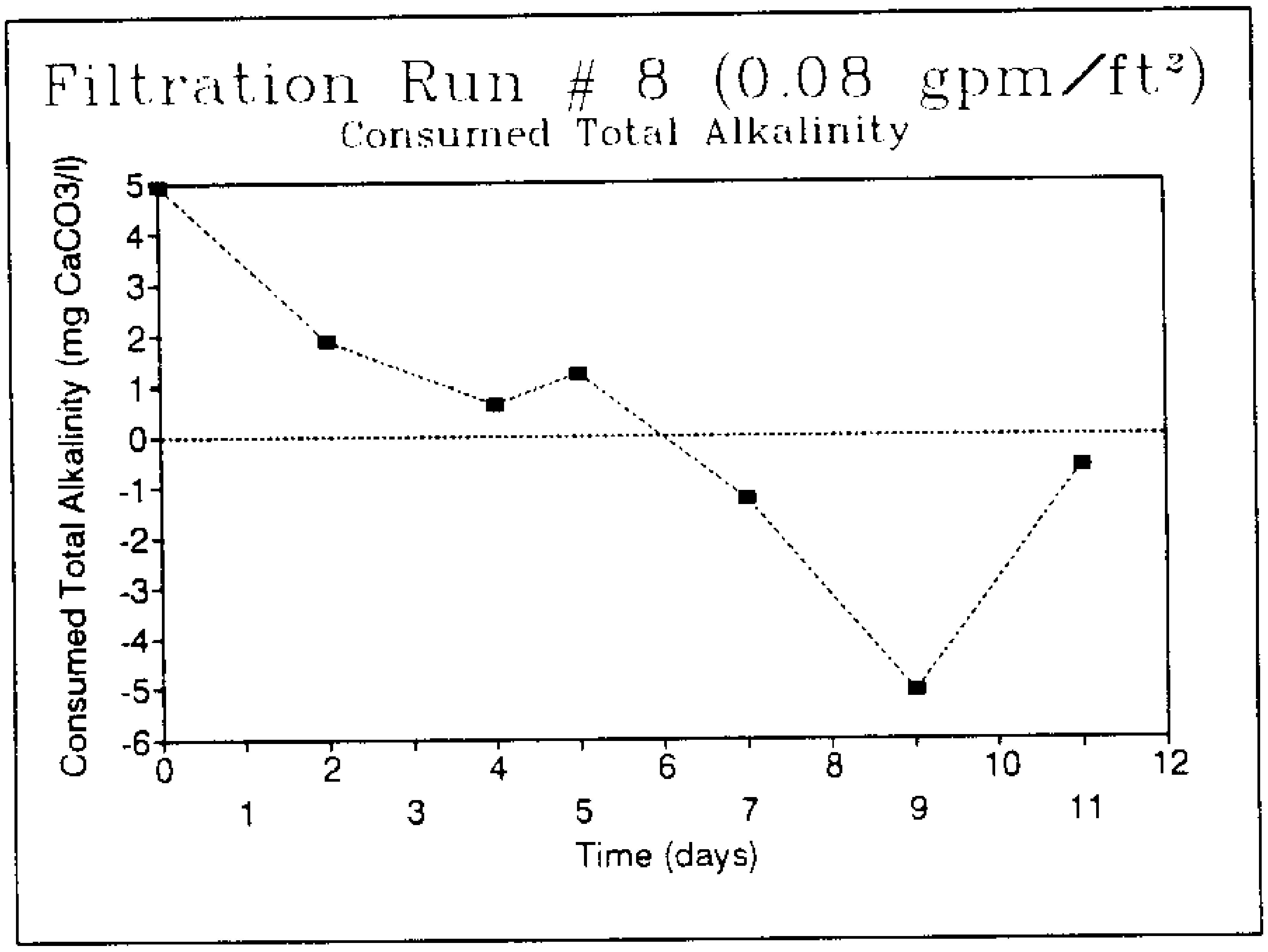

FIG. H-10.- Consumed Total Alkalinity for Filtration Run 8

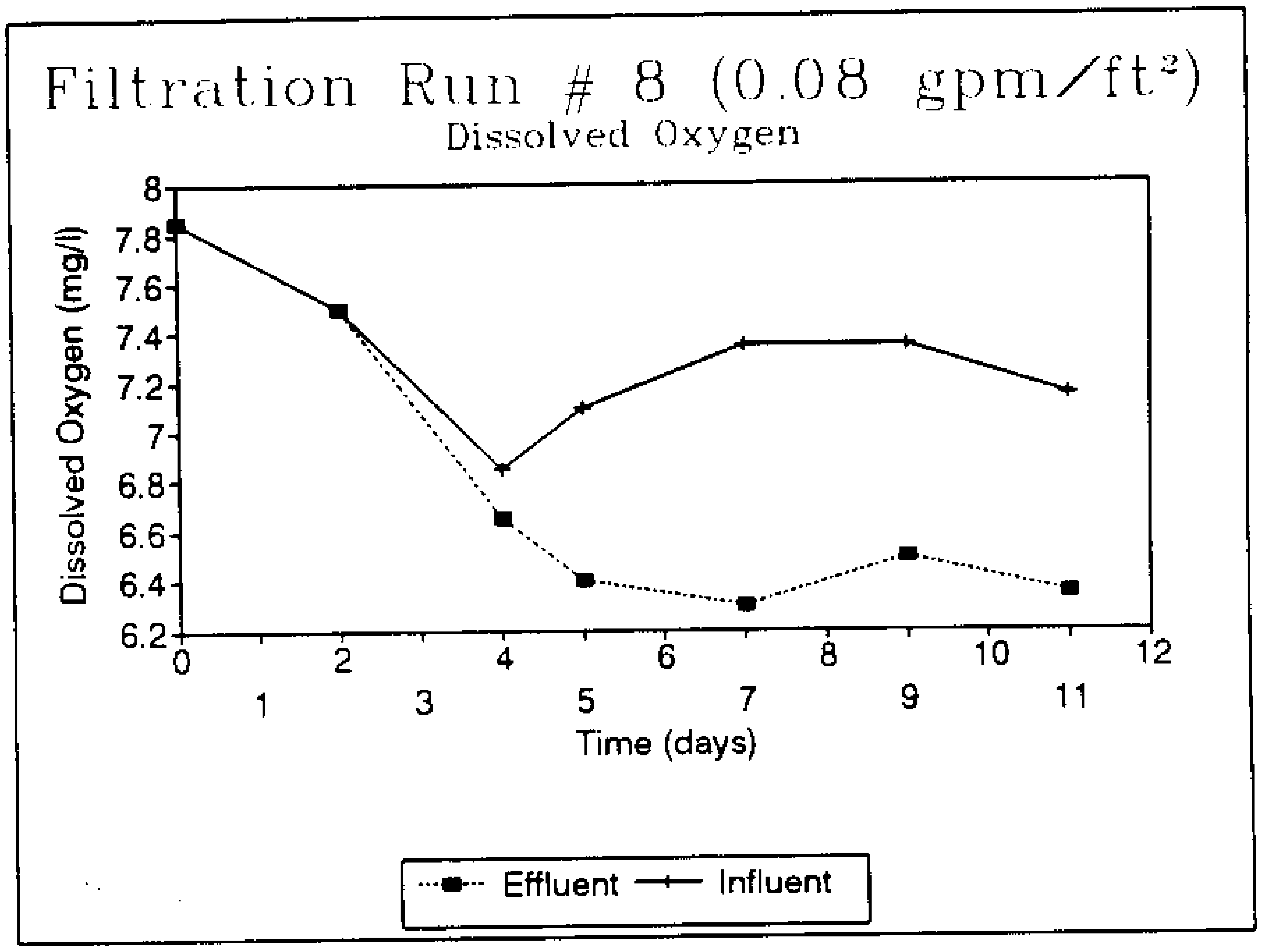

FIG. H-11.- Dissolved Oxygen for Filtration Run 8

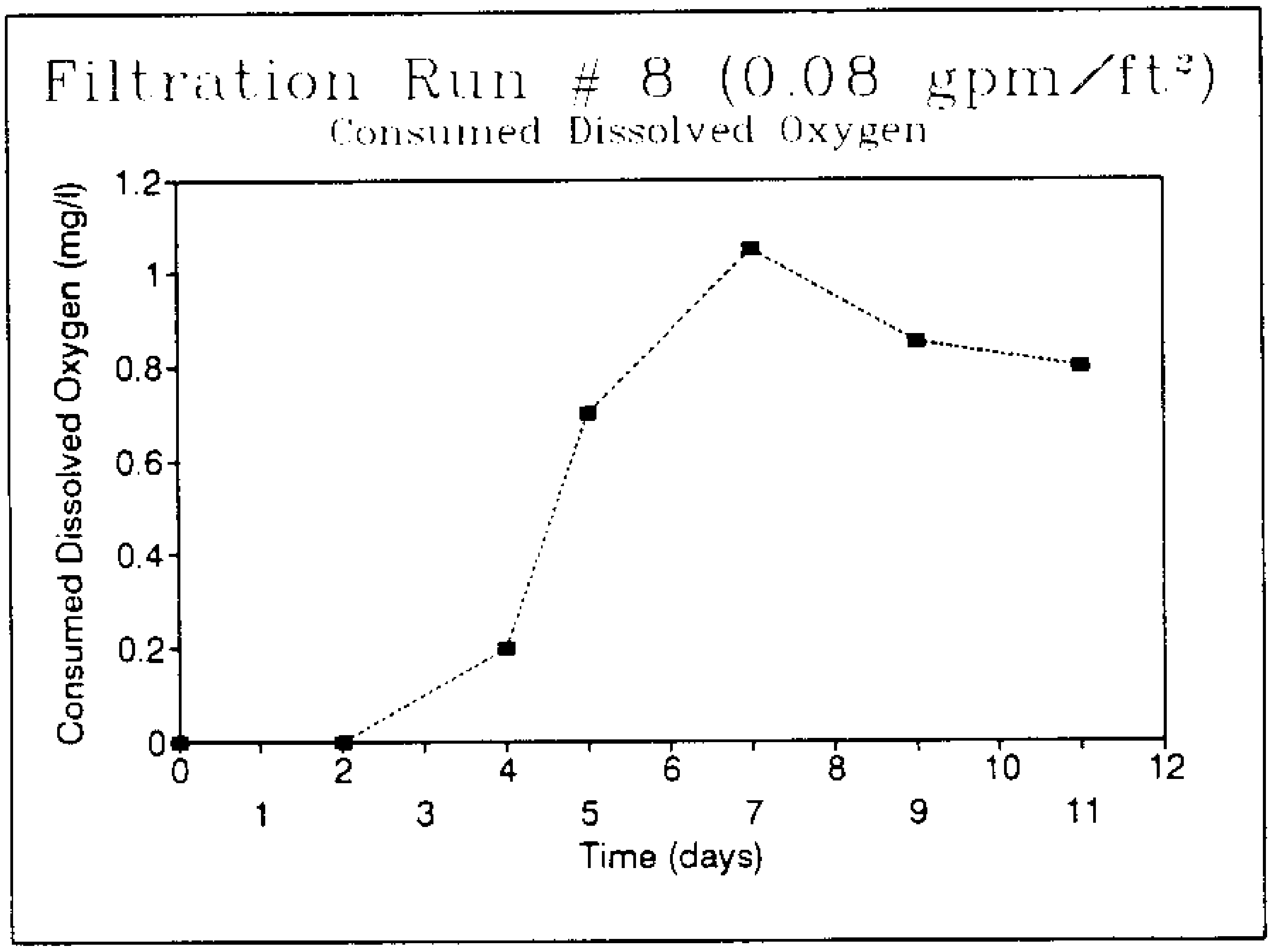

FIG. H-12.- Consumed Dissolved Oxygen for Filtration Run 8

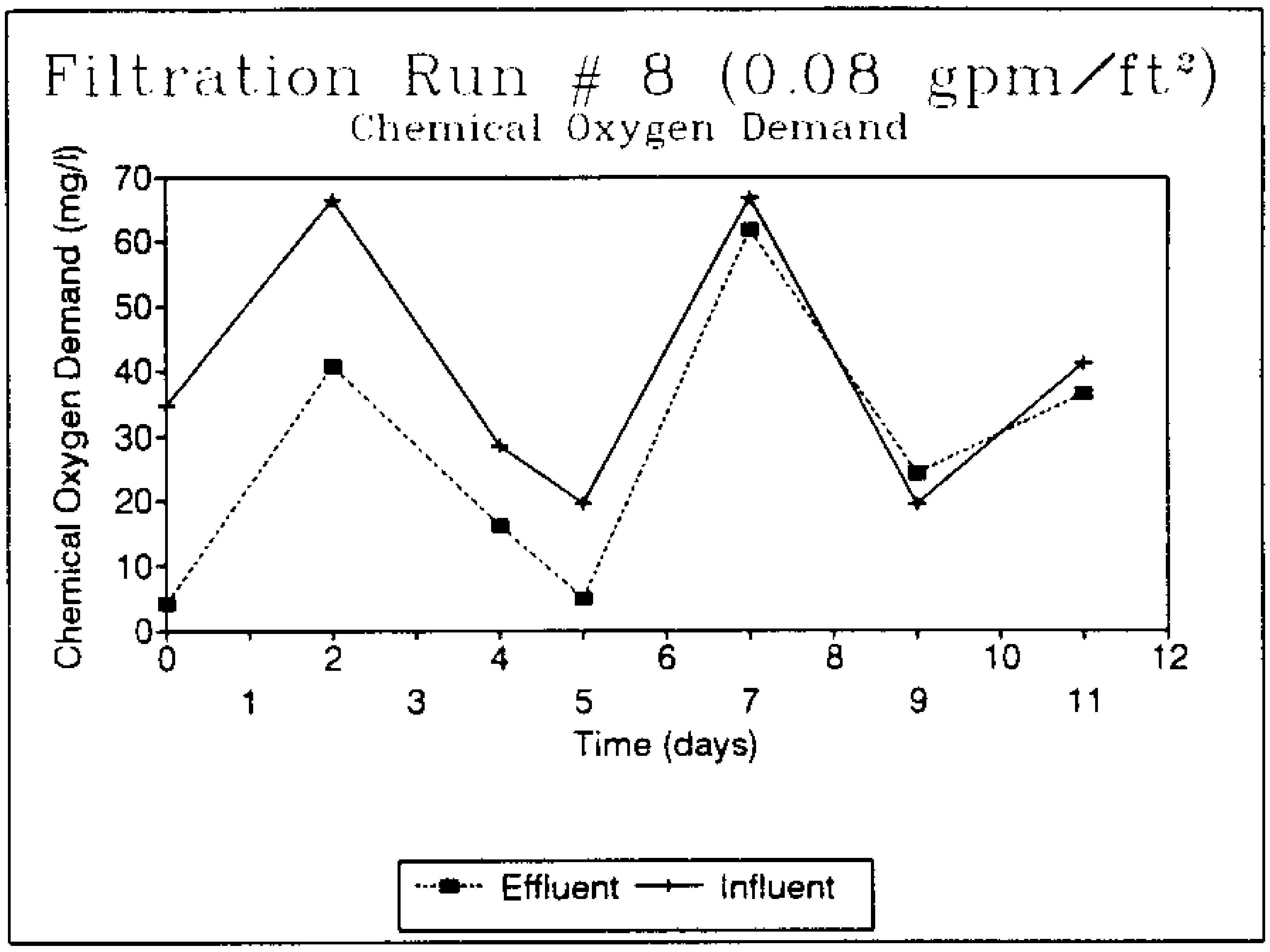

FIG. H-13.- Chemical Oxygen Demand (COD) for Filtration Run 8

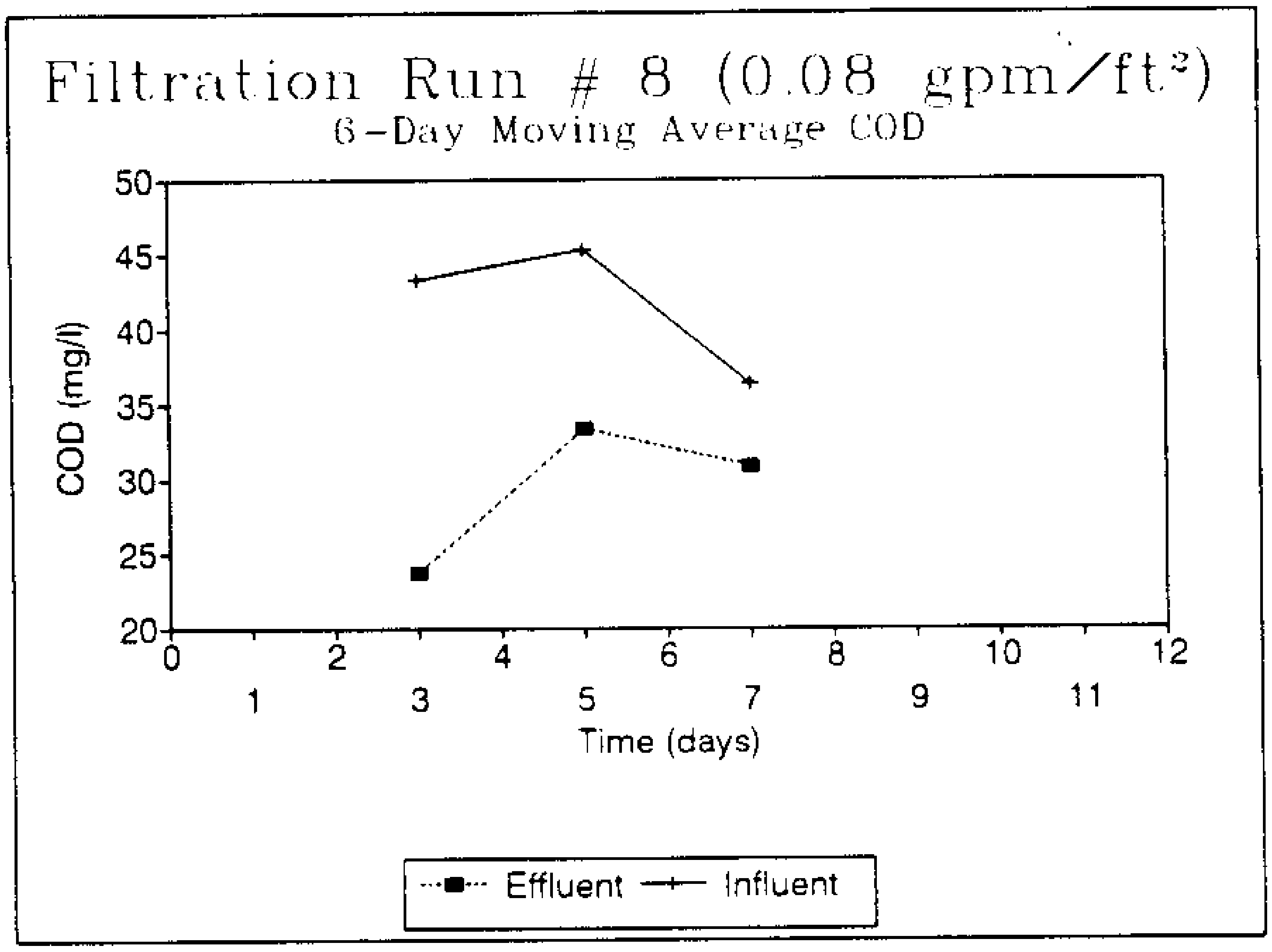

FIG. H-14.- 6-Day Moving Average COD for Filtration Run 8

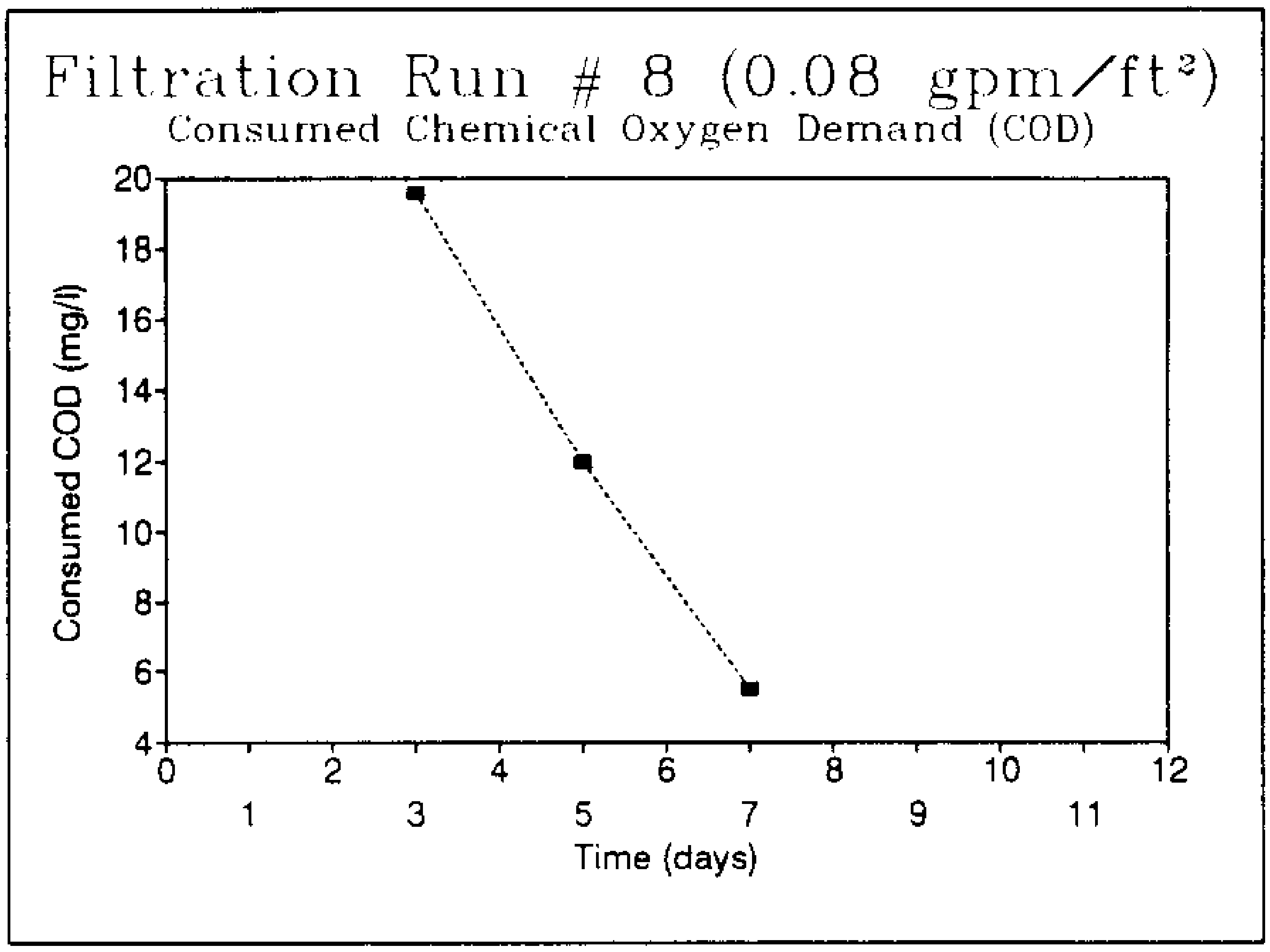

FIG. H-15.- Consumed COD for Filtration Run 8

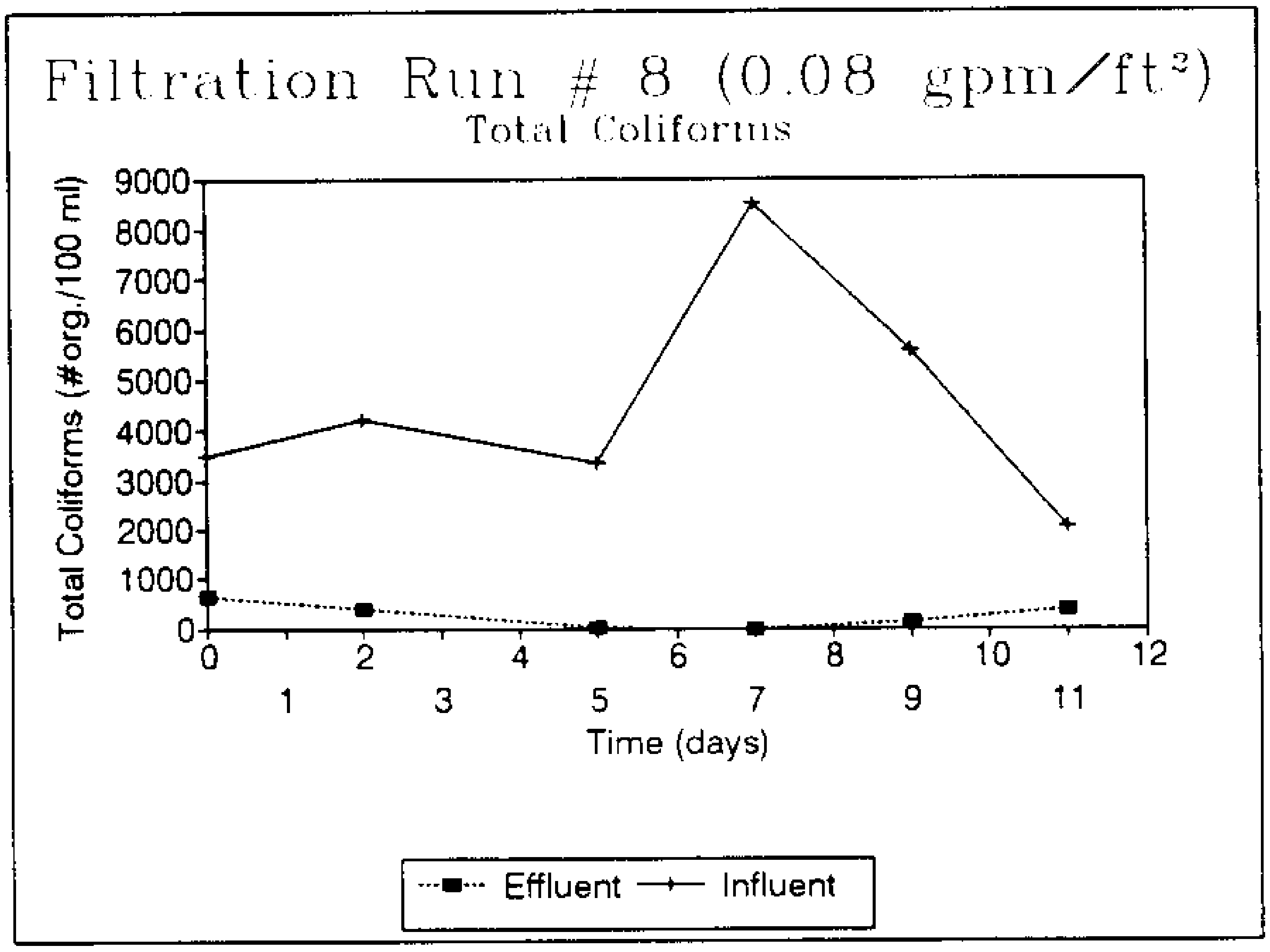

FIG. H-16.- Total Coliforms for Filtration Run 8

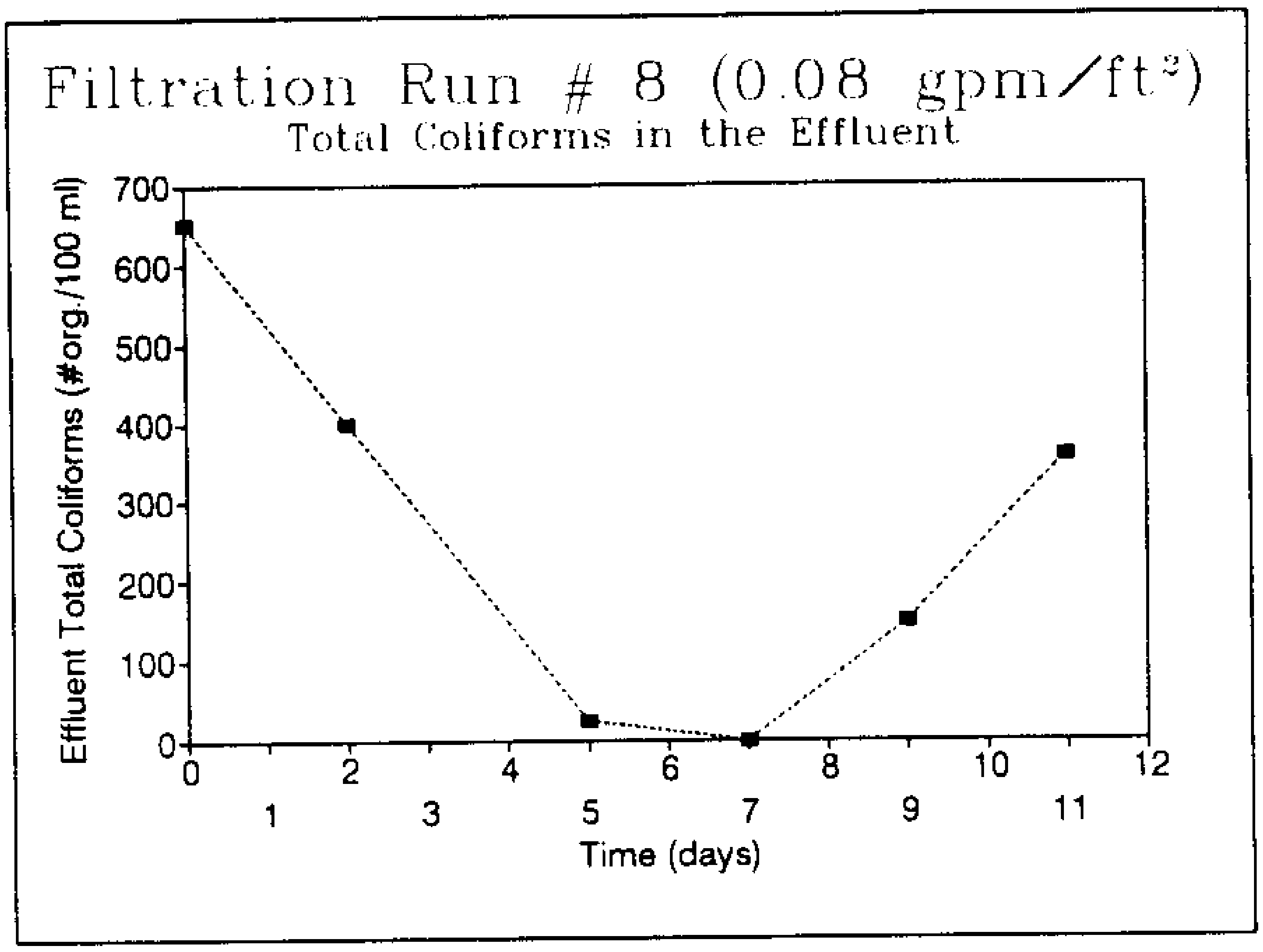

FIG. H-17.- Effluent Total Coliforms for Filtration Run 8

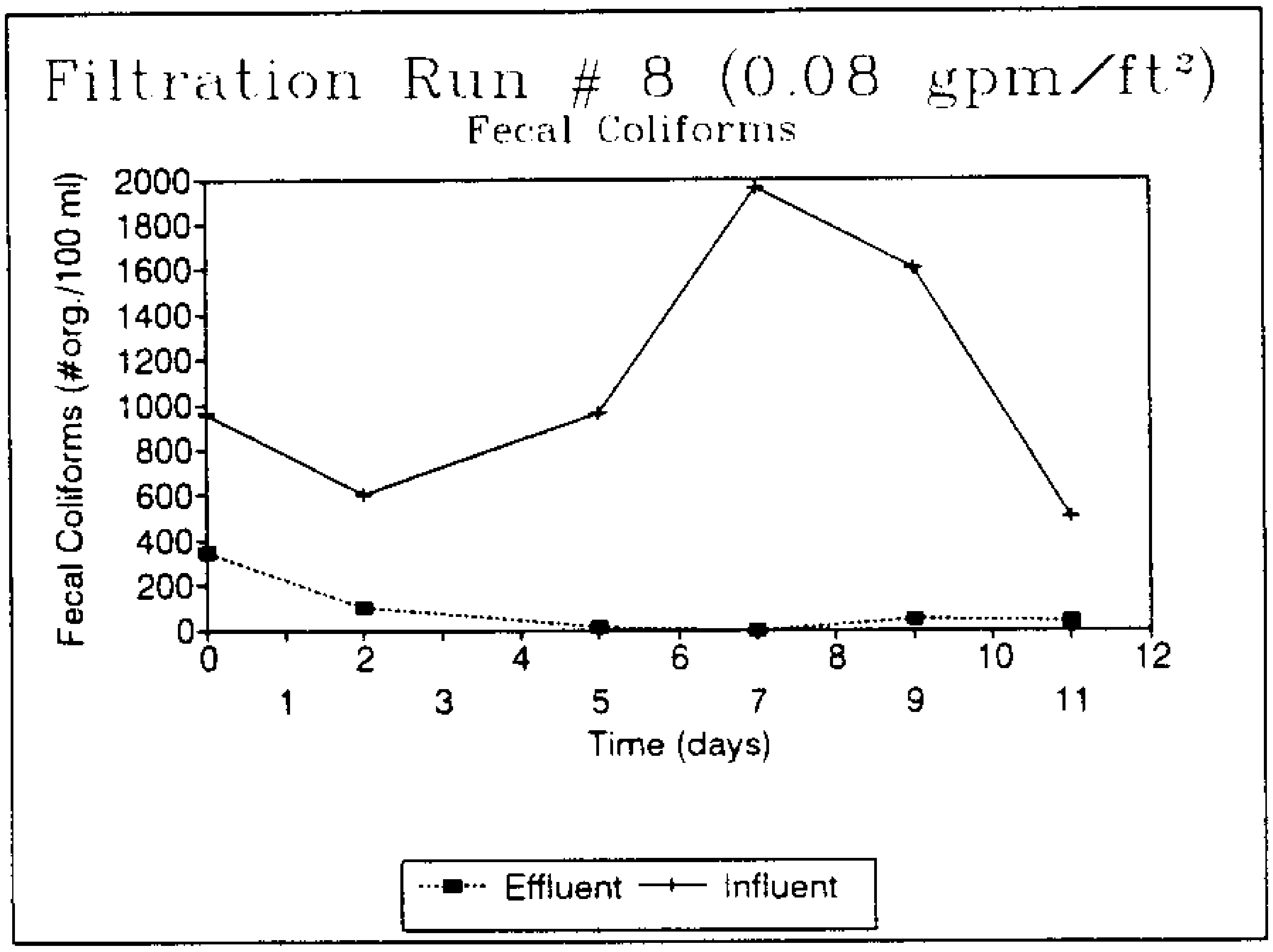

FIG. H-18.- Fecal Coliforms for Filtration Run 8

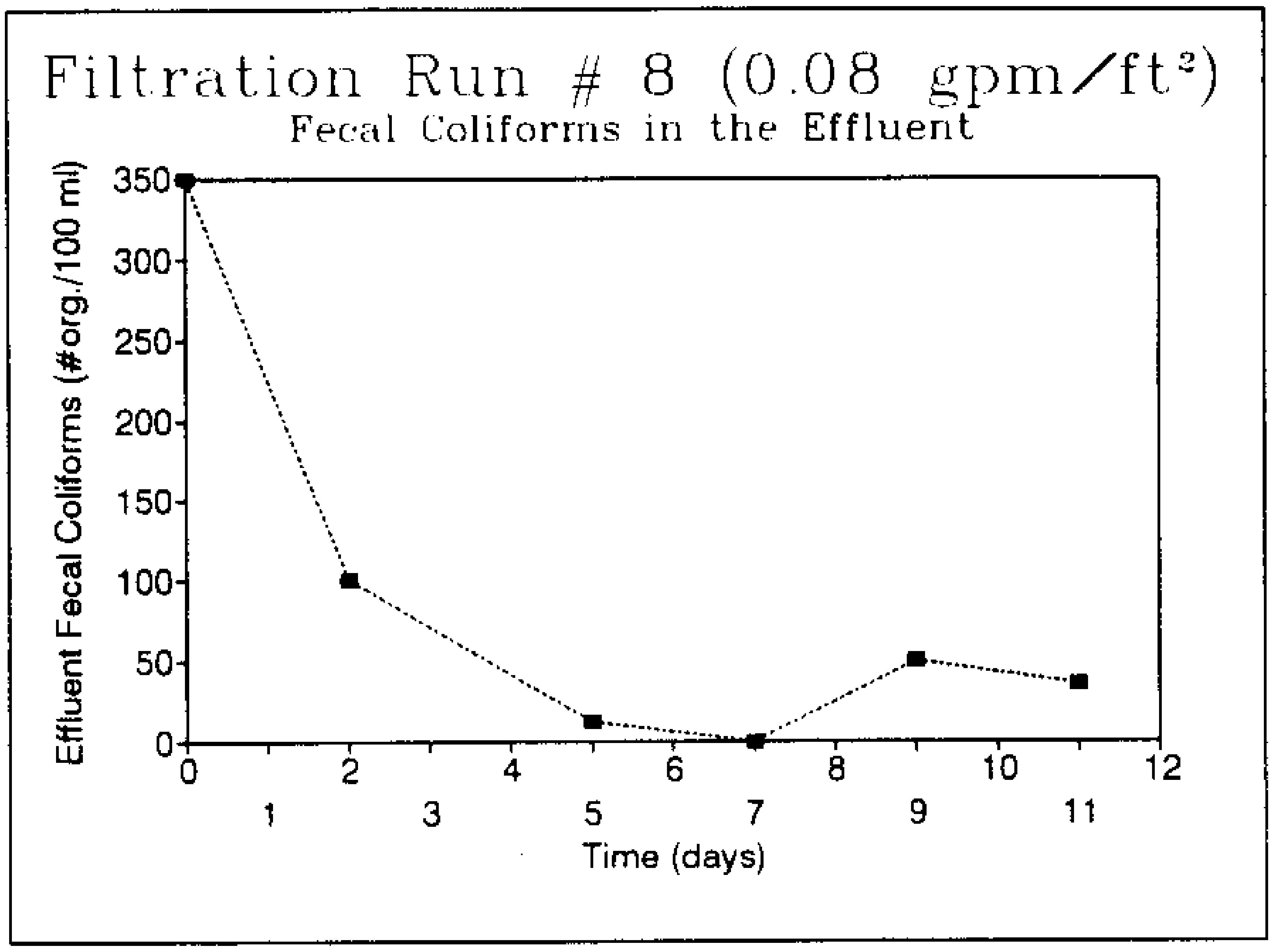

FIG. H-19.- Effluent Fecal Coliforms for Filtration Run 8

Table H-1.- Biochemical Oxygen Demand: Day # 0 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.25	7.40	8.23	7.38	1	0.0010	0
0.5%	8.30	7.48	8.23	7.38	1	0.0050	-5
1%	8.28	7.40	8.23	7.38	1	0.0100	2.5
5%	8.25	7.48	8.23	7.38	1	0.0500	-1.5
Glucose	8.25	3.60	8.23	7.38	1	0.0200	190

Table H-2.- Biochemical Oxygen Demand: Day # 0 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.25	7.50	8.23	7.38	1	0.0010	-100
0.5%	8.28	7.48	8.23	7.38	1	0.0050	-10
1%	8.25	7.63	8.23	7.38	1	0.0100	-22.5
5%	8.25	7.60	8.23	7.38	1	0.0500	-4
Glucose	8.25	3.60	8.23	7.38	1	0.0200	190

Table H-3.- Biochemical Oxygen Demand: Day # 6 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.70	8.08	8.70	8.03	1	0.0010	-50
0.5%	8.70	8.10	8.70	8.03	1	0.0050	-15
1%	8.73	8.10	8.70	8.03	1	0.0100	-5
5%	8.78	8.05	8.70	8.03	1	0.0500	1
Glucose	8.70	4.63	8.70	8.03	1	0.0200	170

Table H-4.- Biochemical Oxygen Demand: Day # 6 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.73	8.10	8.70	8.03	1	0.0010	-50
0.5%	8.80	8.13	8.70	8.03	1	0.0050	0
1%	8.83	8.13	8.70	8.03	1	0.0100	2.5
5%	8.95	8.15	8.70	8.03	1	0.0500	2.5
Glucose	8.70	4.63	8.70	8.03	1	0.0200	170

Table H-5.- Biochemical Oxygen Demand: Day # 11 - Effluent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.25	7.48	8.20	7.43	1	0.0010	0
0.5%	8.25	7.50	8.20	7.43	1	0.0050	-5
1%	8.28	7.53	8.20	7.43	1	0.0100	-2.5
5%	8.28	7.48	8.20	7.43	1	0.0500	0.5
Glucose	8.20	2.70	8.20	7.43	1	0.0200	236.25

Table H-6.- Biochemical Oxygen Demand: Day # 11 - Influent

BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.25	7.40	8.20	7.43	1	0.0010	75
0.5%	8.15	7.45	8.20	7.43	1	0.0050	-15
1%	8.28	7.50	8.20	7.43	1	0.0100	0
5%	8.25	7.20	8.20	7.43	1	0.0500	5.5
Glucose	8.20	2.70	8.20	7.43	1	0.0200	236.25

Table H-7.- Schmutzdecke Biochemical Oxygen Demand

$BOD(mg/l) = ((D1-D2) - (B1-B2)*f)/P$

Dilution	D1 (mg/l)	D2 (mg/l)	B1 (mg/l)	B2 (mg/l)	f	P	BOD (mg/l)
0.1%	8.23	7.18	8.20	7.43	1	0.0010	275
0.5%	8.23	7.13	8.20	7.43	1	0.0050	65
1%	8.20	6.73	8.20	7.43	1	0.0100	70
5%	8.25	5.00	8.20	7.43	1	0.0500	49.5
Glucose	8.20	2.70	8.20	7.43	1	0.0200	236.25

Table H-8.- Schmutzdecke Chemical Oxygen Demand

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	COD (mg/l)	Average COD (mg/l)
S.A.+P.D.	0.00	4.13	4.13	-	
S.A.+P.D.	4.13	8.20	4.07	-	-
S.A.+P.D.	0.00	4.15	4.15	-	
Blank	4.15	8.17	4.02	-	-
Blank	0.00	3.97	3.97	-	
Blank	3.97	8.06	4.09	-	-
Standard	0.00	3.09	3.09	455.06	
Standard	3.09	6.04	2.95	523.08	489.07
Sch. 1/10	0.00	3.98	3.98	2267.21	
Sch. 1/10	3.98	7.96	3.98	2267.21	
Sch.1/10	3.99	7.70	3.71	1538.46	2024.29

Table H-9.- Schmutzdecke Electrical Conductivity and Total Dissolved Solids

Sample	Conductivity (µmho/cm)	TDS (mg/l)	Average Conductivity (µmho/cm)	Average TDS (mg/l)
1	46.00	30.82		
2	46.50	31.16	46.25	30.99

Table H-10.- Schmutzdecke pH

Sample	pH	Average pH
1	7.58	
2	7.50	7.54

Table H-11.- Schmutzdecke Turbidity

Sample	Turbidity 1/100 (NTU)	Turbidity 1/10 (NTU)	Average Turbidity (NTU)
1	2400	790	
2	2500	800	1623

Table H-12.- Schmutzdecke Alkalinity

A = 2.5002
B = 40.00
C = 19.05

Sample	Initial Reading (ml)	Final Reading (ml)	Volume of Titrant Used (ml)	Normality of Acid	Alkalinity to pH=4.5 (Total) (mg CaCO3/l)	Average Alkalinity to pH=4.5 (Total) (mg CaCO3/l)
1	23.30	24.90	1.60	0.09905215	39.62	
2	24.90	26.45	1.55	0.09905215	38.38	39.00

Table H-13.- Schmutzdecke Fecal and Total Coliforms

Sample	Fecal Coliforms (# org./100 ml)	Total Coliforms (# org./100 ml)
1	1010.10	4040.40
2	1010.10	3030.30
Average	1010.10	3535.35

Table H-14.- Schmutzdecke Suspended and Volatile Suspended Solids

Crucible #	Tare Weight (g)	Filtered Volume (ml)	Weight (103°C) (g)	Suspended Solids (mg/l)	Average Suspended Solids (mg/l)	Weight (550°C) (g)	Volatile Suspended Solids (mg/l)	Average Volatile Suspended Solids (mg/l)
101	17.98032	5	17.99689	3314		17.99383	612	
0	16.65465	5	16.67117	3304	3309	16.66815	604	608

Table H-15.- Schmutzdecke Total Solids, Volatile Total Solids, and Inorganic Residue

Crucible #	Tare Weight (g)	Evaporated Volume (ml)	Weight (Dry) (g)	Total Solids (mg/l)	Average Total Solids (mg/l)	Weight (550°C) (g)	Total Volatile Solids (mg/l)	Average Total Volatile Solids (mg/l)	Inorganic Residue (mg/l)	Average Inorganic Residue (mg/l)
26	36.96049	20	37.01829	2890.00		37.00829	500.00		2390.00	
6E	37.64961	20	37.70809	2924.00	2907	37.69712	548.50	524.25	2375.50	2382.75

Appendix I: Flow and Hydraulic Loading Rates

Table I-1.- Flow Rates

Filtration Run #	Theoretical Flow (gal/hr)	Real Flow (gal/hr)
1	0.94	0.75
2	1.88	1.85
3	3.77	3.65
4	2.83	2.69
5	0.94	0.98
6	1.88	1.92
7	2.83	2.61
8	3.77	3.71

Table I-2.- Hydraulic Loading Rates (Q/A)

Filtration Run #	Theoretical Q/A (gpm/ft^2)	Real Q/A (gpm/ft^2)
1	0.020	0.016
2	0.040	0.039
3	0.080	0.077
4	0.060	0.057
5	0.020	0.021
6	0.040	0.041
7	0.060	0.055
8	0.080	0.079

Appendix J: *Giardia lamblia* Removal

Table J-1.- *Giardia lamblia* Removal

Filtration Run #	# of Cysts Added	# of Cysts in Effluent	% Removal
1	778	0	100%
2	769	0	100%
3	813	0	100%
4	1519	0	100%
5	7715	0	100%
6	126260	0	100%
7	48529	0	100%
8	317816	0	100%