ENVIRONMENTAL ENGINEERING AND HEALTH SCIENCES LABORATORY (EEHSL)

EEHSL REPORT NO. 94-1

Evaluation of the ATS/UV System for Tertiary Wastewater Treatment at Patterson, California

Final Report

by

Rupert J. Craggs
Walter H. Adey
Kyle R. Jensen
Matthias St. John
F. Bailey Green
and
William J. Oswald

December 1994

UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720

Table of Contents

List of Tables

List of Figures

Executive Summary

This summary describes a year of experimental work with an Algal Turf Scrubber (ATS) and supplementary equipment at Patterson, California, and recommends further studies. The ATS is an invention of Dr. Walter Adey of the Smithsonian Institution, Washington D. C., and is being evaluated for use in Patterson by the Algae Research Group of the Environmental Engineering and Health Sciences Laboratory, University of California under contract with Eco Aquatic Scrubbers, Inc.

As currently constructed at Patterson, the ATS is a two dimensional, (6.5 m x 152.4 m, 1012 m^2) fixed film reactor. It is lined with rough heavy plastic and has confining side rails to support a harvester. It is primarily a tertiary nutrient removal system intended to improve the quality of wastewater by growing periphyton (filamentous algae and symbiotic aerobic bacteria and fungi) on the surface of a gently sloped, continuously wetted floway. Nutrients for growth of the organisms are extracted from wastewater and possibly from the air in contact with the surface of the film. Sunlight is the primary source of energy for growth of the photosynthetic portion of the fixed film. Added energy for bacterial and fungal growth may be extracted from organic matter in the wastewater when present, or from new organic matter excreted by the algae. In order to maintain continuing growth the film is harvested periodically with a rotating brush and suction apparatus developed by architect Kyle Jensen.

Under the California Administrative Code Title 22 governing the reuse of wastewater for all purposes other than domestic (e.g. drinking and bathing), wastewater, properly treated to the secondary degree, must be subjected to coagulation, flocculation, sedimentation, filtration, disinfection, and certified laboratory testing prior to, and during, reuse. Currently proof of purity involves frequent certified laboratory evaluation of MPN of *E. coli.* faecal coli, pH, DO, BOD, ammonium (in terms of chronic bioassays), suspended solids (measured in terms of NTU) and proof of at least 5 logs of viral removal. There is presently no requirement for removal of nitrate and phosphorus although requirements are anticipated in the future. Levels of the above quality criteria for Patterson to discharge to the San Joaquin River are shown in Table 1.1 of the text.

The purposes of the experimental evaluation at Patterson were:

To evaluate the potential of this prototype ATS with required supplementary equipment to improve the quality of Patterson's secondary wastewater effluent to a point that it can be legally discharged to the San Joaquin River now and in the future.

To determine design criteria for improvement of future ATS systems.

To determine the quantities of biomass per unit of area and unit of wastewater that can be grown on the floway; and

To determine the quality and value of biomass grown on the floway.

Few problems were encountered in developing a dense "turf" covering the entire floway, and successful harvesting of the turf was attained. Turf productivity's are among the highest ever reported, although a significant fraction of the dry weight is ash, including calcium carbonate and possibly calcium ammonium phosphate. Initially UV disinfection was installed to assure that any algal product produced would be free of infectious material. However, due to the presence of microalgae in the influent waters drawn from a Patterson evaporation pond for secondary treated waste, the necessary transmission of UV could not be attained. It was also determined that the hydraulic loading velocity (HLV), (cubic meters per square meter per day or meters per day) of 1.2 meters per day on the floway was excessive when comparing nutrients applied vs nutrients removed. Resulting from these observations the UV unit was placed after the floway, following a rotary strainer to remove clumps of periphyton released from the floway and a sand filter to remove turbidity. Due to algal turbidity in the floway effluent, an efficient filter is needed to assure the required transmissivity of UV light for viral inactivation in the UV unit. With these essential modifications we also decreased the HLV to about 0.9 m/day. This resulted in an increased pH and improved phosphorus removal. It would also result in improved metal removal, although this was not studied extensively. It was noted that much of the algal turf consisted of cyanobacteria and diatoms both favoring nitrate to ammonium as their source of nitrogen. Nitrate is of course the principal form of inorganic nitrogen discharged by Patterson's extended aeration oxidation ditch. A materials balance appears to indicate some denitrification on the floway, perhaps indicating denitrification in an anoxic portion of the turf.

As a result of further reduction of HLV to 0.4 meters per day, phosphorus removal improved to as much as 80 % of influent values. In comparing the HLV levels thus far explored, with those for other natural systems, it appears that reductions in HLV to as low as 0.25 meters per day would improve performance and remain economical. Accordingly these levels of HLV should be explored before designs are finalized. We have not found the ATS to evidence any decrease in effluent BOD, but this is neither unexpected nor needed, since Patterson's effluent BOD is always below 30 mg l^{-1}. The same is true for suspended solids. Patterson's DO is greatly improved by the ATS; and with more green algae on the floway and lower HLV, we can expect improved N removal and virtually complete P removal. The odorless nutrient removal promised by the ATS should be compared with the highly odorous processes now used that are very expensive because they require huge amounts of energy and must be inclosed to avoid odor complaints.

It should be kept in mind that, as its name implies, the ATS is primarily a reducing system, which has the potential to remove carbonates, nitrates, ammonium and phosphorus from waste streams. Some of these processes may require more available organic carbon than is present in the Patterson effluent. For this reason it has been suggested that the ATS should be placed in series with an Advanced Facultative Pond (AFP) for added study. This appears reasonable since an AFP would cost as little as one half as much to build and operate as Patterson's current system. Before this step is taken there is an opportunity to study the system under controlled conditions at the U.C. Berkeley's Richmond Field Station. One weakness of the current set up at Patterson is lack of a duplicate ATS with which we could virtually eliminate climatological and wastewater variations from our findings. Such a control would be an essential part of the apparatus used in ATS studies at the Richmond Field Station. If studies were to be continued at Patterson it would be worthwhile to consider dividing the raceway longitudinally to provide the needed control unit. Resultant problems with harvesting would of course need to be dealt with.

It should be recalled that all photosynthetic systems are strongly influenced by climate, and accordingly system designs must be made for periods of cold weather. Although we do have some winter data, it lacks a control and was carried out at unrealistically high HLVs. Accordingly, before further designs are contemplated an additional year of controlled studies is recommended.

In the meantime it appears that until California's Inland Surface Water Plan and the new National NPDES standards go into effect, Patterson's secondary plant followed by an ATS, reliable sand filtration and UV disinfection would provide an effluent that meets all current standards for discharge to the San Joaquin River. This must of course be verified and certified to by competent authority. A notice of waste discharge and discharge specifications will have to be consistently met in accordance with the discharge permit. Frequent reports of effluent characteristics will be an absolute requirement, and failure to file such reports would result in severe and expensive penalties. These expenses must be included in the economic analysis of the ATS and any competitive systems that may be considered.

1.0 Introduction

Urbanization, industrialization and agriculture have increased demand for potable water resources, while at the same time, have caused widespread pollution of natural water bodies (Gloyna, 1971). In the past, dilution of wastewaters discharged to lakes and rivers was an adequate method of treatment. However, both the concentration and volume of the sewage effluent and agricultural run-off now discharged, are too great to be treated by dilution alone (Harlin & Darley, 1988). Eutrophication of freshwaters, particularly due to excessive phosphorus concentrations is an increasing problem world wide. Moreover, the remediation of natural water bodies which are now eutrophic and/or contaminated with heavy metals and organics is of major environmental concern. Traditional wastewater treatment methods rely on mechanical processes and are costly to construct and operate (Metcalf & Eddy, 1991). They also have low treatment efficiencies, especially for inorganic nutrients, refractory organic compounds and heavy metals (Oswald, 1988). In many instances, chlorination is used to disinfect partially treated municipal sewage prior to discharge. But, since chlorine residues may be toxic to aquatic life, the chlorinated effluent must be dechlorinated. Recently, chlorination has been related to the production of organic carcinogens, such as trihalomethanes in wastewaters. Despite the scarcity and cost of producing potable water, little wastewater is currently reused. In the USA, much of this potentially valuable resource is "abandoned" in ponds after primary or secondary treatment to evaporate or infiltrate into ground waters. More efficient and economical alternative treatment methods which enable recycling of this water resource are therefore required.

The controlled use of green microalgae in wastewater treatment was established more than 40 years ago by Oswald and colleagues at the University of Berkeley, California (Oswald, 1953a & b). Algal treatment systems enable optimization and control of treatment processes which occur naturally while greatly reducing the treatment area required for less controlled pond systems. Algal treatment is typically preceded by advanced facultative ponds in which fermentation converts volatile organic solids to methane, reducing biochemical oxygen demand (BOD), chemical oxygen demand (COD) and suspended solids (SS) levels (Green *et al.*, 1994). Unlike traditional bacterial systems, controlled algal treatment has the potential to meet tertiary treatment standards necessary for discharge to surface waters, enabling direct water reuse. Algal treatment of wastewater often consists of raceways (High Rate Ponds) which are gently mixed and shallow in depth (Oswald, 1988). These systems use microalgae to capture energy from sunlight and oxygenate the wastewater. Photosynthetic oxygenation drives heterotrophic breakdown of the organic waste by bacteria, which reduces the BOD, COD and suspended solids. The inorganic nutrients and carbon dioxide produced, promotes further algal growth and oxygen production. Thus, the algae both oxygenate the wastewater and remove inorganic nutrients. Nutrients may be assimilated directly into algal primary production, or phosphorus may be precipitated and ammonia volatilized as a consequence of high pH due to photosynthesis (Hemens and Mason, 1968; Cook *et al.*, 1986). The algal biomass may then be harvested and has many potentially commercially viable applications, such as soil amendment, animal feed and chemical production (Ryther *et al.*, 1987; Lembi & Waaland, 1988; Becker, 1988; Hall & Rao, 1989). Algae are also known for their high affinity for certain organic compounds and heavy metals (Greene & Bedell, 1989; Gadd, 1990), the removal of which has become a requirement for wastewater reclamation. Organic compounds may be broken down and hence made non-toxic, while heavy metals can be accumulated in the algal biomass, either adsorbed to the surface of the cells or stored within them.

The Algal Turf Scrubber (ATS)™ represents a novel algal wastewater treatment system which cultures attached or benthic bacteria, microalgae and periphyton (filamentous algae) on an inclined floway as opposed to bacteria and phytoplankton in a pond. This system has several advantages to ponds in that, given adequate light much higher rates of photosynthesis and algal production can be achieved (Adey *et al.*, 1993; Russian Ref). In addition, it is linear (treatment may be made in a single pass and treated water is not mixed with untreated water), mixing is not required as the water flows with gravity, and harvesting (removal of pollutants bound to or incorporated in the algal biomass) may be achieved simply by scraping the biomass from the surface. The difficulty of removing microscopic phytoplankton from pond systems has been a major obstacle to the use of algae to treat wastewaters.

1.1 Algal Turf Scrubber Development

The ATS is essentially an artificial stream which has been designed and engineered to promote biological wastewater treatment using periphyton. Most underwater surfaces which are illuminated will become colonized by a succession of bacteria, microalgae (particularly diatoms) and periphyton. The use of such a community for water treatment was developed by Adey and associates at the Smithsonian Institution, Washington D.C. over the last fifteen years (Adey & Loveland, 1991). While investigating the productivity of periphyton turfs on coral reefs, Adey discovered that these communities could remove nutrients present at extremely low concentrations ($\mu g\ l^{-1}$) (Adey & Hackney, 1989). Algal Turf Scrubbers have been used to remove nutrients from artificial reef and wetland ecosystems and for maintaining water quality in aquaria (Adey, 1983; Williams & Adey, 1983; Tangley, 1985; Adey, 1987; many of which are described in Adey & Loveland, 1991). Several laboratory experiments and small-scale pilot projects have shown removal of inorganic nutrients (Adey *et al.*, 1993), refractory organics (Adey *et al.*, 1994) and heavy metals (Adey *et al.*, 1994) from polluted waters by the ATS. The capability to remove phosphorus from agricultural run-off was demonstrated in a small-scale outdoor pilot plant in Florida (Adey *et al.*, 1993). The simplicity of ATS treatment systems and the ease with which configuration and operational parameters such as hydraulic loading, floway length and harvest period can be changed, should enable the optimization of the system for treatment of a specific waste.

1.2 Algal Turf Scrubber Design

Algal turf scrubbers are low-cost treatment systems which are simple in design and construction. The floway consists of a liner which covers laser graded soil and lies between two precast concrete grade beams, to which the liner is attached (Figure 1.1). The liner (60 mil. textured high density polyethylene landfill liner (Polyflex Corporation, Houston TX)) provides a surface for periphyton attachment. The grade beams provide both a vertical edge to the floway and rails to support and distribute the weight of a mechanical harvester for use on even the softest soils. The soil is initially compacted and graded to maintain uniform water flow. The influent is delivered with a surging device which produces a series of waves to raise the efficiency of treatment by increasing the contact between the algae and the wastewater. To maintain efficiency of nutrient removal and exponential growth rates, the periphyton community is harvested after stopping the flow of wastewater and draining the floway for one hour. Hence, all pollutants accumulated by the algal turf are easily removed in the harvested solids.

1.3 The Patterson ATS Project

The ATS project at Patterson, California was undertaken to determine whether the ATS, in conjunction with ultra-violet (UV) disinfection, could treat the effluent from the Patterson wastewater treatment facility to meet all regulatory requirements to permit discharge to the San Joaquin River. Since this effluent is presently abandoned to evaporation and infiltration ponds at the facility, discharge of the ATS/UV polished effluent to the San Joaquin River would provide a water "credit". This credit might then be "traded" by the Western Hills water district to provide water for Diablo Grande, a 33,000 acre resort development in the foothills due east of Patterson.

The California regulatory standards for the discharge of treated wastewaters which apply to Patterson are published in three documents: The Californian Inland Surface Waters Plan (State Water Resources Control Board); Wastewater Reclamation Criteria, California Administrative Code Title 22, Environmental Health (California Department of Health Services, State of California); and the National Pollutant Discharge Elimination System Permit for the City of Patterson wastewater treatment facility (Central Valley Regional Water Quality Control Board). Table 1.1 summarizes the current requirements for discharge from these documents.

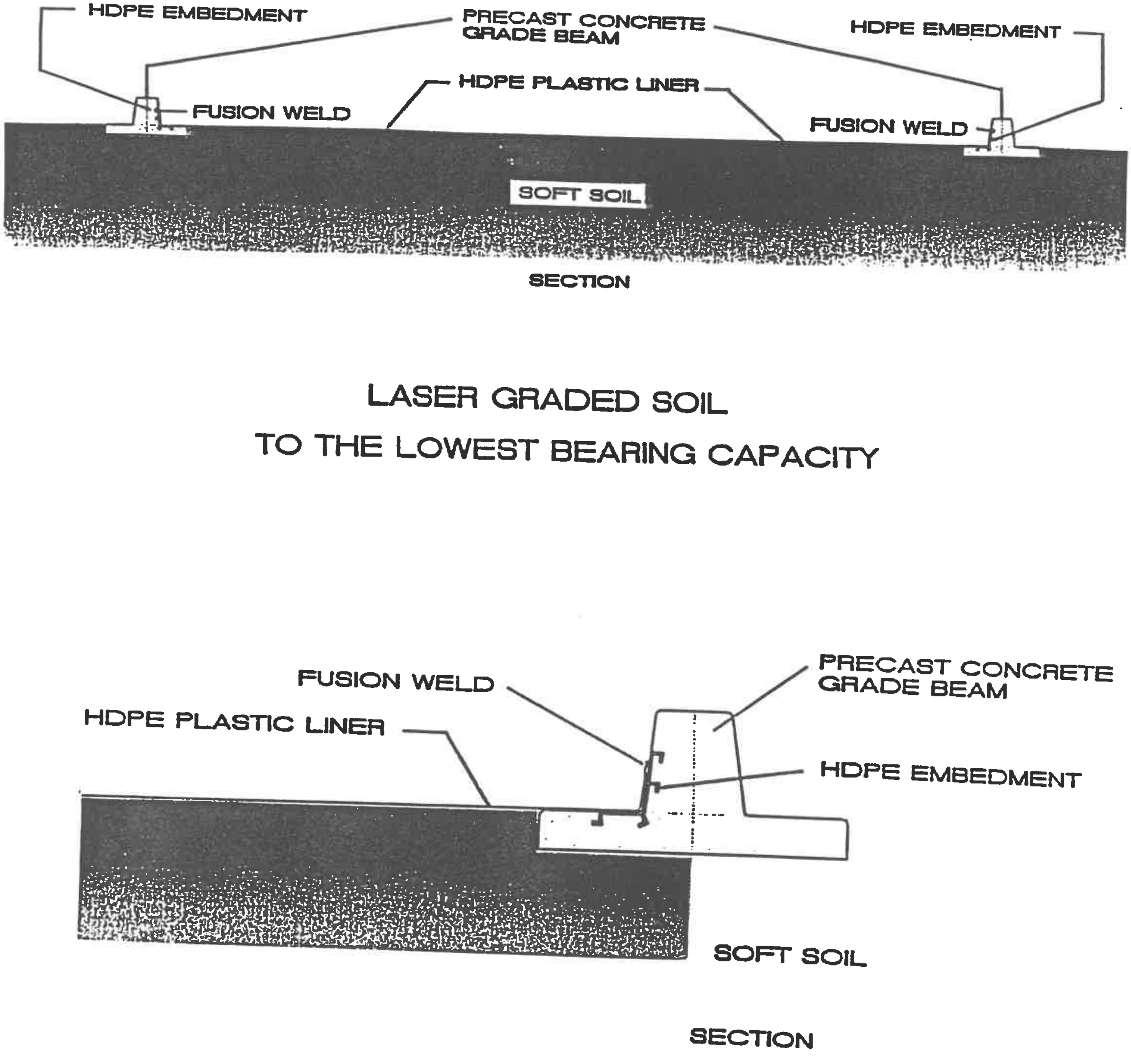


Figure 1.1 Cross-section of Algal Turf Scrubber

Table 1.1 California regulatory standards for discharge to the San Joaquin River

Parameter	Effluent Regulatory Standards	Drinking Water Standards
Physical Parameters		
Temperature (^{o}C)	(≤ 15 increase in receiving water^{b})	-
Dissolved Oxygen (mg l^{-1})	(> 7 in receiving water^{b})	-
pH	6.5 - 8.5^{b} (≤ 0.5 increase in receiving water^{b})	-
Alkalinity (mg l^{-1} as $CaCO_3$)	-	-
Hardness (mg l^{-1} as $CaCO_3$)	-	-
Conductivity (mS m^{-1})	500^{a}	90^{d}
Nutrients		
Ammonium (mg l^{-1})	Acute toxic level for flathead minnow	-
Nitrate/Nitrite (mg l^{-1})	-	45 (as NO_3^{2-})^{d}
Total Organic Nitrogen (mg l^{-1})	-	-
Soluble Reactive Phosphorus (mg l^{-1})	-	-
Total Phosphorus (mg l^{-1})	-	-
Organic Matter		
Biochemical Oxygen Demand (BOD) (mg l^{-1})	30^{b}	-
Chemical Oxygen Demand (COD) (mg l^{-1})	-	-
Total Organic Carbon (TOC) (mg l^{-1})	-	-
	-	-
Solids		
Ultra Violet (UV) transmittance (%)	55 %^{e}	-
Turbidity (NTU)	2^{c} (20 % increase in receiving waters^{b})	5^{d}
Total Suspended solids (mg l^{-1})	30^{b}	-
Settleable solids (ml l^{-1})	0.1 ml l^{-1b}	-
Microbiology		
Faecal Coliforms (MPN 100 ml^{-1})	2.2^{c}	-
Total Coliforms (MPN 100 ml^{-1})	30 day median of 23^{b} 2.2^{c}	< 5 % of 40 samples month^{-1} > 2.2^{d}
F- Male specific bacteriophage (MPN 100 ml^{-1})	5 log reduction credited for sand filtration and UV disinfection^{f}	-

[a] Inland Surface Water Plan, State Water Resources Control Board

[b] National Pollution Discharge Elimination System Permit, USEPA, Central Valley Regional Water Quality Control Board

[c] Title 22 California Department of Health Services

[d] California Safe Drinking Water Act & Related Laws

[e] UV Disinfection Guidelines for Wastewater Reclamation in California and UV Disinfection Research Needs Identification

[f] Personal communication with Bob Hultquist at Department of Health Services; UV Disinfection Guidelines for Wastewater Reclamation in California and UV Disinfection Research Needs Identification

Neither the Inland surface water plan nor the revised Title 22 have been adopted. A revised version of Title 22 is expected early next year, while the Inland surface water plan is still under review

The principle aims of the present study were:

1) To evaluate the ATS/UV system for treatment of Patterson wastewater to California regulatory standards permitting final effluent discharge to the San Joaquin River.

2) To determine if the ATS/UV system removes parameters such as nutrients which are likely to be included in future wastewater discharge regulations in California.

3) To measure the productivity of algal biomass using secondary treated wastewater as a substrate.

2.0 Materials and Methods

2.1 Patterson Wastewater Treatment Facility

The city of Patterson (latitude and longitude) is situated in the Central Valley of California, approximately 70 miles south east of San Francisco. Patterson has hot summers, mild winters with fog during January to March. The Patterson wastewater treatment facility (Figure 2.1) is located three miles north east of the town. The treatment train includes influent screening, comminution, extended aeration in an oxidation ditch, clarification and sludge removal. Part of the sludge is used to reseed the oxidation ditch while the majority is dried in the drying beds and ploughed into the ground. The mean and range values of parameters measured in the Patterson wastewater treatment facility influent and effluent are shown in Table 2.1. The facility has a design flow of 1.0 million gallons per day, and the treated wastewater is disposed of on-site to 51 acres of evaporation and infiltration ponds. During the summer some of the plant effluent is used to irrigate a city owned field for fodder crop production. Chlorination, followed by dechlorination, has been used in the past to disinfect the effluent prior to discharging to the San Joaquin River. Presently, no water is discharged, and none has been discharged since 1983.

2.2 Patterson Algal Turf Scrubber / UV system

The pilot ATS/UV treatment system built at Patterson had several components (Fig. 2.2): an algal turf scrubber floway with a pneumatic wave maker, a 400 μm rotary screen strainer, a sand filtration system, an ultra-violet disinfection system, and a harvester. The algal turf scrubber was 152.4 m (500 ft) long and 6.5 m (21 ft 4 in) wide, had a total surface area of 1012 m^2 (10667 ft^2), and was oriented so that water flowed from north to south. To maintain the uniform flow down the ATS, the top half was inclined at a 0.5 % slope and the bottom at a 0.25 % slope. The total change in elevation

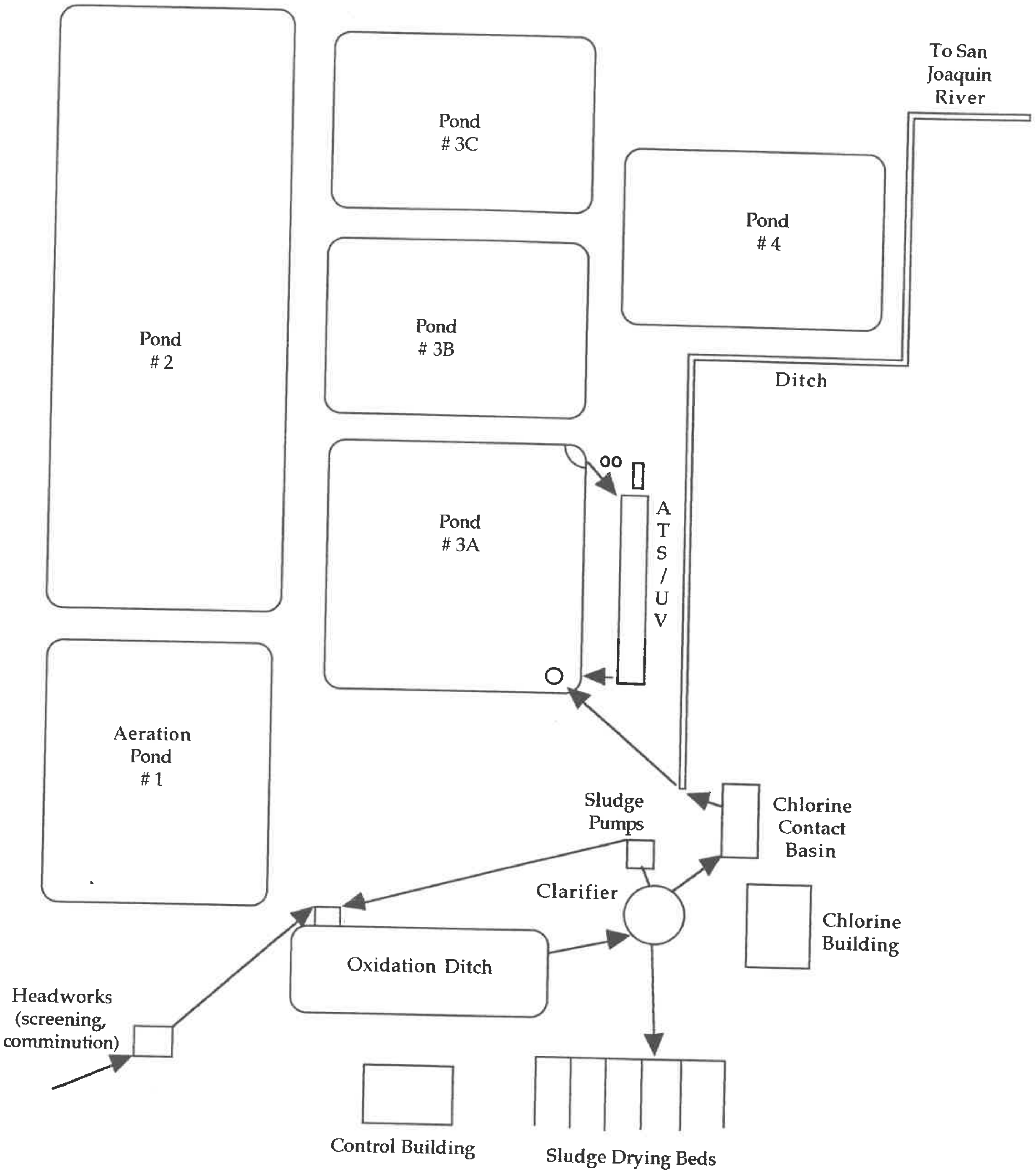
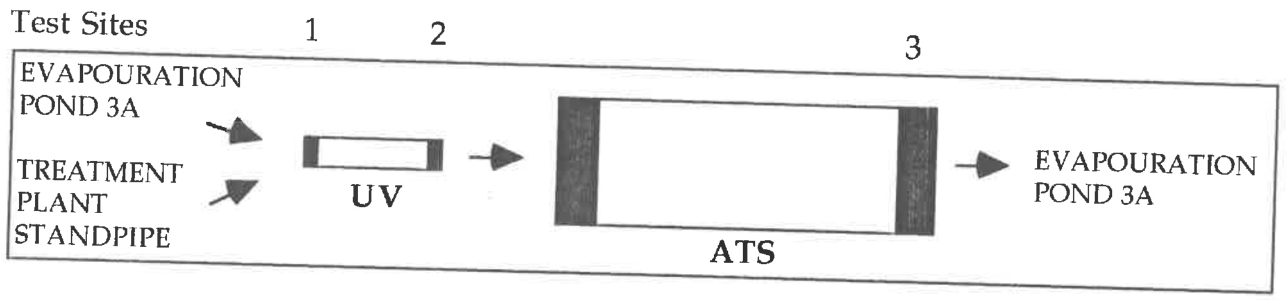


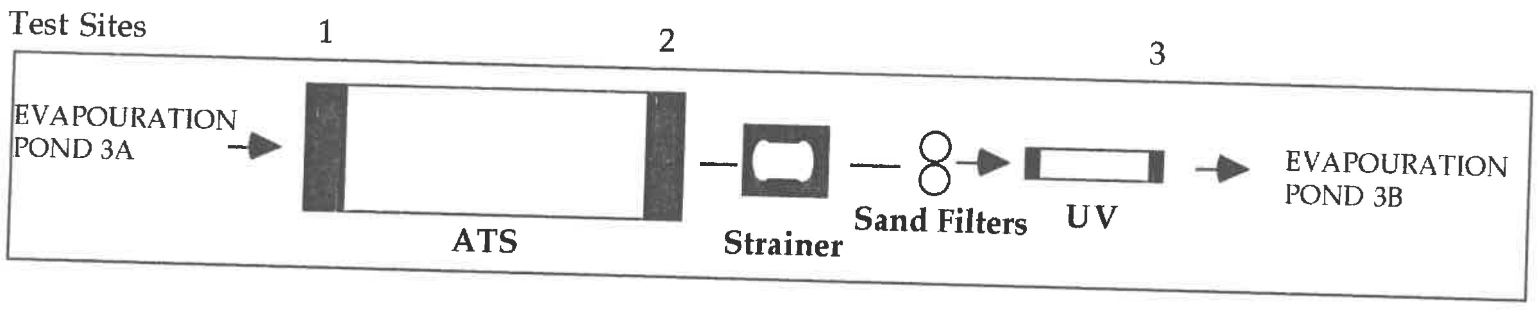
Figure 2.1 Schematic diagram of City of Patterson wastewater treatment facility, showing the location of the ATS/UV system.

Table 2.1 Water quality measurements of Patterson wastewater treatment facility influent and effluent measured over the period of operation of the ATS/UV system. The mean ± s.d. and range flow were 0.83 ± 0.04 (0.71 - 1.07) million gallons per day.

Parameter	Influent Mean ± s.d.	Range	Effluent Mean ± s.d.	Range
Temperature (^oC)	22.77 ± 2.93	18 - 28		
Dissolved Oxygen (mg l^{-1})	0.25 ± 0.08	0.2 - 0.60	3.36 ± 0.54	1.4 - 5.9
pH	7.61 ± 0.10	7.13 - 8.00	7.38 ± 0.10	7.00 - 8.20
Conductivity (mS m^{-1})			210.56 ± 7.23	180.00 - 235.00
BOD (mg l^{-1})	188.38 ± 39.64	140 - 198	6.92 ±6.92	2.7 - 6.3
TSS (mg l^{-1})	210.79 ±53.53	183 - 252	7.79 ±5.00	2.6 - 6.9
Settleable solids (ml l^{-1})	10.04 ± 2.13	6.00 - 12.50	< 0.1	<0.1 - 0.1



a. Initial Configuration



b. Fall Configuration

Figure 2.2 Configuration of the Patterson Algal Turf Scrubber/Ultraviolet disinfection wastewater treatment system was approximately 0.61 m (24") over the entire length. The surge was produced using two compressed air cylinders (4" bore by 12" stroke) to drive a 6.1 m (20 ft) wooden beam in and out of a 208 litre (55 gallon) influent trough.

The rotary screen strainer collected any algae that sloughed off the floway surface. The strainer was made from a coarse mesh barrel 0.76 m by 1.22 m (30" x 48") which supported a stainless steel screen (400 μm) on its outer surface. The barrel rotated continuously and high pressure jets (using the filtered effluent) washed the filtrate from the screen on to a drying bed.

Two pressurized sand filters (Effco, California) were used to filter microscopic particles from the effluent. Both filters had a volume of 0.3 m^3, and contained 5 μm spherical sand over a 5 cm bottom layer of coarse grain sand.

The UV disinfection unit (Trojan technologies, Canada) was composed of three troughs (2.44 m long, 0.53 m wide and 0.37 m high (8 ft x 21 inches x 14.5 inches). The unit held a total of 42 lamps (40 Watt), with seven mounts of two lamps in each trough. The lamps were enclosed within a quartz shield which had to be cleaned periodically.

The harvester (Aquatic Bio-Enhancement Systems, Texas) removed the algal turf from the floway and transferred it to a tanker. An internal combustion gasoline engine powered the entire harvester unit including hydraulic wheel drive, an articulated vacuum nozzle, cyclone separator and transfer pump.

2.3 Operation

Evaluation Period

Evaluation of the ATS/UV system was conducted over one year from the 30th of August 1993 to the 24th of October 1994 with a preliminary study period and four, 8 week quarters, corresponding to the solar seasons. This enabled performance to be related to seasonal variations, such as light intensity and temperature. Since this was the first large scale ATS to be constructed, various operational regimes were tested.

Seeding

A natural assemblage of bacteria, microalgae and periphyton developed on the floway. This development was initially aided by placing screens in near-by streams and rivers. After algae attached to the screens these were then placed at the top of the floway, and algae from the screens colonized the floway. In the last three weeks of the summer quarter and during the whole of the fall quarter, the floway was seeded with algal biomass collected from near-by streams and harvested algae from the floway. This "seed" algae was broken up in a barrel and distributed down the floway.

Configuration

Two configurations of the treatment system were tested. For the first three quarters the UV disinfection unit was placed in front of the ATS (Fig. 2.2a). During the fall quarter the complete ATS/UV system was in place, consisting of the ATS, rotating drum strainer, sand filters, and UV units in series.(Fig. 2.2b).

Flow Rate

The influent was pumped using two 3 HP pumps (Dayton Electric Mfg. Co., Illinois). The influent flow rate was varied from 175 gal min^{-1} during the winter quarter, to 225 gal min^{-1} during the spring, to 165 gal min^{-1} during the summer and first month of fall quarter, and finally to 80 gal min^{-1} in the last month on the fall quarter. The flow rate was measured using a Doppler flow meter (Dynamic fluid systems, New York, model HFM-1).

Influent

The influent was taken from two sources, the evaporation/ infiltration Pond 3A or from the Patterson treatment plant effluent stand-pipe (Fig. 2.2a). The influent was taken from the stand pipe during the spring quarter when the turbidity was low. During the spring quarter high turbidity of the treatment plant effluent was detected by a photoelectric switch which opened a diversion valve (monitored using a pressure recorder), permitting only pond water to be used as the influent. The influent was taken from Pond 3A during the remaining quarters (winter, summer, and fall).

Surge Frequency

The time interval between surges was dependent on the time necessary to fill the surge trough. The time interval between surges varied from 15 - 35 seconds depending on the flow rate.

Harvest Frequency

The frequency of harvest was varied from a two week interval during the less productive winter quarter, to a one week interval at all other times.

UV Lamp Cleaning Frequency and Replacement

The UV lamps were cleaned weekly during the winter and spring quarters, and twice weekly during the summer and fall quarters. The lamps were replaced prior to the fall quarter in accordance with the manufactures relamping recommendations.

2.4 Analytical Methods

2.4.1 Sampling and Analytical Protocol

The sampling and analytical protocol was previously approved by both the California Department. of Health Services and the Central Valley Regional Water Quality Control Board after a series of meetings in 1993. The water quality parameters that were measured, the frequency of testing and the analytical methods used are shown in Table 2.2. Samples were collected at 11:00 am. Each quarter included a 5-day intensive week with daily testing of all parameters, and two diurnals, during which parameters were measured at 4 hour intervals to determine the daily variations in treatment.

All water quality parameters were measured from duplicate samples except for viruses, which were measured from a single sample. During diurnal tests only single samples were taken for all parameters. Samples were taken from three sites in the combined ATS/UV disinfection system: the influent, the UV effluent and the ATS effluent (Fig. 2.2). Sampling at each of the sites was timed to correspond with the residence time of the system. Prior to the installation of the rotating drum strainer and sand filters, samples of the ATS effluent were filtered with a 400 micron mesh. Samples for parameters which could not be measured directly were collected in high density polyethylene bottles (Nalgene). The sample bottles were rinsed twice with the sample water and then filled to the top to prevent air spaces. Samples which required acidification to a pH of below 2 for preservation were treated appropriately with concentrated H_2SO_4 (APHA, 1992). All phosphorus samples were collected in dilute HCl acid-washed glass vials. Soluble reactive phosphorus samples were prefiltered through a disposable Millipore filter immediately after sampling. Samples for coliform analysis were collected in sterile glass bottles, and virus samples were collected in EPA bacteriophage sterile sample containers neither of which were rinsed. All samples were stored on ice or in a refrigerator until analysed. Preliminary samples taken between August 30th and November 21st, 1993 were analyzed by A&L laboratories in Modesto. Samples from the four quarters of testing were all analyzed at the Applied Algae Research Group laboratory of Professor Oswald at the Environmental Engineering and Health Sciences Laboratory, UC Berkeley. Quality control of all parameters tested was maintained by comparison to standards and by analyzing spike concentrations.

The viral numbers of the influent to the ATS/UV system were below the necessary level for demonstrating a five-log reduction by the UV disinfection system. Therefore virus seeding experiments at different hydraulic loading rates and water turbidities were conducted. Male-specific MS_2 bacteriophage seed (approximately 10^{12} ml^{-1}) were obtained from BioVir Laboratories (Benecia, CA). The seed was mixed in a 1000 litre or 600 litre tank, then passed through the sand filter and UV disinfection units. Sand

Table 2.2 Parameters tested, the frequency and method of testing[a].

Parameter	Frequency	Method
Climate		
Light	Mon - Fri	Lux Meter (LX 101, Lutron) Photometer (LI - 190SA, Licor, Nebraska).
Temperature	Mon - Fri	Max/Min thermometer
Physical Parameters		
Dissolved Oxygen (mg l^{-1})	Mon - Fri	DO/Temperature Meter (Model 820, Orion Research Inc, Massachusettes)
Temperature (°C)	Mon - Fri	
pH	Mon - Fri	pH Meter (Model 240, Corning Science products, NY)
Alkalinity (mg l^{-1} as $CaCO_3$)	Mon, Wed, Fri	Acid titration
Hardness (mg l^{-1} as $CaCO_3$)	Mon, Wed, Fri	Chelation titration
Conductivity (mS m^{-1})	Mon - Fri	Conductivity probe (Lectro mho-meter (lab-line inst., inc. Illinois).
Nutrients		
Ammonium (mg l^{-1})	Wed, Fri	Distillation and titration
Nitrate/Nitrite (mg l^{-1})	Wed, Fri	Cadmium reduction
Total Organic Nitrogen (mg l^{-1})	Wed, Fri	Kjeldahl
Soluble Reactive Phosphorus (mg l^{-1})	Wed, Fri	Ascorbic acid
Total Phosphorus (mg l^{-1})	Wed, Fri	Ascorbic acid
Organic Matter		
BOD (mg l^{-1})	Mon, Wed, Fri	5-day incubation
COD (mg l^{-1})	Mon, Wed, Fri	Dichromate digestion, titration method[b]
TOC (mg l^{-1})	Mon, Wed, Fri	Infrared analysis
Solids		
UV transmittance (%)	Mon - Fri	Spectrophotometer (253.7 nm)
Turbidity (NTU)	Mon - Fri	Nephelometer (Model DRT 100, HF Scientific inc. Bolton, Ontario, Canada). (0.02 NTU reference HF Scientific inc.)
Total Suspended solids (mg l^{-1})	Mon, Wed, Fri	Dried at 103-105 °C
Settleable solids (ml l^{-1})	Mon - Fri	Imhoff Settling Cones (Nalgene Brand Products, model 1000 ml, polycarb)

Parameter	Frequency	Method
Microbiology		
Faecal Coliforms (MPN 100 ml^{-1})	Mon, Wed, Fri	Multiple tube fermentation
Total Coliforms (MPN 100 ml^{-1})	Mon, Wed, Fri	Multiple tube fermentation
F- Male specific bacteriophage (MPN 100 ml^{-1})	Mon, Wed, Fri	Multiple tube method, assay adopted from Kott
General Minerals (mg l^{-1}) ($Na+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, Cl^-$)	Twice per quarter	Na^+, Mg^{2+}, Ca^{2+} measured on ICP SO_4^{2-} and Cl^-: titration
Harvestable solids		
Productivity (g m^{-2} d^{-1})	Fri	Oven dried at 105 °C
Volatile solids (g m^{-2} d^{-1})	Fri	Ignited at 550 °C
Nutrient content (g kg^{-1})	Fri	Nitric acid digestion, measured on ICP (Phosphorus) Kjeldahl digestion (Nitrogen)
Mineral content (g kg^{-1})	Fri	Nitric acid digestion, measured on ICP
Heavy Metal content (g kg^{-1})	Fri	Nitric acid digestion, measured on ICP
Microscopic analysis	Fri	Compound Microscope (Fisher Micromaster, model CK, w/Trinocular)

[a] All methods carried out according to Standard Methods for the Examination of Water and Wastewater, 18th ed., 1992, unless otherwise indicated.

[b] Bioscience accu-TEST™ COD Method.

filter and UV effluent samples were collected at time intervals corresponding to the residence time of the units, and tested for bacteriophage, turbidity and UV transmittance.

Harvested solids of the top and bottom of the floway were both sampled from five random 0.093 m^2 (1 ft^2) sites and used to calculate the mean for the floway. At several times during the test period samples of solids from the top, middle and bottom of the floway were dried and analyzed for chemical composition by A&L laboratories in Modesto. The Algal biomass which sloughed off the floway during the growth period was also measured periodically using drying screens which collected the biomass in the wash water from the rotary drum strainer.

3.0 Results

This was the first large-scale ATS to be built, therefore, many of the operational parameters were changed during the evaluation period to optimize treatment performance. The yearly mean ± s.d. and range values of all the parameters measured during the study are shown in Table 3.1. The fall quarter mean ± s.d. of all the parameters at the two hydraulic loading rates are given in Table 3.2. The yearly, fall quarter and diurnal results for all of the parameters are graphed in the appendix. The large standard deviations of the yearly and fall means are due to the wide variation of the levels in the influent, as demonstrated by the ranges (Tables 3.1 & 3.2). However, the yearly means indicate the general trends for treatment by the ATS/UV system which are more clearly seen in the fall quarter means when the complete ATS/UV system was operating.

The treatment capabilities of the ATS/UV system are described below.

- Temperature, dissolved oxygen concentration (DO) and pH of the wastewater were all increased by the ATS/UV system (Tables 3.1 & 3.2). All three parameters were within the limits for discharge effluents and receiving waters (Table 1.1).
- Alkalinity, conductivity and hardness of the wastewater were all reduced by the ATS/UV system and were below the levels permissible for river discharge (Tables 1.1, 3.1 & 3.2).
- Concentrations of all forms of nitrogen and phosphorus were reduced by the ATS/UV system (Table 3.1 & 3.2). There are no regulatory levels for the discharge of nutrients at present, but the ATS/UV system may be

Table 3.1 Yearly mean ± s.d. and range values of all parameters measured in the influent and effluent of the ATS/UV system.

Parameter	**ATS/UV System Influent**		**ATS/UV System Effluent**	
	Mean ± s.d.	**Range**	**Mean ± s.d.**	**Range**
Physical Parameters				
Temperature (^{o}C)	18.86 ± 5.25	7.20 - 27.2	24.43 ± 6.94	7.10 - 36.80
Dissolved Oxygen (mg l^{-1})	4.79 ± 3.13	0.60 - 22.00	24.86 ± 4.94	11.70 - 35.50
pH	8.43	7.01 - 9.50	9.48	8.50 - 10.14
Alkalinity (mg l^{-1} as $CaCO_3$)	235.00 ± 34.35	150.20 - 325.80	210.39 ± 30.79	138.06 - 297.47
Hardness (mg l^{-1} as $CaCO_3$)	460.67 ± 26.99	402.60 - 528.00	434.98 ± 23.09	380.00 - 515.00
Conductivity (mS m^{-1})	215.31 ± 10.10	12.68 - 178.76	206.00 ± 9.13	177.84 - 236.57
Nutrients				
Ammonium (mg l^{-1})	3.25 ± 6.66	0.00 - 34.00	2.53 ± 5.61	0.00 - 31.00
Nitrate/Nitrite (mg l^{-1})	4.98 ± 7.45	0.01 - 50.00	3.79 ± 5.89	0.00 - 37.00
Total Organic Nitrogen (mg l^{-1})	4.95 ± 9.54	0.35 - 69.1	3.86 ± 6.02	0.22 - 28.77
Soluble Reactive Phosphorus (mg l^{-1})	2.69 ± 1.16	0.18 - 4.70	1.18 ± 0.98	0.00 - 3.30
Total Phosphorus (mg l^{-1})	3.14 ± 1.01	0.45 - 4.80	1.67 ± 0.91	0.43 - 3.50
Organic Matter				
BOD (mg l^{-1})	9.65 ± 11.56	0.83 - 48.85	9.66 ± 10.85	0.89 - 46.66
COD (mg l^{-1})	44.39 ± 34.41	12.68 - 178.76	47.20 ± 33.29	13.82 - 179.36
TOC (mg l^{-1})	10.42 ± 10.02	0.98 - 60.34	11.95 ± 10.77	1.23 - 63.61
Solids				
UV transmittance (%)	66.39 ± 12,86	28.15 - 82.70	66.18 ± 12.40	81.00 - 28.35
Turbidity (NTU)	7.88 ± 9.01	0.95 - 38.25	6.34 ± 7.62	1.25 - 33.75
Total Suspended solids (mg l^{-1})	15.08 ± 25.73	0.00 - 83.00	12.69 ± 18.86	0.00 - 75.00
Settleable solids (ml l^{-1})	< 0.1	< 0.1 - 0.2	< 0.1	< 0.1 - 0.1
Microbiology				
Faecal Coliforms (MPN 100 ml^{-1})	$2.0 \times 10^4 \pm 5.6 \times 10^4$	$< 2.2 - 3.0 \times 10^5$	3.81 ± 9.10	< 2.2 - 80.0
Total Coliforms (MPN 100 ml^{-1})	$1.0 \times 10^5 \pm 5.0 \times 10^5$	$< 2.2 - 3.0 \times 10^6$	20.26 ± 61.91 (median < 2.2)	< 2.2 - 485.0
F- Male specific bacteriophage (MPN 100 ml^{-1})	$1.9 \times 10^2 \pm 2.4 \times 10^2$	$< 2.2 - 1.1 \times 10^3$	< 2.2 ± 1.75	< 2.2 - 9.1

Table 3.2 Fall quarter mean ± s.d. values of all parameters measured in the influent and effluent of the ATS/UV system.

Parameter	ATS/UV System Fall 889 m^3 d^{-1}		ATS/UV System Fall 436 m^3 d^{-1}	
	Influent Mean ± s.d.	**Effluent Mean ± s.d.**	**Influent Mean ± s.d.**	**Effluent Mean ± s.d.**
Physical Parameters				
Temperature (^{o}C)	23.58 ± 1.19	29.27 ± 2.05	19.02 ± 2.79	25.54 ± 3.37
Dissolved Oxygen (mg l^{-1})	5.00 ± 1.32	21.14 ± 3.55	3.33 ± 1.01	22.99 ± 3.84
pH	8.08	9.28	7.73	9.76
Alkalinity (mg l^{-1} as $CaCO_3$)	245.05 ± 17.62	223.93 ± 18.22	244.77 ± 11.25	192.88 ± 14.75
Hardness (mg l^{-1} as $CaCO_3$)	480.77 ± 8.11	454.23 ± 10.35	484.11 ± 17.72	421.96 ± 20.17
Conductivity (mS m^{-1})	215.55 ± 6.32	205.97 ± 5.06	218.09 ± 10.57	202.72 ± 6.35
Nutrients				
Ammonium (mg l^{-1})	0.00	0.00	0.00	0.00
Nitrate/Nitrite (mg l^{-1})	4.20 ± 2.62	2.17 ± 1.80	2.11 ± 2.37	0.93 ± 1.62
Total Organic Nitrogen (mg l^{-1})	1.39 ± 0.24	1.35 ± 0.15	1.10 ± 0.15	1.03 ± 0.15
Soluble Reactive Phosphorus (mg l^{-1})	3.05 ± 0.12	0.88 ± 0.33	3.04 ± 0.53	0.43 ± 0.27
Total Phosphorus (mg l^{-1})	3.47 ± 0.11	1.22 ± 0.33	3.69 ± 0.33	0.79 ± 0.19
Organic Matter				
BOD (mg l^{-1})	4.86 ± 3.67	3.86 ± 3.90	1.89 ± 0.39	1.66 ± 0.44
COD (mg l^{-1})	23.60 ± 8.17	22.14 ± 7.37	18.75 ± 3.23	23.56 ± 4.39
TOC (mg l^{-1})	6.62 ± 1.83	6.98 ± 1.80	5.86 ± 1.50	6.37 ± 1.59
Solids				
UV transmittance (%)	70.43 ± 1.62	73.22 ± 1.47	73.98 ± 2.11	75.40 ± 1.09
Turbidity (NTU)	6.83 ± 1.00	3.18 ± 0.69	3.40 ± 2.36	2.02 ± 0.68
Total Suspended solids (mg l^{-1})	13.34 ± 2.66	5.22 ± 2.55	6.25 ± 4.92	3.64 ± 1.91
Settleable solids (ml l^{-1})	< 0.1	< 0.1	< 0.1	< 0.1
Microbiology				
Faecal Coliforms (MPN 100 ml^{-1})	1.0 x 10^3 ± 8.4 x 10^2	< 2.2 ± 0.0	1.0 x 10^3 ± 1.7 x 10^3	< 2.2 ± 0.0
Total Coliforms (MPN 100 ml^{-1})	7.7 x 10^3 ± 6.8 x 10^2	< 2.2 ± 1.8	3.5 x 10^3 ± 3.3 x 10^3	< 2.2 ± 0.52

capable of reducing levels present in Patterson wastewater to meet future requirements (Table 1.1).

- At the concentrations found in Patterson secondary effluent, organic constituents measured as BOD, COD and TOC were only minimally reduced, not reduced at all, or in some instances increased by the ATS/UV system (Tables 3.1,3.2 & Fig. 3.1). The influent values, and subsequently the ATS/UV effluent values, were below the regulatory levels for discharge (Table 1.1).

- The ATS/UV system was effective at reducing turbidity and suspended solids and increasing the UV % transmittance of the wastewater (Table 3.1). Installation of the rotary drum strainer and sand filters in the fall quarter, significantly improved suspended solids removal (Table 3.2).

- Coliform and viral numbers in the wastewater were reduced by the ATS/UV system (Table 3.1). During the fall quarter when the influent to the ATS/UV system was taken from Pond 3A, and filtration of particulates by the rotating drum strainer and sand filters was implemented, coliform and bacteriophage numbers were reduced to below regulatory levels (Tables 1.1 & 3.2). Virus seeding experiments demonstrated that a five-log reduction in viral concentration was attained by the ATS/UV system (Table 3.3).

Various hydraulic loading rates were used throughout the year-long study. The effects of this parameter on treatment by the ATS/UV system are demonstrated by the results for the two loading rates used during the fall quarter. Lowering the hydraulic loading rate caused greater reduction of alkalinity, conductivity and hardness, and increased removal of both total phosphorus and soluble reactive phosphorus (Table 3.2). When these parameters are plotted against flow rate for the entire year an inverse relationship can be seen (Fig. 3.2). The concentration of phosphorus and cations (calcium, magnesium, and aluminum) in the harvested biomass also shows this trend (Table 3.4). However a comparison of phosphorus removal based on 24 hour total removal to mean daily removal, as determined by the 11:00 am samples for each quarter, indicates that the lower hydraulic loading rate caused increased daily removal, but not increased diurnal removal (Table 3.5). The pH of the ATS/UV effluent showed an inverse relationship with flow rate, indicating that pH was most likely involved in the reduction of phosphorus and the cations (Figs. 3.2 & 3.3). The results of the 24 hour studies also showed that the removal of phosphorus, reduction of alkalinity, conductivity and hardness were related to change in pH with solar irradiance. This relationship was more pronounced at the lower hydraulic loading rates (Fig. 3.4). All forms of nitrogen were removed by the ATS (Tables 3.1 & 3.2). The ability of the ATS to remove nitrate was best shown during the fall

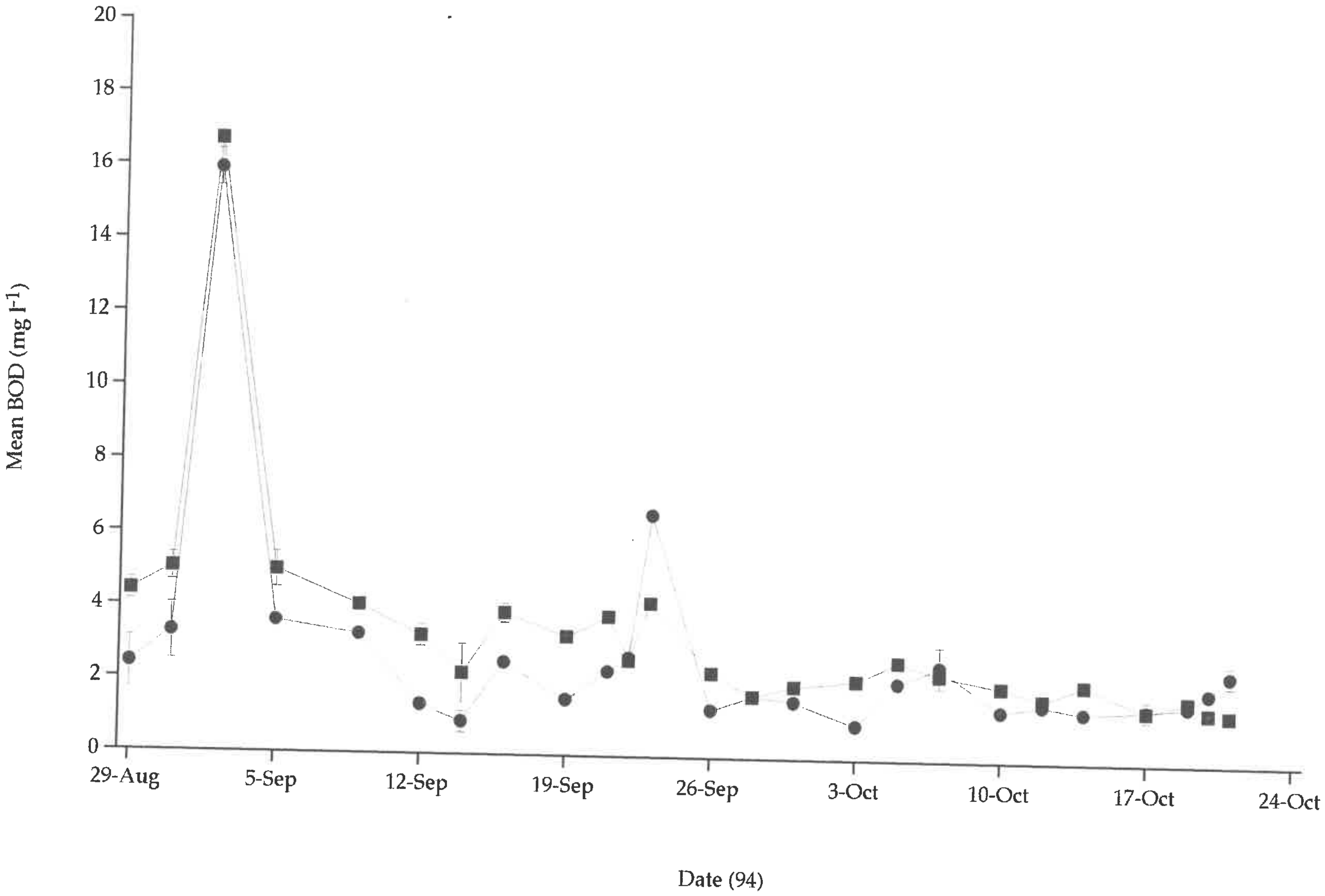


Figure 3.1 Fall quarter. Biochemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.

Table 3.3 Fall quarter Male Specific-2 Bacteriophage[a] seeding experiment values and parameters.

Date	Mixed Seed Effluent	Sand Filter Effluent	UV Effluent	Hydraulic Loading ($m^3\ d^{-1}$)	Turbidity (NTU)
Sep 26	9.0×10^5	9.0×10^4	< 3	427	6.4
Oct 7	4.3×10^7	9.3×10^1	< 3	214	20
Oct 14	4.0×10^5	9.3×10^3	< 3	684	3
Oct 17	1.1×10^9	$> 1.1 \times 10^4$	9.1	1004	3

[a] Assay adopted from Kott, multiple tube method, host fAmp.

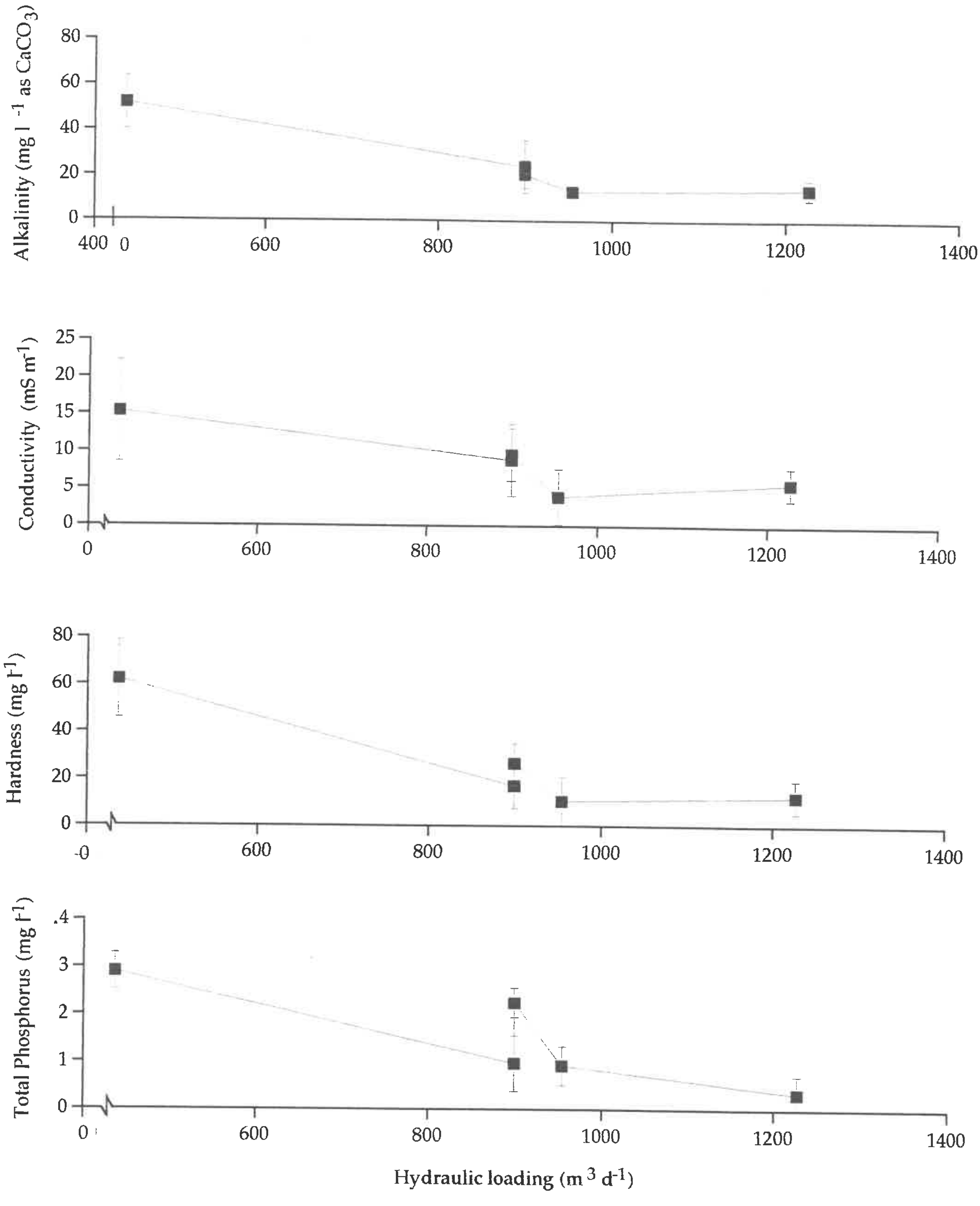


Figure 3.2 Total phosphorus removal and alkalinity, conductiviy and hardness reduction by the ATS/UV system at different hydraulic loadings. Values are means ± s.d. (n=19).

Table 3.4 Comparison of ATS fall quarter total harvested solids composition at two hydraulic loadings and mean weekly pH.

Date	Hydraulic Loading $m^3 d^{-1}$ ($ft d^{-1}$)	Mean Weekly pH	pH Range	Mean Harvested Solids ($g m^{-2} d^{-1}$)	N Content ($g kg^{-1}$)	P Content ($g kg^{-1}$)	N Removed ($g m^{-2} d^{-1}$)	P Removed ($g m^{-2} d^{-1}$)	Mg Content ($g kg^{-1}$)	Ca Content ($g kg^{-1}$)	Al Content ($g kg^{-1}$)
23-Sep	899 (2.89)	9.47	9.28 - 9.60	24.47 ± 0.20	33.70	21.23	0.82	0.52	25.13	26.70	15.99
21-Oct	436 (1.40)	10.08	9.50 - 10.28	19,73 ± 3.80	32.17	23.37	0.63	0.46	30.80	35.90	10.00

Table 3.5a Comparison of mean daily phosphorus removal and mean and range daily pH values with mean influent concentration at two hydraulic loading rates during the fall quarter.

Date	Hydraulic Loading ($m^3 d^{-1}$)	ATS Effluent pH Mean	 Range	Solubel Reactive Phosphorus Influent Concentration ($mg l^{-1}$) Means ± s.d.	 Removal ($mg l^{-1}$) Means ± s.d.	Total Phosphorus Influent Concentration ($mg l^{-1}$) Means ± s.d.	 Removal ($mg l^{-1}$) Means ± s.d.	 Mass TP Removed ($g m^{-2} d^{-1}$)
Daily Means								
19-23 Sep	898	9.47	9.28 - 9.60	2.98 ± 0.14	2.08 ± 0.66	3.40 ± 0.08	2.05 ± 0.45	1.82
17-21 Oct	428	10.08	9.50 - 10.28	2.97 ± 0.10	2.50 ± 0.26	3.40 ± 0.05	2.65 ± 0.24	1.12
24 h Means								
20-21 Sep	898	9.27	8.05 - 9.60	3.09 ± 0.03	0.65 ± 1.70	3.35 ± 0.07	0.61 ± 1.62	0.54
19-20 Oct	428	9.81	8.16 - 10.26	2.94 ± 0.10	0.65 ± 1.76	3.30 ± 0.07	0.58 ± 1.71	0.25

Table 3.5b Comparison of mean daily ammonium, nitrate/nitrite and total kjeldahl nitrogen removal and mean and range daily pH values with mean influent concentration at two hydraulic loading rates during the fall quarter.

Date	Hydraulic Loading ($m^3 d^{-1}$)	ATS Effluent pH Mean	 Range	Nitrate/Nitrite Influent Concentration ($mg l^{-1}$) Means ± s.d.	 Removal ($mg l^{-1}$) Means ± s.d.	Total Kjeldahl Nitrogen Influent Concentration ($mg l^{-1}$) Means ± s.d.	 Removal ($mg l^{-1}$) Means ± s.d.	Total Nitrogen Removal ($mg l^{-1}$)	Mass N Removed ($g m^{-2} d^{-1}$)
Daily Means									
19-23 Sep	898	9.47	9.28 - 9.60	7.68 ± 0.63	3.22 ± 1.16	1.14 ± 0.4	1.14 ± 0.14	4.36	3.87
17-21 Oct	428	10.08	9.50 - 10.28	1.23 ± 0.24	1.01 ± 0.09	1.01 ± 0.09	0.80 ± 0.05	1.81	0.77
24 h Means									
20-21 Sep	898	9.27	8.05 - 9.60	7.78 ± 0.52	1.76 ± 1.65	1.20 ± 0.08	0.09 ± 0.24	1.85	1.64
19-20 Oct	428	9.81	8.16 - 10.26	0.93 ± 0.11	0.77 ± 0.13	1.02 ± 0.08	0.16 ± 0.13	0.93	0.39

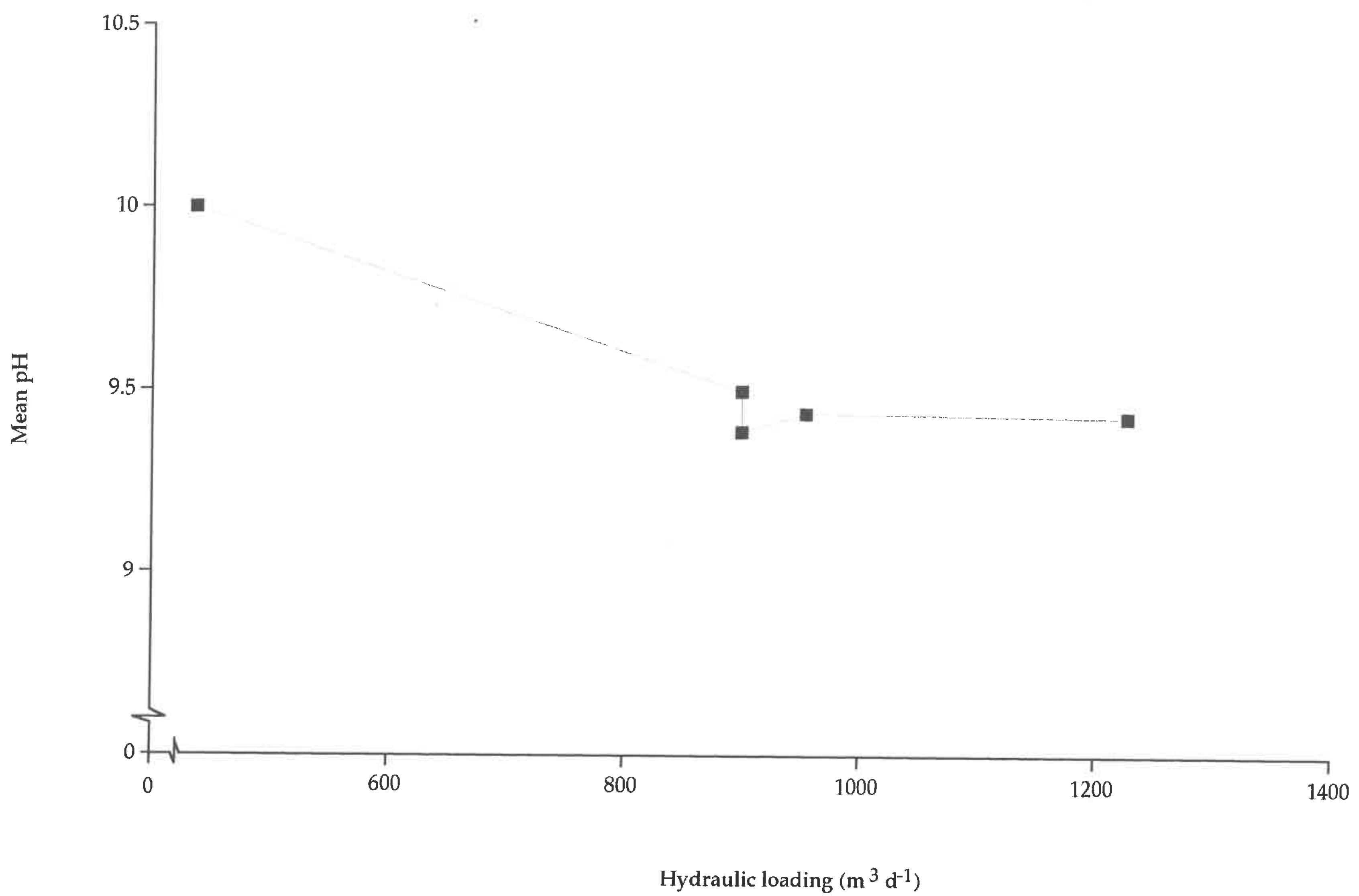


Figure 3.3 pH of the effluent of the ATS/UV system at different hydraulic loadings. Values are means ± s.d. (n=19).

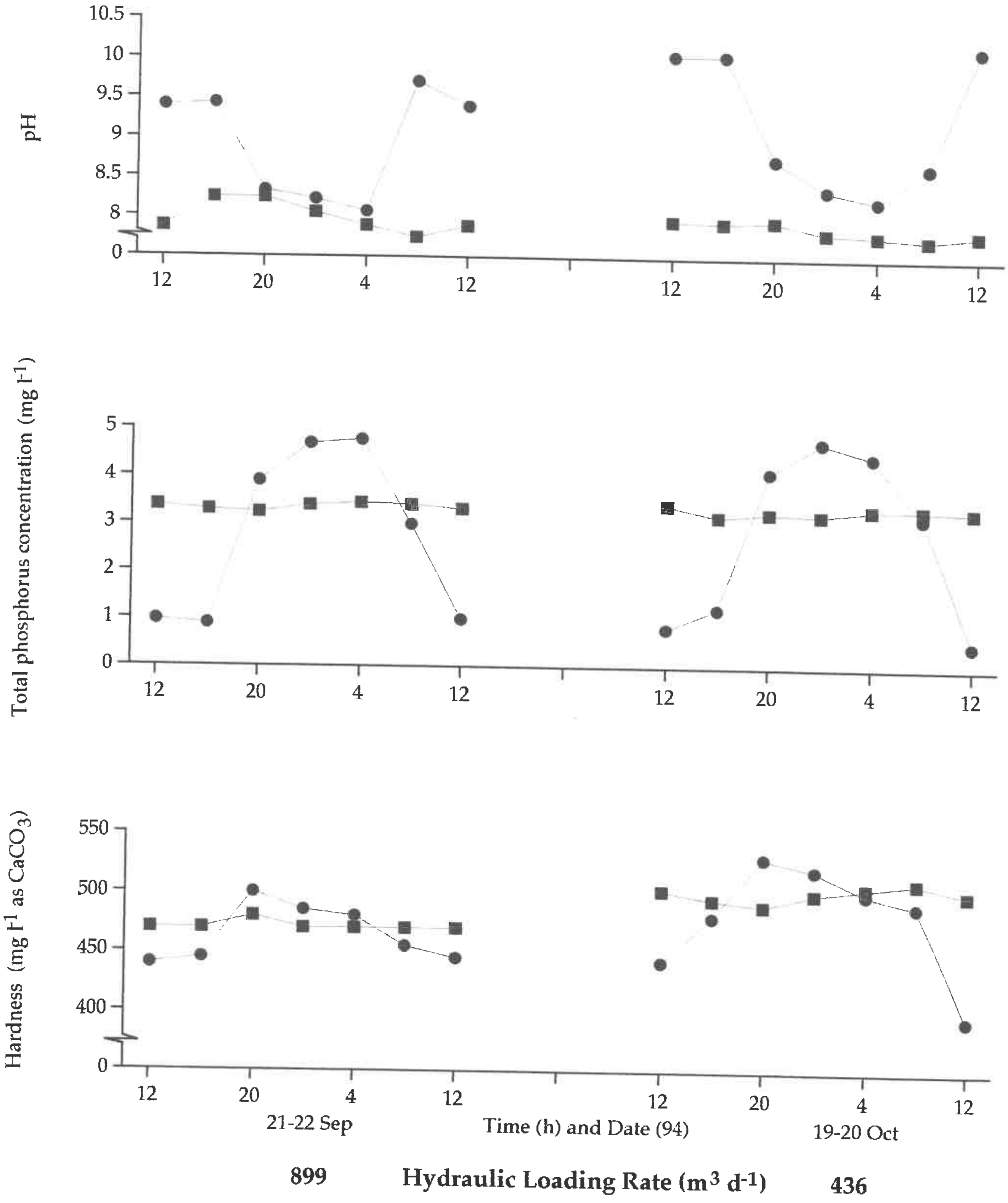


Figure 3.4 24 hour variation in pH, total phosphorus concentration and hardness of the influent (■) and effluent (●) of the ATS/UV system at two hydraulic loading rates.

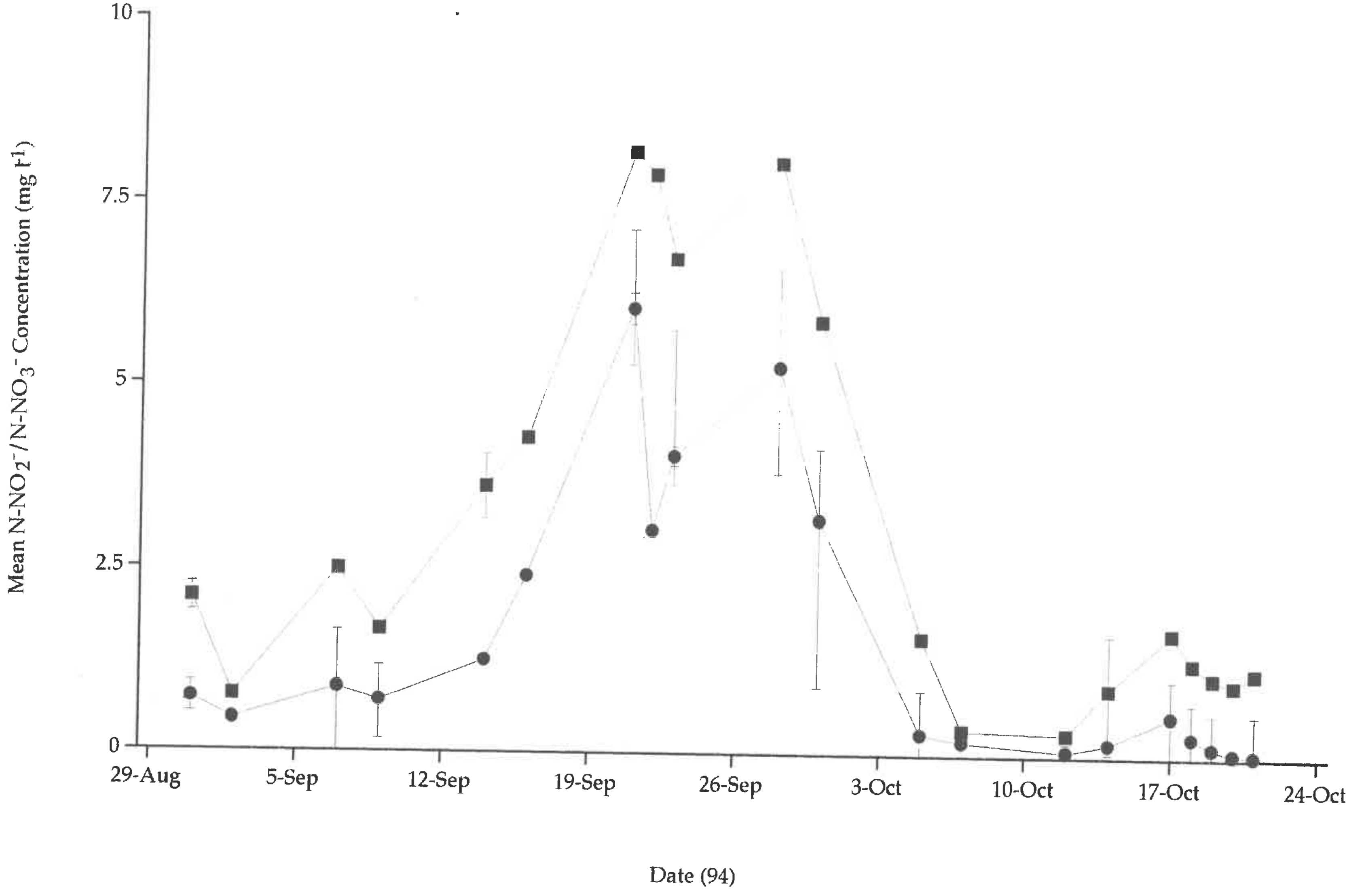


Figure 3.5 Fall quarter. Nitrite- and Nitrate-nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.

quarter (Fig. 3.5). The mean nitrogen content of the total harvested solids was 3.1%; however, the nitrogen content of the biomass was actually reduced at the lower hydraulic loading (Table 3.4).

The harvested solids varied over the year with season and solar irradiance, with a mean of 23.75 ± 16.39 g m^{-2} d^{-1} (dry wt.), summer maximum of 60.91 g m^{-2} d^{-1} and winter minimum of 4.17 g m^{-2} d^{-1}. The decrease of hydraulic loading rate in the fall quarter seemed to reduce the decline in productivity seen during the fall quarter (Fig. 3.6). Species composition of the algal turf varied over the study period (Table 3.6). For much of the year the predominant algal species were cyanobacteria (*Oscillatoria* and unidentified fine filamentous sp.) and diatoms (*Navicula* sp., *Nitzschia* sp. and *Cyclotella* sp.). However green filamentous species (*Ulothrix* sp., *Cladophora* sp. and *Microspora* sp.) which were prevalent on the floway during the preliminary test period, were lost when the floway dried out due to accidental power failure in October 1993. These filamentous species did not naturally reseed on the floway, and were only reestablished in the last three weeks of the summer quarter when seeding of the floway following harvest was initiated. A rapid recovery of species diversity and productivity followed a second drying out of the floway in August 94 (Fig. 3.6), due to weekly reseeding. Several filamentous species (*Cladophora* sp., *Ulothrix* sp., *Stigeoclonium* sp., *Spyrogyra* sp., *Tribonema* sp., and *Rhizoclonium* sp.) were prevalent during the fall quarter.

A number of invertebrate species were found on the floway. The most abundant were the amphipods and midge larvae or chironomids. The chironomids settled on the floway surface and dislodged the algal turf surrounding their cocoons. They were most prevalent during August 94, when they caused algal productivity to be reduced (Fig. 3.6). However, drying out of the floway following harvest on the 26th August, successfully killed the larvae, and productivity of the floway was quickly restored by seeding.

4.0 Discussion

The ATS/UV system was tested under ambient conditions for one year using various configurations and operational regimes. The ability of this system to treat the effluent from the Patterson wastewater treatment facility to within the Californian regulatory standards for discharge to the San Joaquin River was evaluated. The yearly mean values, and particularly the fall mean values, demonstrate the capability of this system to meet all of the regulatory standards based on the present influent water quality conditions (Tables 1.1, 3.1 & 3.2). Although many of the parameters that were measured are not currently regulated, some are used as indicators of water quality and treatment performance. Other parameters, particularly nutrients, are likely to be included in future regulations.

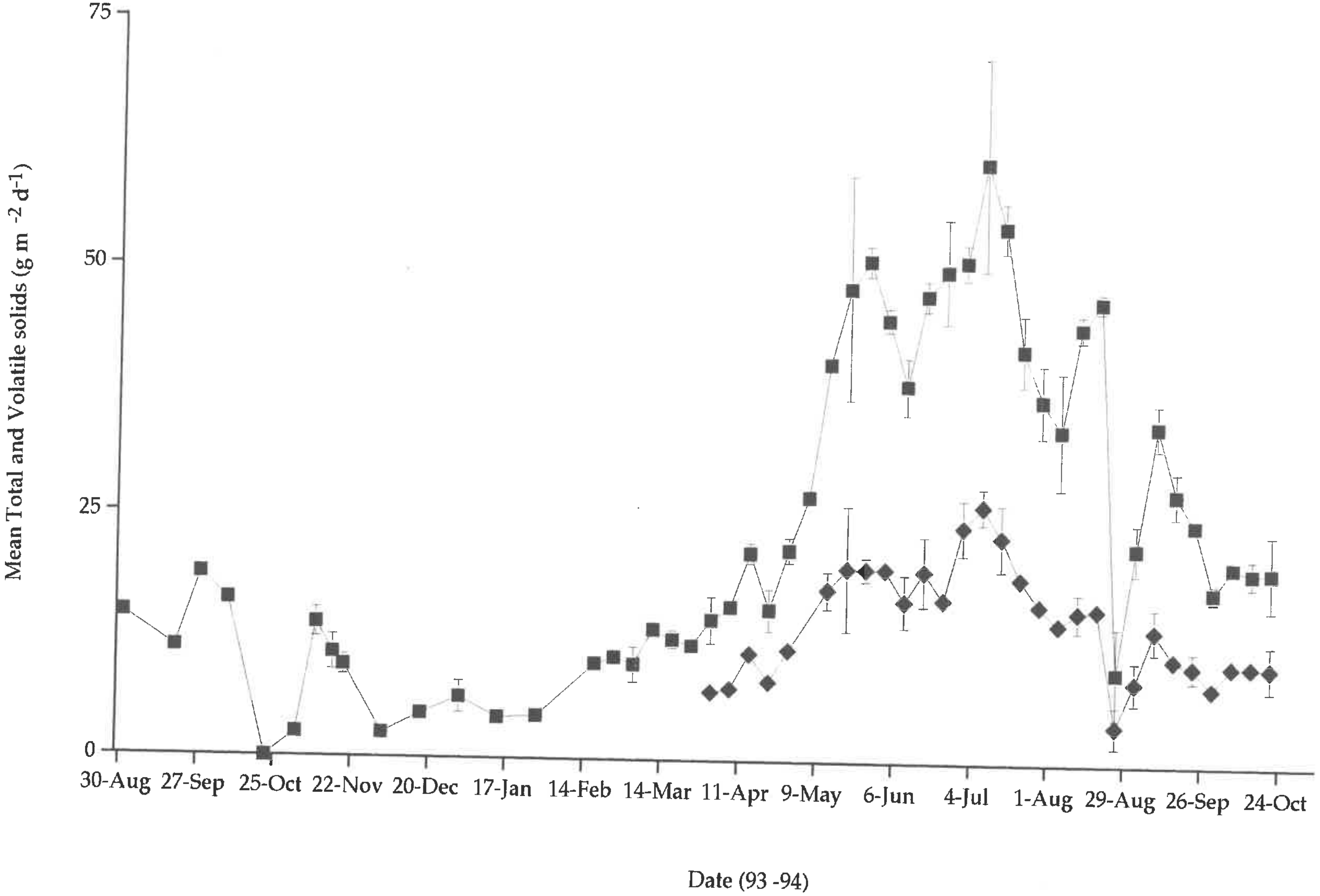


Figure 3.6 Total (■) and Volatile (◆) solids from the ATS. Values are means ± s.d. of two composite samples, each from five sites.

Table 3.6 Dominant algal species of the ATS floway during a 1 year study at Patterson, California.

Algal Species	Preliminary Period	Winter Quarter	Spring Quarter	Summer Quarter		Fall Quarter
				W 1-5	W 6-8	
Cyanophyceae						
Oscillatoria sp.	2	4	4	4	3	3
Unidentified fine filamentous sp.	-	-	4	4	3	3
Spirulina sp.	3	2	-	-	1	1
Anabena sp.	-	-	-	-	1	-
Bacillariophyceae						
Navicula sp.	4	4	4	4	4	4
Nitzschia sp.	4	4	2	2	2	2
Cyclotella sp.	-	-	2	3	4	4
Fragillaria sp.	-	-	-	-	-	3
Melosira sp.	-	-	-	-	-	2
Stauroneis sp.	-	1	-	-	2	2
Surirella sp.	-	1	-	-	-	-
Chlorophyceae						
Chlorella sp.	-	-	-	1	1	-
Scenedesmus sp.	1	-	-	-	1	1
Closterium sp.	1	-	-	-	-	-
Chroococcus sp.	3	1	-	-	-	-
Selenastrum sp.	-	-	-	-	-	2
Cladophora sp.	2	2	1	-	-	2
Ulothrix sp.	4	-	-	-	4	3
Stigeoclonium sp.	-	-	-	-	-	2
Spyrogyra sp.	-	-	-	-	-	4
Tribonema sp.	-	-	-	-	-	3
Rhizoclonium sp.	-	-	-	-	-	3
Hydradictyon sp.	-	-	-	-	-	2
Microspora sp.	-	1	-	-	-	-

W1-5	Weeks one to five
1	Present
2	Few
3	Many
4	Major

Many of the operational parameters for the Patterson ATS were developed concurrently with collection of data for evaluation of the system. Due to the fact that operational parameters were changed, and the final configuration was not established until the fall quarter, the mean yearly values of some of the parameters did not meet regulatory standards. In addition, seasonal variations attributed to the yearly values not meeting regulatory standards. During the summer quarter, phytoplankton blooms in the pond increased the solids and organic loading of the influent to the ATS/UV system. Consequently, the organic load of the ATS/UV effluent was also increased, due to the fact that the ATS has only limited ability to filter these microscopic algae from the water. Reduced coliform disinfection during the summer quarter may have been due to the phytoplankton blooms increasing the turbidity of the ATS/UV influent. Increased turbidity reduces the efficiency of UV disinfection due to increased scattering and absorption of UV light (NWRI, 1993). In the spring quarter, when the influent to the ATS/UV system was taken directly from the treatment facility stand pipe, it was observed that the UV bulbs became quickly coated with mineral scales and mucilage. The coating on the quartz shields may have contributed to reduced disinfection, especially since the quartz shields were only cleaned at two week intervals during this quarter. Placement of the UV disinfection unit after the ATS, and the addition of the rotating drum strainer and sand filters in the fall quarter, enabled complete UV disinfection to be maintained throughout the quarter, despite variations in influent turbidity. The sand filter increased removal of suspended solids, while reduction of hardness by the ATS may have reduced the scaling of the UV bulbs.

Given the high DO concentrations of the ATS/UV system effluent, it was expected that more organic matter (measured as BOD, COD and TOC) would have been removed by the system. All water bodies and biological systems have a background organic content (pers. comm. W. Oswald). It is conceivable that the BOD and COD concentrations of the influent were already at the background levels for the ATS/UV system. Further, the BOD and COD tests do not differentiate between the organic content of the wastewater and that of the algal matter, which is considered to be less of a pollutant to aquatic environments. In addition, algae are also known to excrete organic compounds which may have resulted in the increase in TOC concentration of the ATS/UV effluent (Tables 3.1 &3.2). The capability of the ATS/UV system to remove these parameters that were already below regulatory levels for discharge is unknown at this time. The removal of BOD and COD by the ATS has been previously described (Adey *et al.*, 1994). However, these studies used recirculating ATS/mesocosm systems which have different operational parameters than the Patterson ATS. Further research is required in this area using an influent wastewater with higher BOD and COD than the Patterson wastewater treatment facility effluent.

UV disinfection is a novel means of inactivating faecal bacteria and viruses (NWRI, 1993). Typically, regulations for the use of UV disinfection require prior coagulation, flocculation, sedimentation and filtration (NWRI, 1993). In this study, microbiological standards were met without the use of a chemical coagulant. Algal excretions may have provided a "natural" coagulant, promoting coagulation and filtration prior to the UV, which enhanced disinfection by the ATS/UV system. The bacteriophage seeding experiment demonstrated considerable reductions by the sand filter, especially at high turbidities, indicating that coagulation and filtration may have been taking place (Table 3.3). The use of an ATS to produce a natural coagulant and to aid in filtration could alleviate the need for costly chemical coagulants, such as alum, which produce a secondary waste product.

Both nitrogen and phosphorus were reduced by the ATS/UV system. The nitrogen content of the total harvested solids during the fall quarter was 3.3 %. However, the calculated nitrogen concentration of the volatile solids was 7.3 %, which is more typical for algal biomass. The mass of nitrogen removed per day by the ATS based on 24 hour removal during the first diurnal of the fall quarter was 1.64 g $m^{-2} d^{-1}$. However, the mass removed per day based on the nitrogen content of the harvested biomass for the week of the first diurnal of the fall quarter was only 0.82 g $m^{-2} d^{-1}$. This discrepancy of nitrogen mass balancing indicates that there was nitrogen removal by a process other than assimilation, perhaps denitrification. The decline in the percent nitrogen of the biomass with decreased flow rate in the fall quarter may have been due to increased carbon deficiency of the system, which was indicated by the increase in pH of the ATS/UV effluent.

Phosphorus may be removed from wastewaters by either filtration, adsorption, assimilation (including luxury uptake), or precipitation (Bogan, 1961; Swift & Nicholas, 1987). Most of the total phosphorus in the Patterson treatment facility effluent was soluble reactive phosphorus, suggesting that removal was either by assimilation or precipitation. The inverse relationships between hydraulic loading and the pH, phosphorus removal, and hardness reductions of the ATS/UV system indicates that precipitation may account for much of the phosphorus removal by the ATS (Figs. 3.2 & 3.3). As the hydraulic loading was reduced, the pH and hardness reductions increased, as did the mean total phosphorus removal. Phosphorus precipitation may explain why the harvested solids from the ATS had a mean phosphorus content of 2.1 %, when periphyton biomass normally contains < 1 % phosphorus (Swift, 1981; Auer & Canale. 1982; Kesler, 1983; Davis *et al.*, 1990). Adey *et al.* (1993) found a phosphorus content of 0.4 % in periphyton grown on agricultural run-off. The precipitation of phosphorus with cations (such as Ca^{2+}, Mg^{2+}, and Al^{3+}) at high pH is known to occur between pH 8.9 - 9.5, depending upon the buffering capacity of the water (Belsare & Belsare, 1987). The increase in the pH of the ATS/UV effluent was most likely a result of the algal turf being carbon limited, and the subsequent use of bicarbonate for photosynthesis (Richmond, 1983; Fabregas *et al.*, 1984; Soeder & Hegewald, 1988). Higher phosphorus removal at the lower hydraulic loading rate (1.40 $m^3 d^{-1}$) during the fall quarter, which were measured by both the daily removal and the biomass content (Tables 3.4 & 3.5), were probably due to increased pH-mediated precipitation. The dissolution of some of this precipitate at night, when the pH declined to below 8.9 accounts for the lower 24 hour phosphorus removal rates (Table 3.5). Nutrient removal values based on biomass analysis are an integration of the total removal by the periphyton and are therefore a more accurate measurement than daily, or even hourly, analysis of water chemistry. The decrease in the mass of nitrogen and phosphorus removed by the ATS/UV system at the lower hydraulic loading rate was due to the lower volume of water treated, as well as a seasonal decrease in productivity of the floway in October compared to September (Tables 3.4 & 3.5; Fig. 3.6).

Maintenance of the pH of the ATS/UV system effluent above that at which precipitation occurs may provide a simple means of optimizing phosphorus removal by the ATS. The pH may be easily maintained by controlling the length of time the wastewater is in contact with the algal turf. This may be done either by reducing the hydraulic loading rate of the floway, or passing the wastewater down a longer floway. Dissolution of precipitated phosphorus at night could possibly be prevented by either recirculating at night, greatly reducing the flow at night such that no water is discharged, or by maintaining the pH by chemical addition.

The ATS could also be operated in two ways to either promote assimilation of phosphorus into algal biomass or promote pH mediated precipitation with cations. Phosphorus assimilation would be promoted by engineering fast growth of biomass, while precipitation would be enhanced by maintenance of high pH. Both of these operations would be affected by the amount of biomass on the floway. Frequent harvesting would maintain exponential growth of the biomass, while a longer harvest interval would maintain a large standing crop to raise pH. Harvesting the floway simulates heavy grazing of the plant community which has been shown to stimulate algal growth (Adey & Loveland, 1991). Previous studies have shown ATS systems to remove nutrients from low levels in agricultural runoff and marine systems (Adey & Loveland, 1991; Adey *et al.*, 1993). Perhaps high levels of phosphorus could first be removed by pH mediated precipitation, and lower concentrations could then be reduced by rapid algal growth on a second floway run in series. Combinations of floway configurations may therefore be used to meet the desired levels. Further study is necessary in this area and to determine whether the use of wastewater with a higher carbon concentration would increase algal assimilation of nutrients. The pH obtained in the ATS/UV system effluent, should have little effect on receiving waters since it is only a result of carbon dioxide (CO_2) deficiency, and CO_2 may be easily returned to the effluent and pH restored to within discharge levels upon mixing with the receiving water.

The harvest interval should be varied with solar irradiance and time of year, to maintain sufficient biomass on the ATS floway. The results of the present study show that a harvest interval of less than one week may be appropriate when the highest productivity's were recorded during the summer, while intervals of up to a month may be required during the winter when productivity is at its lowest (Fig. 3.6). The maximum productivity (total solids dry weight) observed in this study (60.91 g m^{-2} d^{-1}) is much greater than that previously reported on periphyton water treatment systems (22 g m^{-2} d^{-1}; Davis *et al.*, 1990b), phytoplankton growing in sewage enriched outdoor mass cultures (Goldman, 1979), and the highest values reported for macrophytes (Reddy & Debusk, 1987). It even exceeds the maximum productivity of phytoplankton (30 g m^{-2} d^{-1}) measured in laboratory experiments. The harvested solids from the present study may seem extraordinarily high, although algal production exceeding 100 g m^{-2} d^{-1} has been found with intensive laboratory systems (NASA). This is likely due to a combination of factors, including the relatively high nutrient content of the Patterson treatment facility effluent, the shallow depth of the water (allowing for rapid gas exchange and high irradiance), fast water flow permitting rapid nutrient assimilation and exchange, and relative absence of grazers (Davis *et al.*, 1990; Adey & Loveland, 1991). Sedimentation, filtration and precipitation of particulates on the floway surface probably also attributed to the high total solids values.

The ATS is a biological treatment system, consisting of a mixed assemblage of bacteria, phytoplankton and periphyton. The algal turf community probably consisted of those species most adapted to, or tolerant of, the growth conditions on the floway surface. The structure of the community was similar to that previously described (Adey & Hackney, 1989; Adey & Loveland, 1991; Adey *et al.*, 1993), except in this study, species diversity was lower and cyanobacteria and diatoms predominated during much of the year. Cyanobacteria are generally known to prefer nitrate as a nitrogen source. Prevalence of nitrate in the influent wastewater used during this study may explain the dominance of *Oscillatoria* sp. and other cyanobacteria on the floway. The low species diversity and reduced performance of the ATS/UV system during the first three quarters were probably due to a lack of algal spores in the Patterson treatment facility effluent which are necessary for seeding of the floway. Particularly, as seeding of the floway in the sixth week of the summer quarter increased species diversity. Algal species diversity was probably maintained on previous ATS floways by recirculating spore laden water through mesocosms (Adey & Loveland, 1991) or using influent from natural water bodies (Adey *et al.*, 1993). Seeding the floway with collected, harvested, or specially cultured algal species, may therefore be an important operational parameter for obtaining optimal performance of ATS treatment systems. Seeding may be particularly critical when treating wastewater, where there is little opportunity for algal spores to enter the system. The maintenance of certain species which have efficient treatment capabilities, or which produce commercially viable products, may be attained by seeding. Further research into the treatment properties of particular algal species, and the ability to maintain the dominance of these species on a floway, needs to be performed.

The texture of the floway surface seems to be of particular importance for the maintenance of algal species and the promotion of algal productivity. All previous research with algal turf scrubbers used a screen mesh on the floway surface (Adey & Goertemiller, 1987; Adey & Hackney, 1989; Adey & Loveland, 1991). The mesh becomes impregnated with algal holdfasts and rhizoids, which remain on the floway following harvest (Brawley & Adey, 1981; Adey & Loveland, 1991). This standing crop of algal species was not left on the Patterson floway, especially when harvesting was done with the mechanical vacuum harvester. Further research is required to identify an economical floway surface which maintains a good standing crop of algae after harvest. The problem of invertebrate infestation should also be taken into account in the selection of floway texture. Chironomid larvae reduced algal productivity at the end of August to the degree that it was necessary to dry out the floway. However, this seems to be only a seasonal problem (Lock *et al.*, 1984; Cook *et al.*, 1986; Davis *et al.*, 1990b), and drying out the turf provides a simple method of control, especially when recolonization and development of the algal turf is aided by seeding from near-by streams. Within two weeks after drying out, the seeded floway had reached typical levels of productivity, whereas, screen seeded floways require 6-12 weeks and several harvests to bring them to full production (Adey & Loveland, 1991). Further research is required into liner texture to promote and maintain the species diversity of the algal turf.

5.0 Conclusions

The results presented in this report indicate the potential of the ATS/UV system for the tertiary polishing of secondary treated wastewater. All the existing discharge requirements for discharge to the San Joaquin River can be met. In addition, the ATS consistently removed nutrients, demonstrating potential to meet future regulations. However, the concentrations of many parameters were already low in the Patterson effluent, and therefore, the full potential of the ATS/UV system for treatment of more concentrated wastewater has yet to be determined. The optimal hydraulic loading rate of the ATS seems to be 250 - 500 $m^3\ d^{-1}$ (25 - 50 $cm\ d^{-1}$), which is in the mid-range of loading rates for other treatment methods (Table 5.1).

Table 5.1a Hydraulic loading rates of the ATS/UV system during the year-long evaluation at Patterson.

Quarter	Hydraulic Loading Rate $m^3\ d^{-1}$	 HLV $m\ d^{-1}$	 $cm\ d^{-1}$
Winter	954	0.94	94
Spring	1226	1.21	121
Summer	899	0.89	89
Fall Weeks 1-4	899	0.89	89
Weeks 5-8	436	0.43	43

Table 5.1b Comparison of the optimal hydraulic loading rates of various wastewater treatment methods (pers. comm. W. J. Oswald).

Wastewater Treatment Method		Hydraulic loading Rate ($cm\ d^{-1}$)
Activated Sludge		1500 - 2000
Fermentation Pit		100 - 200
Oxidation Ditch		100 - 150
Algal Turf Scrubber		25 - 50
Facultative Pond		10 - 20
High-Rate Oxidation Pond		5 - 10
Wetland:	Overflowing	3 - 5
	Terminal	1 - 2
Irrigation		0.25 - 0.5

All microbiological standards were met using the ATS/UV system in it's final configuration. The ATS may increase coagulation and filtration by filtering particulates, precipitating hardness and possibly releasing organic coagulants. The high pH, oxygen and temperature of the ATS effluent may also attribute to the reduction of bacteria numbers in the ATS effluent.

ATS phosphorus removal is probably due to a combination of biological uptake (including luxury uptake) and precipitation. Precipitation seems to be the dominant process of removal, although by adjusting the operation and configuration of the system a combination of removal processes may be used to achieve desired effluent levels.

Extremely high productivity's were recorded as harvested solids from the floway. Analysis of the N and P concentrations in the biomass show mean concentrations of P=2.1 % and N=3.1 %. Based on these percentages of the harvested solids, mean removal of phosphorus was 0.73 ± 0.28 g m^{-2} d^{-1}, and the mean removal of nitrogen was 1.11 ± 0.48 g m^{-2} d^{-1}.

The ATS, with its natural assemblage of periphyton and invertebrates is not only aesthetically pleasing but provides a feeding ground for many species of birds. Other biological tertiary treatment systems, such as anoxic denitrification, create odors unless treatment is within expensive containers. The ATS, on the other hand, creates no unpleasant odors, while removing nutrients.

The simplicity of ATS treatment systems enables process control through alteration of operational parameter such as hydraulic loading, floway length and harvest period.

6.0 Further Research

Bioassays for the acute and chronic toxicity of the ATS/UV effluent are a requirement for the National Pollution Discharge Elimination Standards permit. The effluent from the Patterson wastewater treatment facility has previously failed these tests (Table 6.1). The higher DO concentration and reduced nutrient concentrations of the ATS/UV effluent indicates that it should not be toxic to freshwater fauna. Observations of fish tanks containing both Patterson treatment facility effluent and ATS/UV effluent showed that while native fish species collected from a local stream did not survive in the Patterson wastewater effluent tank, they did survive in the ATS/UV effluent tank. Acute and chronic toxicity bioassays must be carried out on the ATS effluent before a permit to discharge will be issued.

Metals or organic compounds with concentrations in the Patterson treatment facility effluent which exceed the regulatory levels of the California

Table 6.1 Chronic toxicity tests using Patterson wastewater treatment facility effluent and receiving stream.

Treatment	Flathead minnow larval survival and growth test		*Ceriodaphnia dubia* survival and reproduction test		*Selenastrum capricornutum* (algal) growth test
	7 d % Survival	Mean dry wt (mg)	7 d % Survival	Mean young per adult	96 h cells ml^{-1}
100 % Patterson Effluent	76.7	1.49	0.0	0.0	410,000
50% Patterson Effluent	100.0	1.04	100.0	18.2	278,333
25 % Patterson Effluent	90.0	0.76	100.0	17.4	373,333
12.5 % Patterson Effluent	100.0	0.65	90.0	17.7	346,667
6.25 % Patterson Effluent	100.0	0.48	100.0	20.5	363,333
Receiving stream	96.7	0.57	100.0	15.8	291,667
Control	93.3	0.32	90.0	21.1	223,333

Table 6.2 Heavy metal and organic pollutant concentrations in the Patterson wastewater treatment facility effluent compared to the water quality objectives for inland surface waters[a] for protection of human health and aquatic life.

	Human Health Drinking water 30-day average ($\mu g\ l^{-1}$)	Human Health Other waters 30-day average ($\mu g\ l^{-1}$)	Aquatic life ($500 mg\ l^{-1}$ Hardness) 4 day average ($\mu g\ l^{-1}$)	Effluent Concentration ($\mu g\ l^{-1}$) 6/16/92	Effluent Concentration ($\mu g\ l^{-1}$) 7/6/92	Effluent Concentration ($\mu g\ l^{-1}$) 30/11/93 chlorinated
Trace elements						
Antimony	14	4300				<2
Arsenic	5		190		< 5	1.9
Beryllium	0.008	0.13				<0.1
Cadmium	10		4		1.5	0.4
Chromium (III)	33000	67000	770		7.7	10
Chromium (VI)	50		11			10
Copper	1000		47		< 10	<10
Lead	50		25		< 1	<1
Mercury	0.012	0.012	2.4 (1 hr)		<1	<0.2
Molybdenum						
Nickel	600	4600	620		2.7	<5
Selenium	10		5		< 3	<1
Silver	50		65		5.9	<2
Thallium	100	370000				<1
Zinc	5000		410		50	40
Purgeable halocarbons (601)						
Carbon tetrachloride	0.22	3.8		< 5		< 0.5
Chlorobenzene	20	4500		< 5		< 0.5
Chloroform	100	480		5.1		3.4
1,2-Dichlorobenzene	2700	18000		< 5		< 0.5
1,3-Dichlorobenzene	400	2600		< 5		< 0.5
1,4-Dichlorobenzene	9.9	64		< 5		< 0.5
Dichloromethane	4.6	1600				ND
1,2-Dichloroethane	0.5	130		< 5		< 0.5
1,3-Dichloropropene	0.057	3.2		< 5		< 0.5
1,2-Dichloroethylene	0.19	31				< 0.5
1,1,2,2-Tetrachloroethane	0.17	11		< 5		< 0.5
Tetrachloroethene	0.62	6.9		< 5		< 0.5
1,1,1-Trichloroethane	200	11000		< 5		< 0.5
1,1,2-Trichloroethane	0.6	42		< 5		< 0.5
Trichloroethene	3.1	92		< 5		< 0.5
Vinyl Chloride	0.13	0.034		< 10		< 0.5

Halomethanes	100	480				
Bromodichoromethane			18		9.5	
Bromoform				15		4.6
Bromomethane						< 1.0
Chloromethane						< 0.5
Dibromochloromethane			35		12	
Purgeable Aromatics (602)						
Benzene	0.34	21		< 5		<0.2
Ethylbenzene	680	29000		< 5		<0.2
Toluene	10000	300000		< 5		<0.2
Acrolein & Acrylonitrile (603)						
Acrolein	320	780				< 10
Acrylonitrile	0.032	0.36				< 10
Phenols (604)						
4-Chloro-3-methylphenol	3000			< 10		< 25
2,4-Dichlorophenol	0.3			< 5		< 10
2,4-Dimethylphenol	400	2300		< 5		< 10
2,4-Dinitrophenol	70	14000		< 10		< 25
2-Methyl-4,6-dinitrophenol	13	770		< 10		< 25
Pentachlorophenol	0.28	4.2	26	< 10		< 25
Phenol	300			< 5		< 10
2,4,6-Trichlorophenol	0.34	1		< 5		< 25
Benzidines (605)						
Benzidine	0.0001	0.0002				< 2.5
3,3-Dichlorobenzidine	0.014	0.03		< 10		< 2.5
Phalate Esters (606)						
Bis(2-ethylhexyl)phthalate	2.9	9.9		< 5		< 5
Dibutyl phthalate	2700	12000		< 5		27.3
Diethyl phthalate	23000	120000		< 5		< 5
Dimethyl phthalate	310000	2900000		< 5		< 5
Nitrosamines (607)						
N-nitrosodimethylamine	0.0022	26		< 5		< 5
N-nitrosodiphenylamine	2.7	8.8		< 5		< 5
Organochlorine Pesticides & PCBs (608)						
Aldrin	0.00013	0.00014		< 0.05		< 0.05
Chlordane	0.00008	0.000081	0.0043	< 0.05		< 0.05
Dieldrin	0.00014	0.00014	0.0019	< 0.05		< 0.05
DDT	0.00059	0.0006	0.001	< 0.05		< 0.05
Endosulfan	0.9	2	0.056	< 0.05		< 0.05
Endrin	0.8	0.8	0.0023	< 0.05		< 0.05
Heptachlor	0.00016	0.00017	0.0038	< 0.05		< 0.05
Heptachlor epoxide	0.00007	0.00007		< 0.05		< 0.05
Hexachlorbenzene	0.00066	0.00069				
Hexachlorocyclohexane						

alpha	0.0039	0.013	0.08		
beta	0.014	0.046			
gamma	0.019	0.062			
Toxaphene	0.00067	0.000069	0.0002	< 1	< 1
PCBs	0.00007	0.00007	0.014		< 1
Nitroaromatics & Isophorone (609)					
2,4-Dinitrotoluene	0.11	9.1		< 5	< 5
Isophorone	8.6	610		< 5	< 5
Nitrobenzene	17	1900		< 5	< 5
PAHs (610)					
Fluoranthene	42	42		< 5	< 5
Total PAHs	0.0028	0.031			< 5
Haloethers (610)					
Bis(2-chloroisopropyl) ether	0.014	0.62		< 5	< 2
Bis(2-chloroethyl) ether	1400	170000		< 5	< 2
Chlorinated Hydrocarbons (612)					
Hexachlorobutadiene	0.44	50		< 5	< 0.4
Hexachlorobenzene	0.00066	0.00069		< 5	< 1
Hexachlorocyclopentadiene	1	17000		< 5	< 1
Hexachloroethane	1.9	8.9		< 5	< 1.5
Dioxins & Furans (1613)					
TCDD equivalents (dioxin)	1.3×10^{-8}	1.4×10^{-9}			
Total TEF					5.8×10^{-7}
Others					
Asbestos	7000000				ND
Cyanide	700	220000	5.2		17.3
1,2-Diphenylhydrazine	0.04	0.54			< 5
Tributyltin			0.02		0.002

[a] Inland Surface Water Plan, State Water Resources Control Board.
The Inland surface water plan has not been adopted and is still under review.

Table 6.3 Dissolved and suspended concentrations of heavy metals in the influent and effluent of the Patterson Algal Turf Scrubber (24 h composite sample).

Metal	Dissolved Influent ($\mu g\ l^{-1}$)	Suspended Influent ($\mu g\ l^{-1}$)	Dissolved Effluent ($\mu g\ l^{-1}$)	Suspended Effluent ($\mu g\ l^{-1}$)
Antimony	< 2	< 2	< 2	< 2
Arsenic	7.1	< 1.5	< 1.5	< 1.5
Cadmium	0.4	< 0.1	0.4	< 0.1
Chromium (III)	< 0.5	0.9	< 0.5	2.5
Copper	< 30	< 30	< 30	< 30
Lead	< 1	1.6	< 1	3
Mercury	< 0.2	0.6	< 0.2	< 0.2
Molybdenum	< 30	60	< 30	60
Nickel	< 5	< 5	< 5	< 5
Selenium	< 2	< 2	< 2	< 2
Silver	6.2	1.4	5.9	< 0.7
Zinc	160	10	130	10

Inland Surface Water Plan (CISWP) must be monitored in the ATS effluent. The Patterson effluent is low in heavy metals and organic compounds (Table 6.2); however, a preliminary study conducted by the City of Modesto, Industrial Pollution Department showed that the ATS can remove zinc, silver and arsenic, even from the low levels found in the Patterson treatment facility effluent (Table 6.3). Analysis of the harvested solids shows that many metals are incorporated into the algal turf biomass. Laboratory experiments, have previously demonstrated the removal of heavy metals and organic compounds from industrial effluents (Adey *et al.*, 1994). Experimental addition of heavy metals and refractory organics should also be carried out at Patterson to determine the ATS/UV systems capability to remove these compounds.

Evaluation of the ATS/UV system to treat a secondary wastewater with higher BOD concentrations than the Patterson wastewater is also necessary. Nutrient removal may be improved at higher BOD levels since the algal turf would be less carbon deficient. Higher BOD levels may be provided by using an influent wastewater such as primary settled sewage or the effluent from an anaerobic digester. Since an ATS/UV system would require some kind of holding pond to buffer changes in daily hydraulic loading, either a primary sedimentation tank or an Advanced Facultative Pond could be installed prior to the ATS. Both primary and anaerobic effluent contain ammonium as the main source on nitrogen which algae assimilate more readily than nitrate and may be volatilized at high pH.

Finally, evaluation of pH and phosphorus profiles down the floway at varying flow rates and solar irradiance values is necessary to determine the site and pH at which precipitation occurs on the Patterson ATS.

Further experimental areas

Seeding v no seeding
Steady flow v surged flow
Floway texture: rough v smooth
Harvest interval: long v short v no harvest
    use of sloughing to predict harvest
Harvest method: vacuum v mechanical rake
Night recirculation for P removal

7.0 Acknowledgements

The authors are particularly grateful to Tryg Lundquist, Lincoln Jaiparsad and Jason Muir and Paul Suto for their help with experimental analysis. We would also like to thank Richard Schroeder at the Patterson wastewater treatment facility and Greg Remsing at Modesto industrial pollution department for their help and advice during this evaluation. The

help of Stan Duck and Cathy Robocker while harvesting the ATS was most appreciated.

Funding for this study was provided by Fountainhead Water Systems Ltd. The algal turf scrubber process is a patented environmental control system developed by W. Adey and held by the Smithsonian Institution. BioEnvironmentals Inc. of Altamonte Springs Florida, holds an exclusive North American license for agricultural uses. Fountainhead Water Systems, holds an exclusive Californian license for municipal wastewater uses.

Disclaimer

Any opinions expressed herin are those of the authors and not of the Regents of the University of California.

References

Adey, W. H. (1983). The microcosm: A new tool for reef research. *Coral Reefs.* **1**: 193-201.

Adey, W. H. (1987). Marine microcosms. In: Jordan, W., J. Aber & M. Gilpin. (eds) *Restoration Ecology: Progress toward a science and art of ecological healing.*

Adey, W. H. & J. M. Hachney (1989). The composition and production of tropical marine algal turf in laboratory and field experiments. In: Adey, W. H. (eds) *The Biology, Ecology, and Mariculture of Mithrax spinosissimus utilizing cultural algal turfs.* The Marinculture Institute, Los Angeles, California.

Adey, W. & K. Loveland (1991). *Dynamic Aquaria: building living ecosystems.* Academic Press, New York.

Adey, W., C. Luckett & K. Jensen (1993). Phosphorus removal from natural waters using controlled algal production. *Restoration Ecology.* **March**: 29-39.

Adey, W., C. Luckett & M. Smith (1994). Purification of industrially contaminated ground waters using controlled ecosystems. *Ecolog. Engineer. J. of Ecotechnol.* (In Press).

APHA. (1992). *Standard methods for the examination of water and wastewater.* Am. Pub. Health Assoc., Am. Water Works Assoc., Water Pollut. Control Federation.,

Auer, M. T. & R. P. Canale (1982). Ecological studies and mathematical modeling of Cladophora in Lake Huron. 3. The dependence of growth rates on internal phosphorus pool size. *J. Great Lakes Res.* **8**: 93-99.

Becker, E. W. (1988). Micro-algae for human and animal consumption. In: Borowitzka, M. A. & L. J. Borowitzka. (eds) *Micro-algal Biotechnology.* C.U.P., Cambridge. 222-256.

Belsare, D. K. & Belsare, S. D. (1987). High-rate oxidation pond for water and nutrient recovery from domestic sewage in urban areas in the tropics. *Arch. Hydrobiol. Beih. Ergebn. Limnol.* **28**: 123-128.

Bogan, R. H. (1961). Removal of sewage nutrients by algae. *Public Health Reports.* **76**: 301-308.

Brawley, S. H. & W. H. Adey (1981). The effect of micrograzers on algal community structure in a coral reef microcosm. *Mar. Biol.* **61**: 167.

Cook, P. E., J. P. Hoffmann, J. W. Morris & L. S. Stuart (1986). Feasibility of tertiary wastewater treament by attached microbes (periphyton) in cold regions. *Completion report, project 84-06 VWRRC, University of Vermont.*

Davis, L. S., J. P. Hoffmann & P. W. Cook (1990a). Seasonal succession of algal periphyton from a wastewater treatment facility. *J. Phycol.* **26**: 611-617.

Davis, L. S., J. P. Hoffmann & P. W. Cook (1990b). Production and nutrient accumulation by periphyton in a wastewater treatment facility. *J. Phycol.* **26**: 617-623.

Fabregas, J., J. Abalde, C. Herrero, B. Cabezas & M. Veiga (1984). Growth of the marine microalga *Tetraselmis suecia* in batch cultures with different salinities and nutrient concentrations. *Aquaculture.* **42**: 207-215.

Gadd, G. M. (1990) Heavy metal accumulation by bacteria and other microorganisms. *Experientia.* **46**: 834-840.

Gloyna, E. F. (1971). Waste stabilization ponds. *W.H.O., Geneva.* 171.

Goldman, J. C. (1979). Outdoor algal mass cultures I. Applications. *Water Res.* **13**: 1-19.

Green, F. B. & W. J. Oswald (1994). Engineering strategies to enhance microalgal use in wastewater treatment. *Wat. Sci. Technol.* (In Press).

Greene, B. & G. Bedell (1989). Algal gels or immobilized algae for metal recovery. In: Akatsuka, I. (eds) *An Introduction to Applied Phycology.* S.B.P. Academic Publ., Amsterdam.

Hall, J. E. (1989). Alternative Uses for Sewage Sludge. Proc. of the Conference Organised by W. R. c. Medmenhan, University of York, 5-7 September.

Harlin, M. M. & W. M. Darley (1988). The algae: an overview. In: Lembi, C. A. & J. R. ( ). Waaland. (eds) *Algae and Human Affairs.* CUP, Cambridge. 3-28.

Hemens, J. & M. H. Mason (1968). Sewage nutrient removal by shallow algal stream. *Wat. Res.* **2**: 277-287.

Kesler, D. H. (1982). Periphyton phosphorus concentrations in a small New England Lake. *J. Freshwater Ecol.* **1**: 507-514.

Lembi, C. A. & J. R. Waaland (1988). Algae and Human Affairs. 590.

Lock, M. A., R. R. Wallace, J. W. Costerton, R. M. Ventullo & S. E. Charlton (1984). River epilithon: toward a structural-functional model. *Oikos.* **42**: 10-22.

Metcalf, E. i. (1991). Wastewater Engineering: Treatment Disposal Reuse. 920pp.

NWRI. (1993). UV disinfection guidelines for wastewater reclamation in California and UV disinfection research needs identification. National Water Research Institute, State of California Dept. of Health Services, Sacramento. 28.

Oswald, W. J., H. B. Gotaas, H. F. Ludwig & V. Lynch (1953a). Algal symbiosis in oxidation ponds II. Growth characteristics of *Chlorella pyrenoidosa* cultured on sewage. *Sew. Indust. Waste.* **25**: 1-26.

Oswald, W. J., H. B. Gotaas, H. F. Ludwig & V. Lynch (1953b). Algal symbiosis in oxidation ponds III. Photosynthetic oxidation. *Sew. Indust. Waste.* **25**: 690-692.

Oswald, W. J. (1988). Micro-algae and waste-water treatment. In: Borowitzka, M. A. & L. J. Borowitzka. (eds) *Micro-algal Biotechnology.* Cambridge University Press, Cambridge. 305-328.

Reddy, K. R. & W. F. DeBusk (1987). Nutrient storage capabilities of aquatic and wetland plants. In: Reddy, K. & W. H. Smith. (eds) *Aquatic Plants for Water Treatment and Resource Recovery.* Magnolia Publ. Inc., Orlando. 337-357.

Richmond, A. (1983). Phototrophic microalgae. In: Dellweg, H. (eds) *Biomass: microorganisms for special applications; microbial products 1; Energy from renewable resources,.* Verlag Chemie, Weinheim:. 119-143.

Ryther, J. H., R. Winfree, J. Holt, R. Creswell, W. Lellis, J. Chaiton, C. Kovach & F. Prahl (1987). Antigua crab mariculture, annual progress report. *Harbor Branch Oceanographic Institution, Fort Pierce, Fla; July 15. 78pp.*

Soeder, C. J. & E. Hegewald (1988). *Scenedesmus*. In: Borowitzka, M. A. & L. J. Borowitzka. (eds) *Micro-algal Biotechnology.* C.U.P., Cambridge. 59-84.

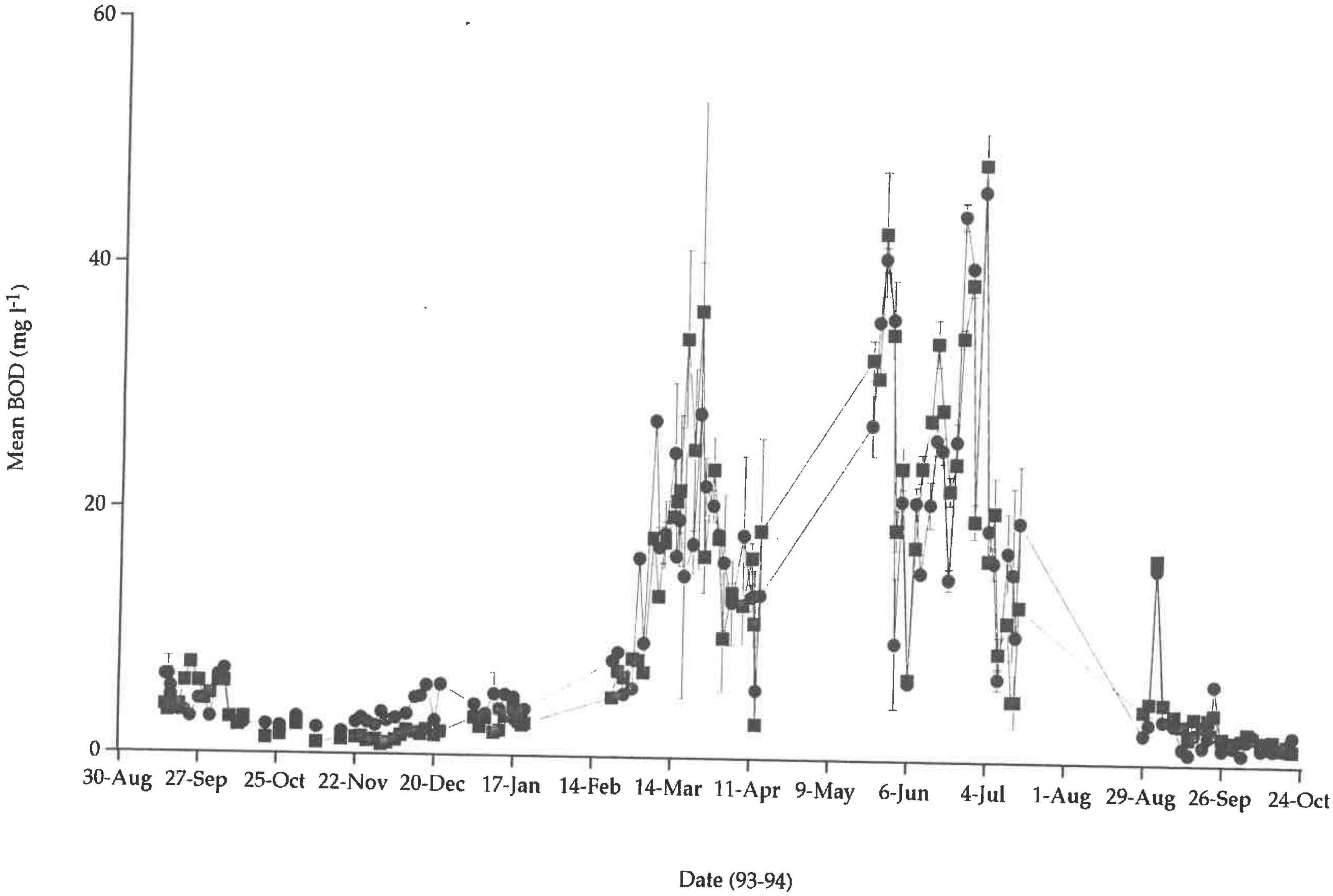
Swift, D. (1981). Preliminary investigation of periphyton and water quality relationships in the Everglades Water Conservation Areas. *Technical Publication 81-5. South Florida Water Management District, West Palm Beach, Florida.*

Swift, D. & R. Nicholas (1987). Periphyton and water quality relationships in the Everglades Water Conservation Areas 1978-1982. *Technical Publication 87-2. South Florida Water Management District, West Palm Beach, Florida.*

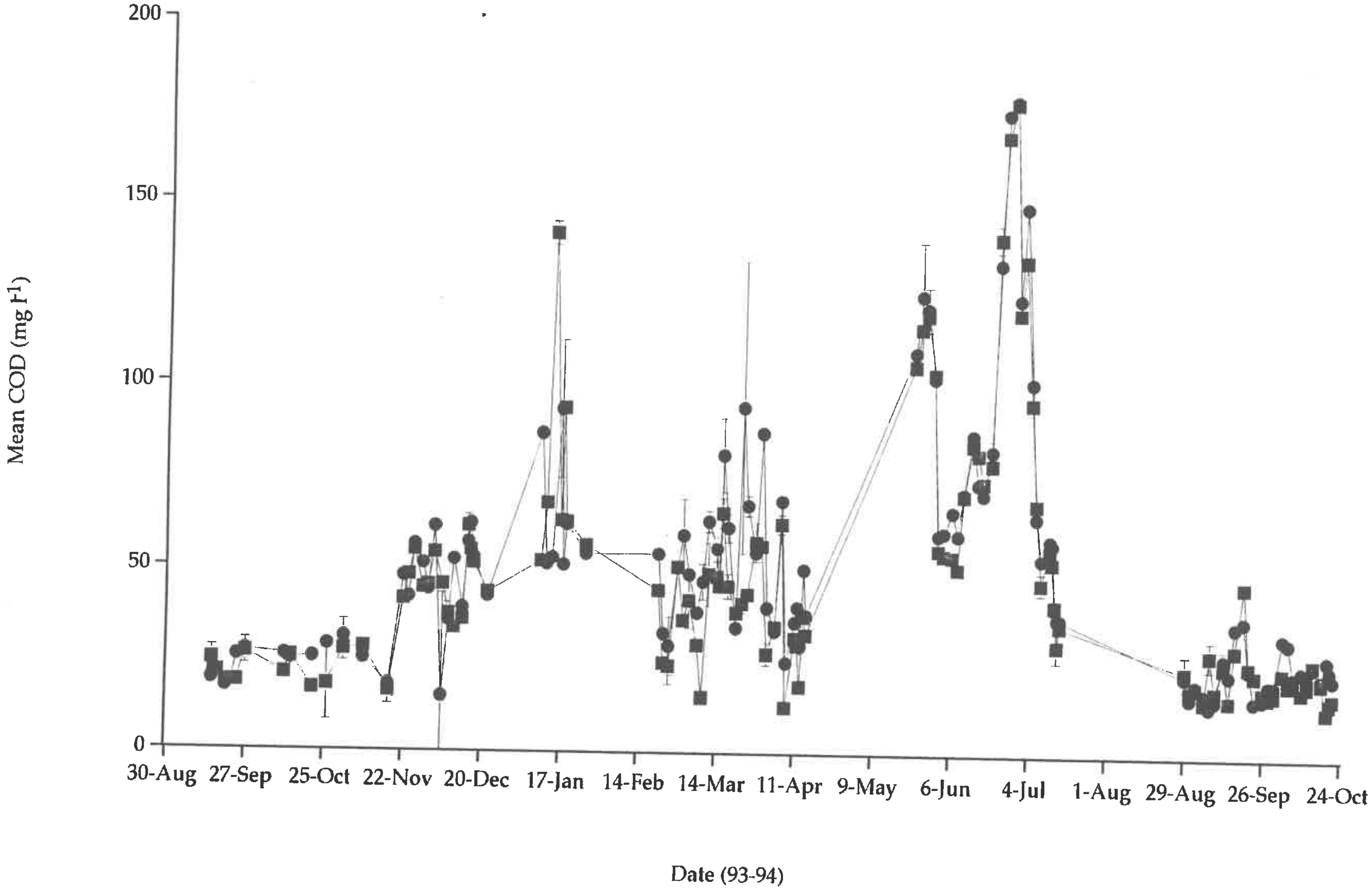
Tangley, L. (1985). And live from the east coast - a miniature Maine ecosystem. *Bioscience.* **35**: 618-619.

Williams, S. L. & W. H. Adey (1983). *Thalssia testudonum* Banks ex Konig seedling success in a coral reef microcosm. *Aquat. Bot.* **16:** 181-188.

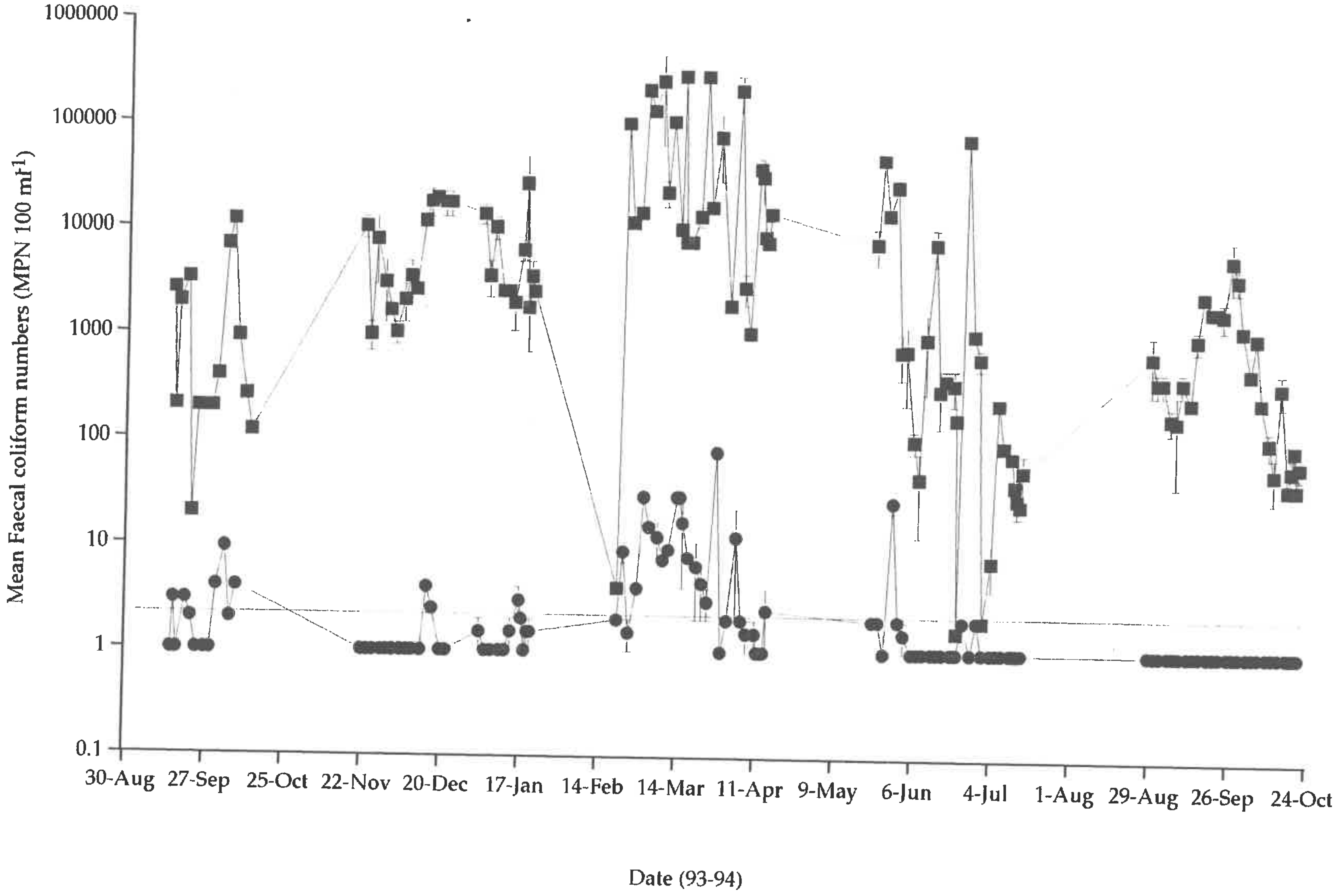
Appendix



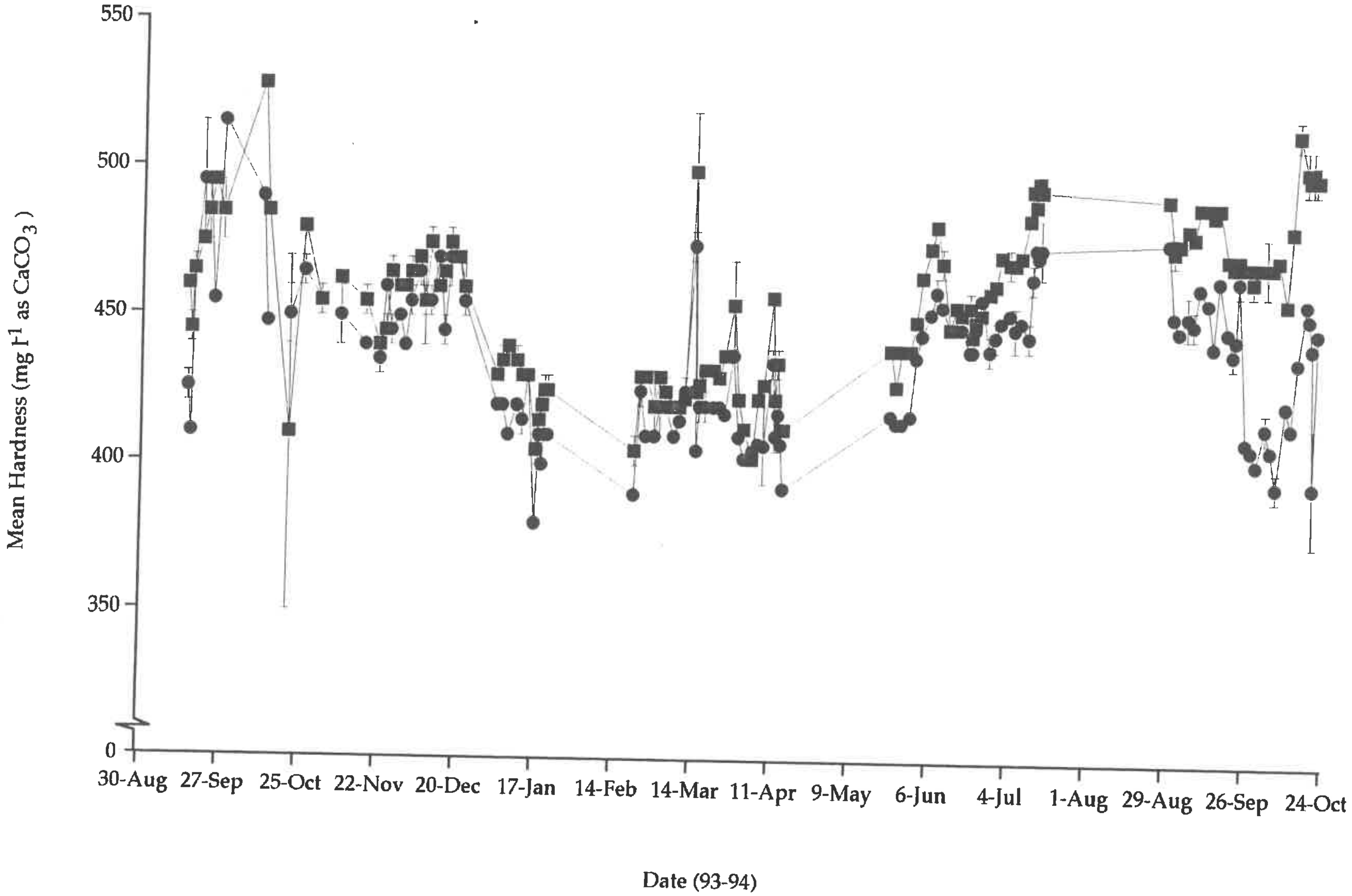
Biochemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



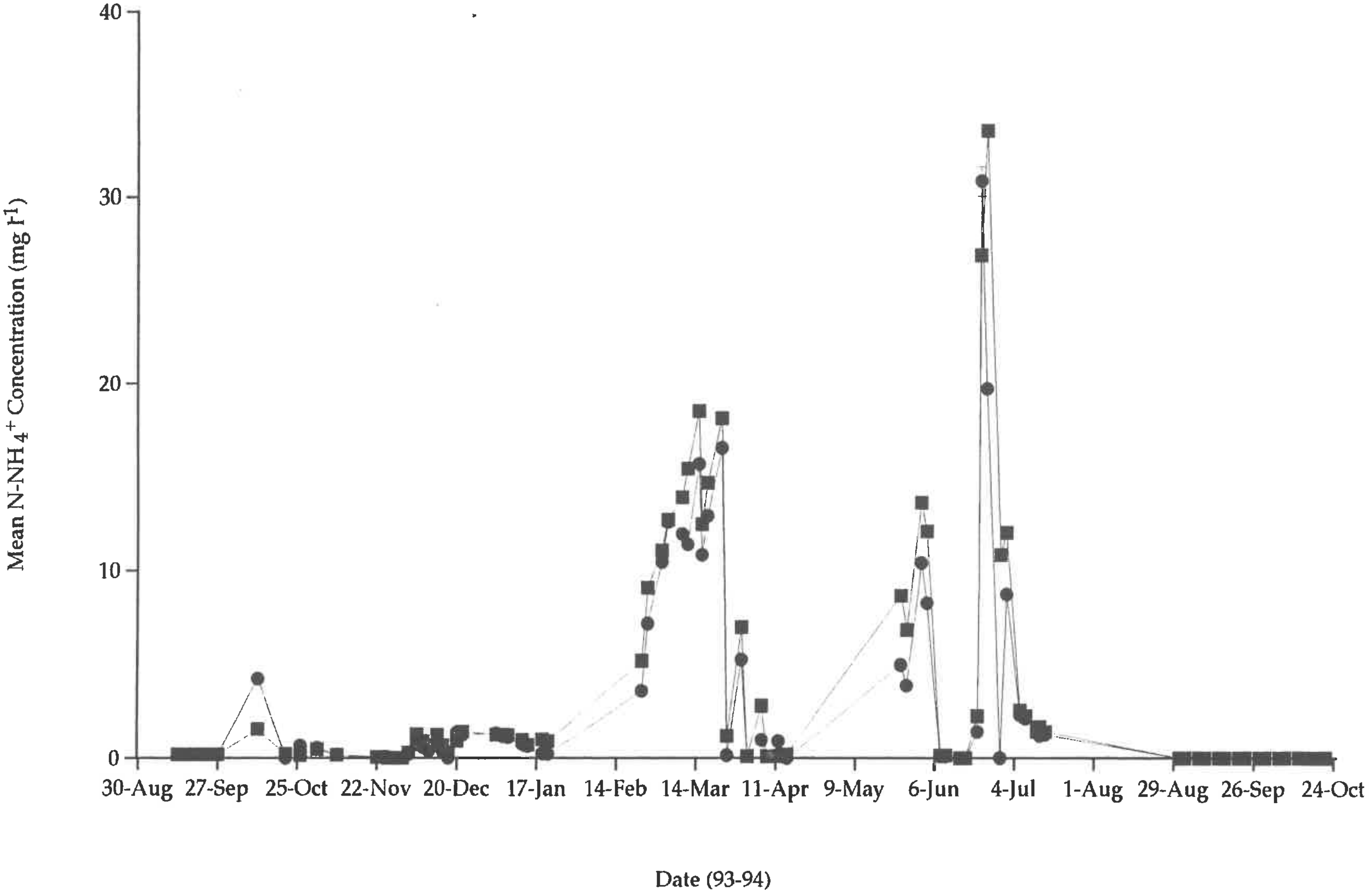
Chemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



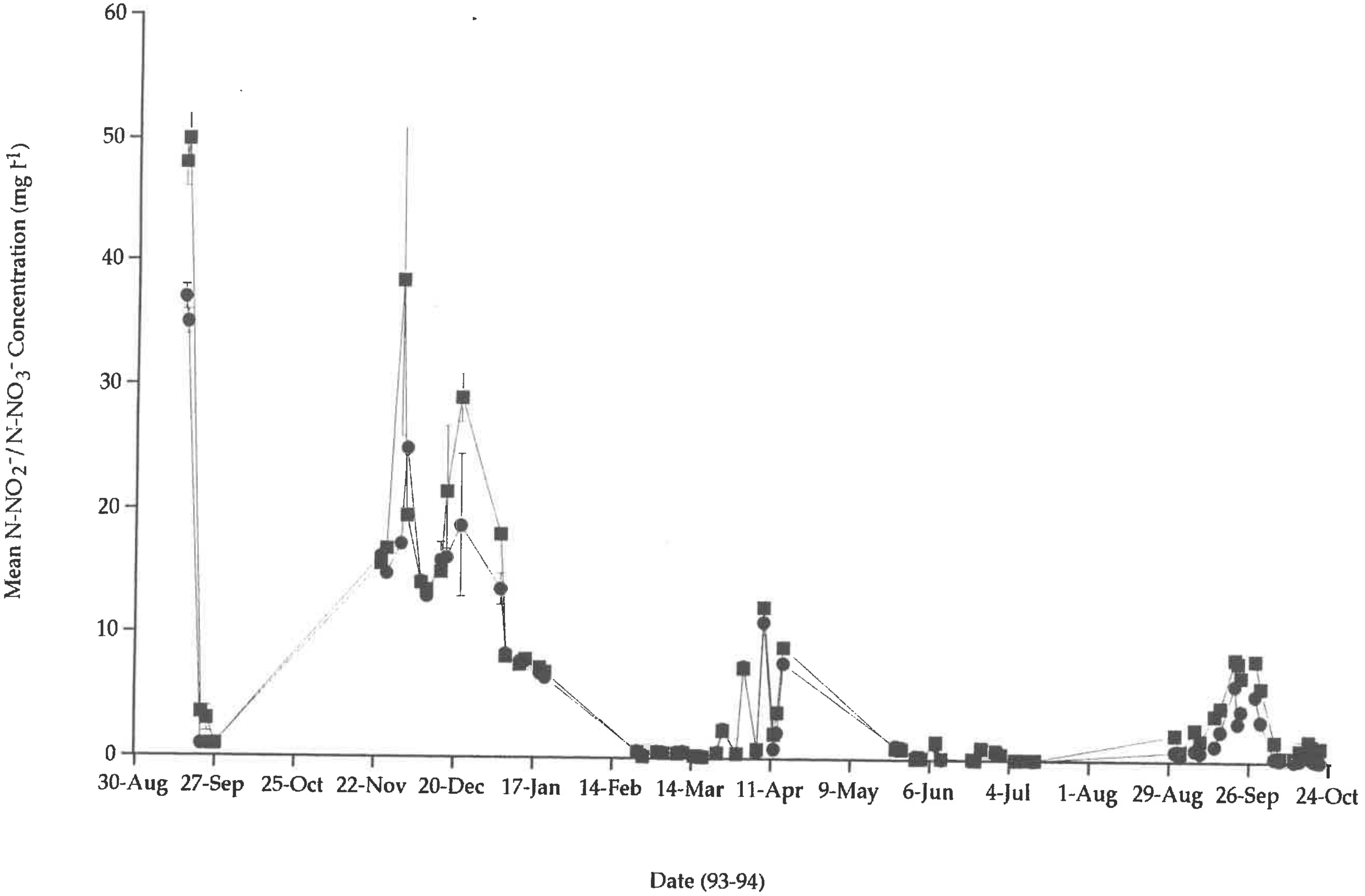
Faecal coliform numbers of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



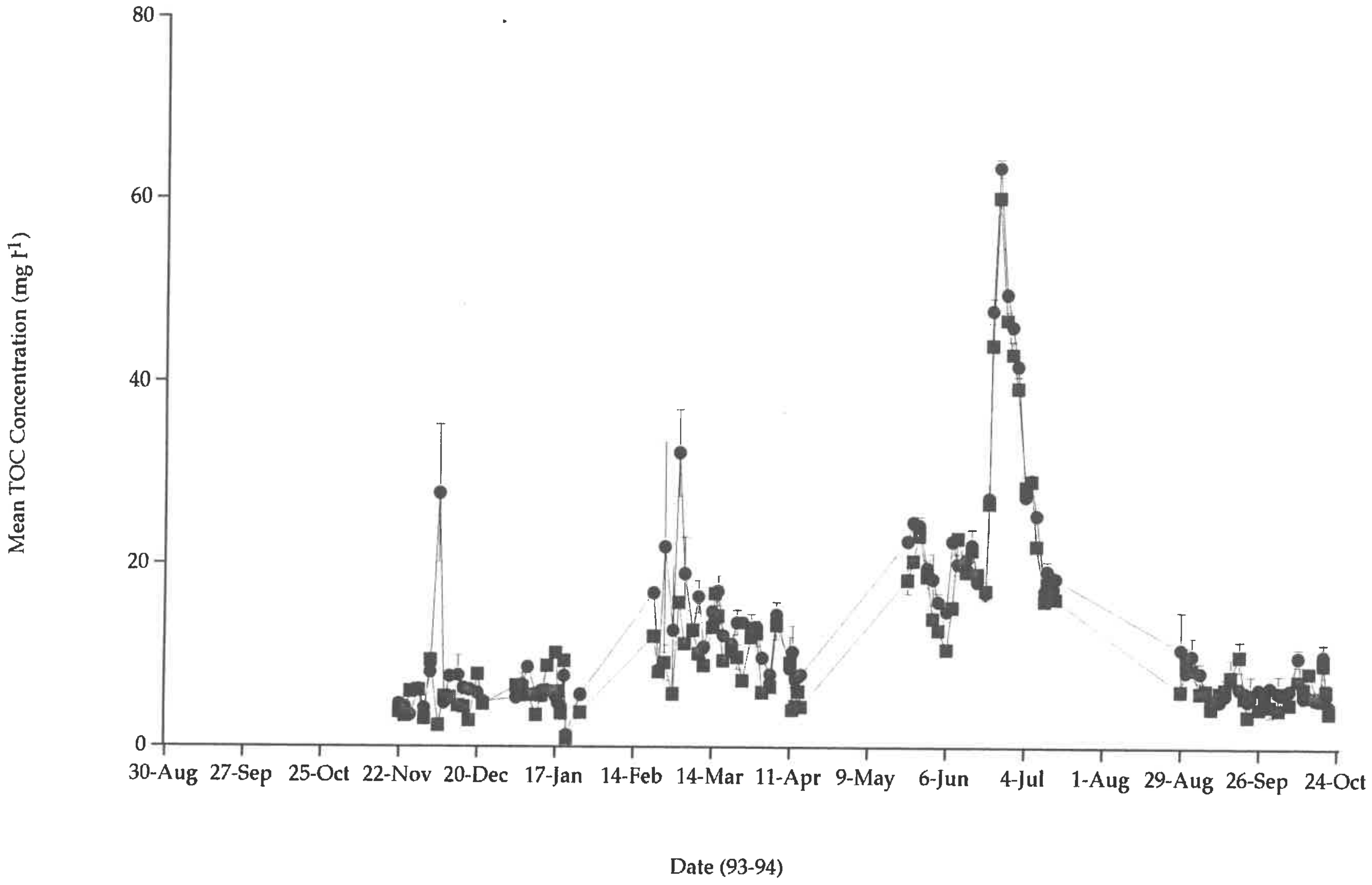
Hardness of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



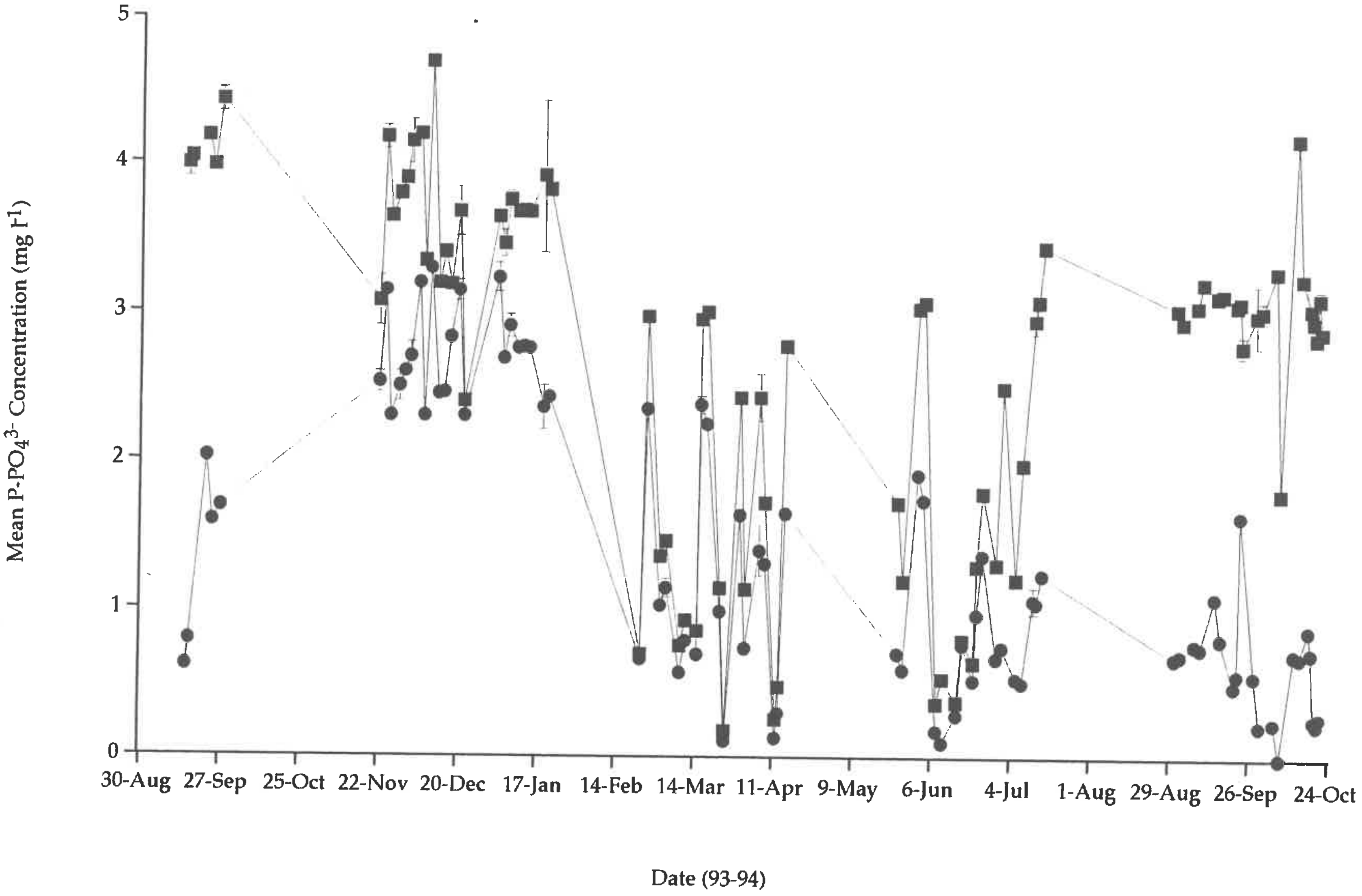
Ammonium-nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



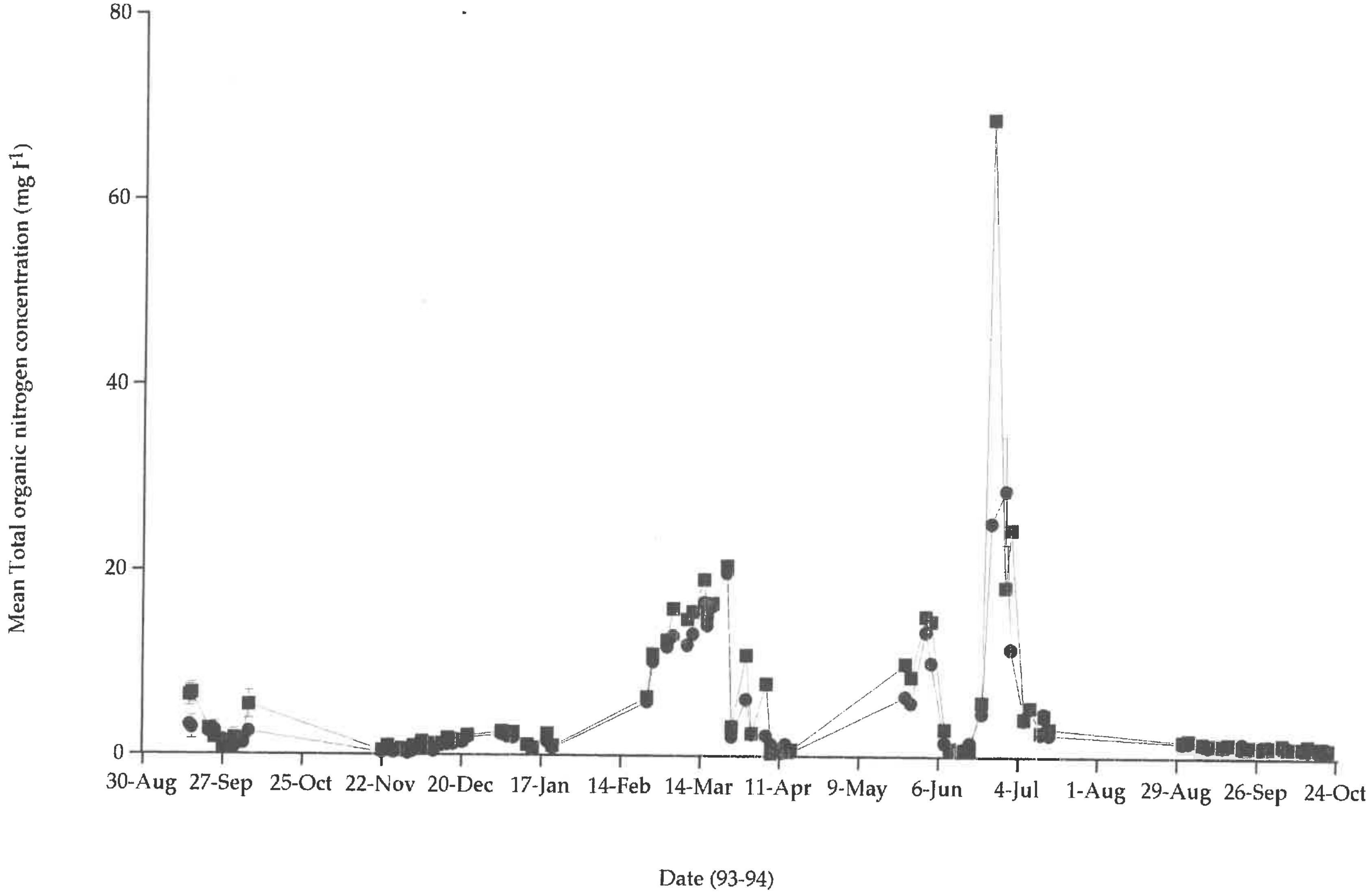
Nitrite- and Nitrate -nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



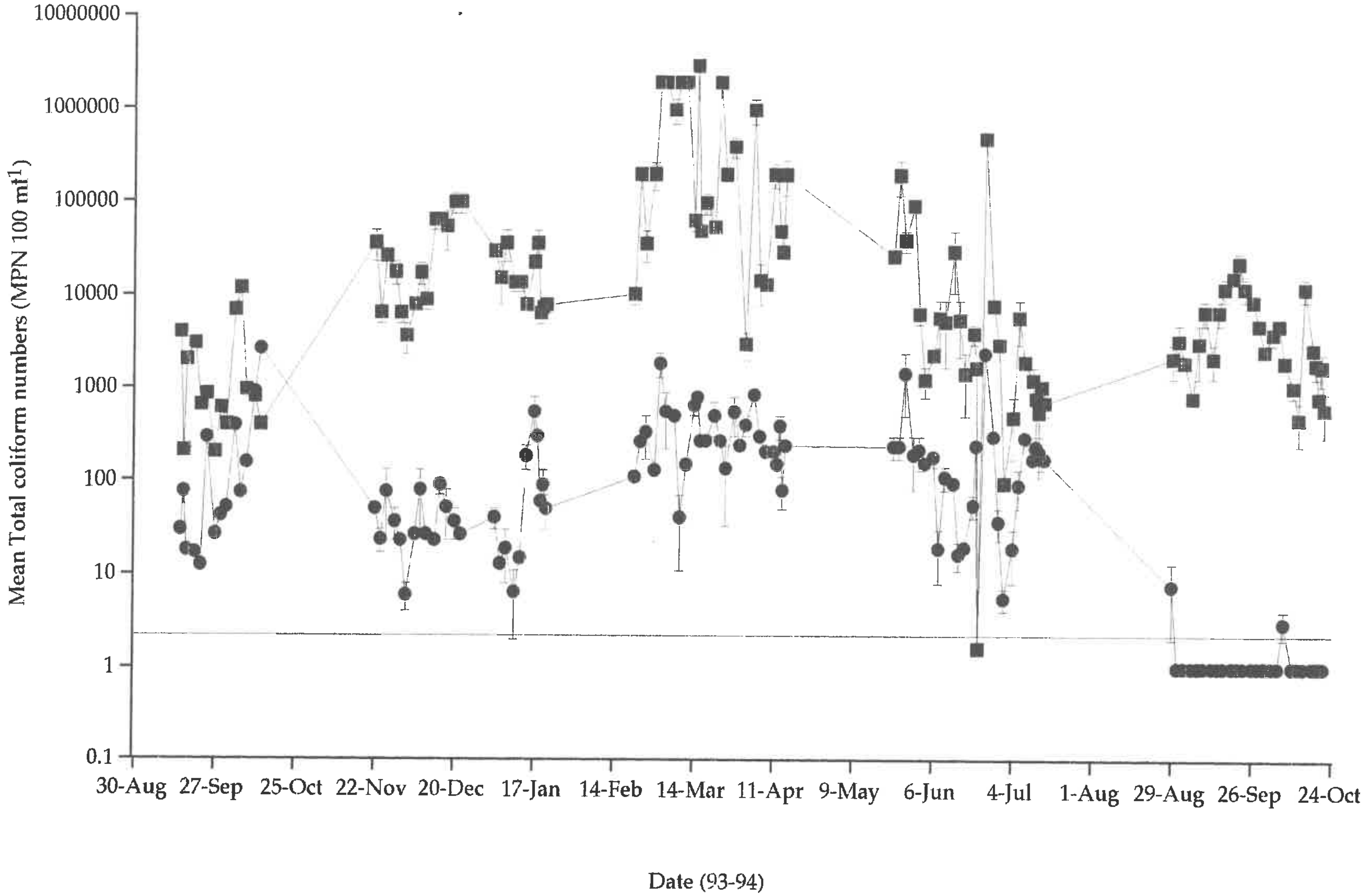
Total organic carbon concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



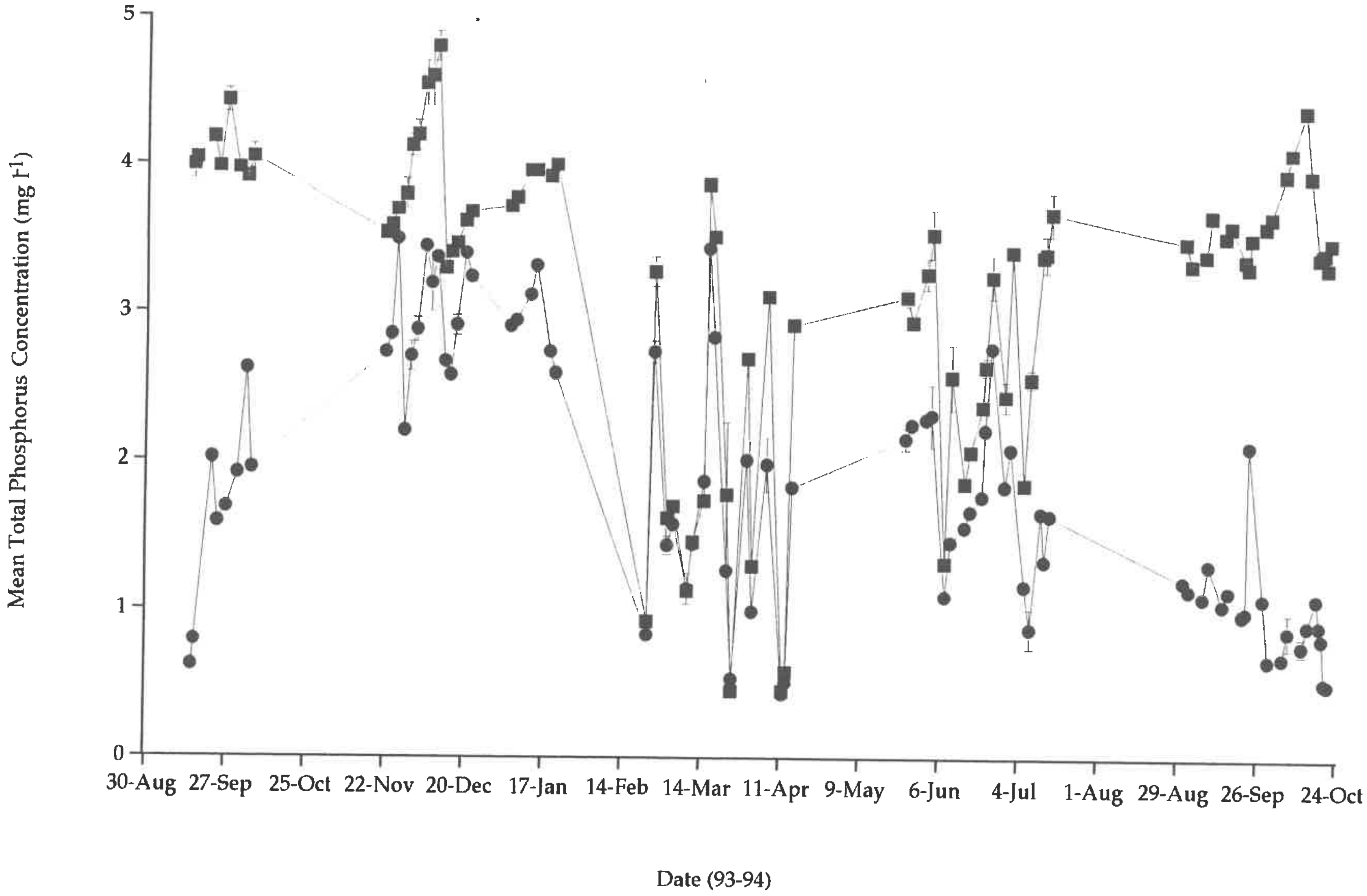
Soluble reactive phosphorus concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



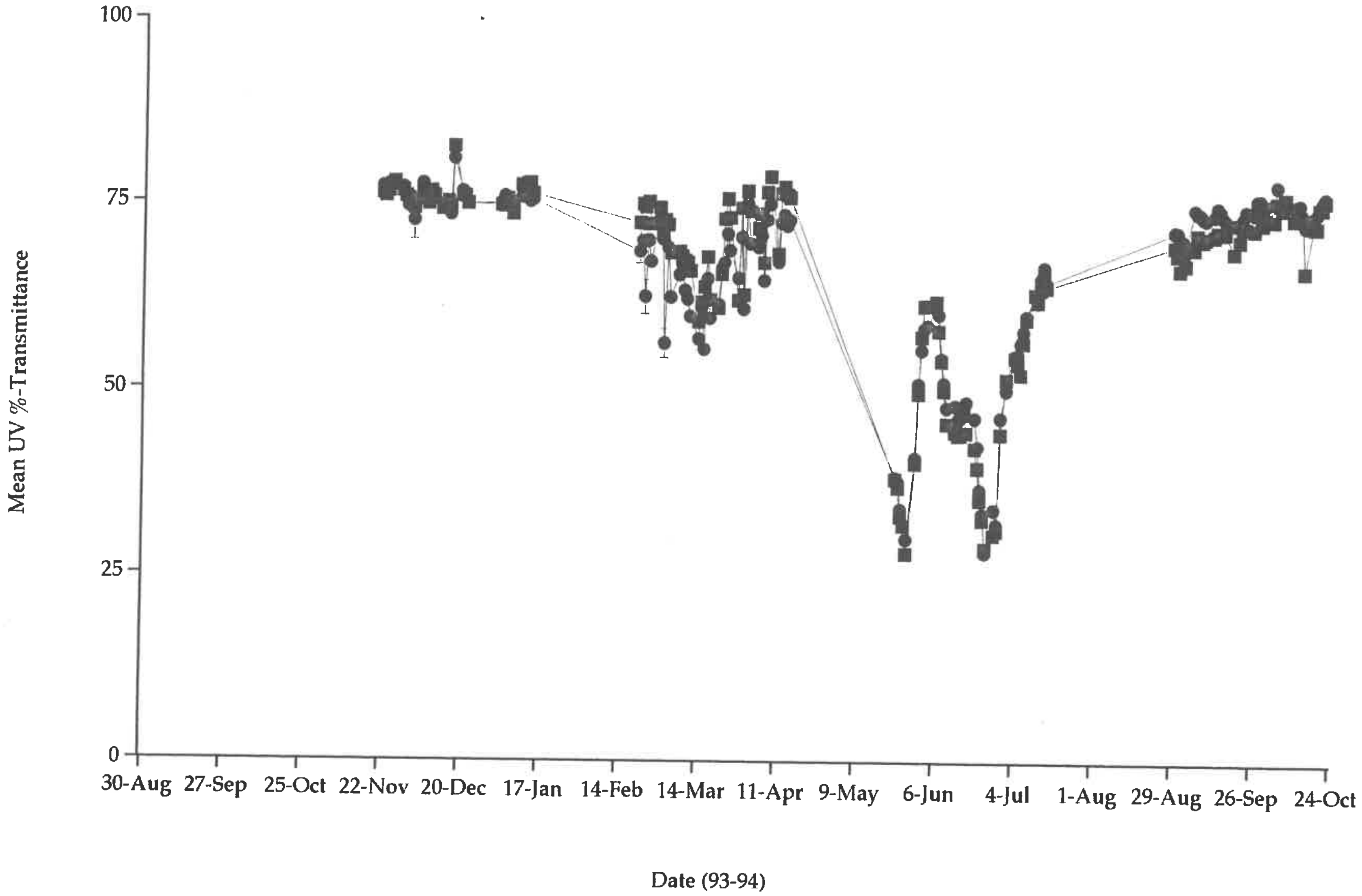
Total organic nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



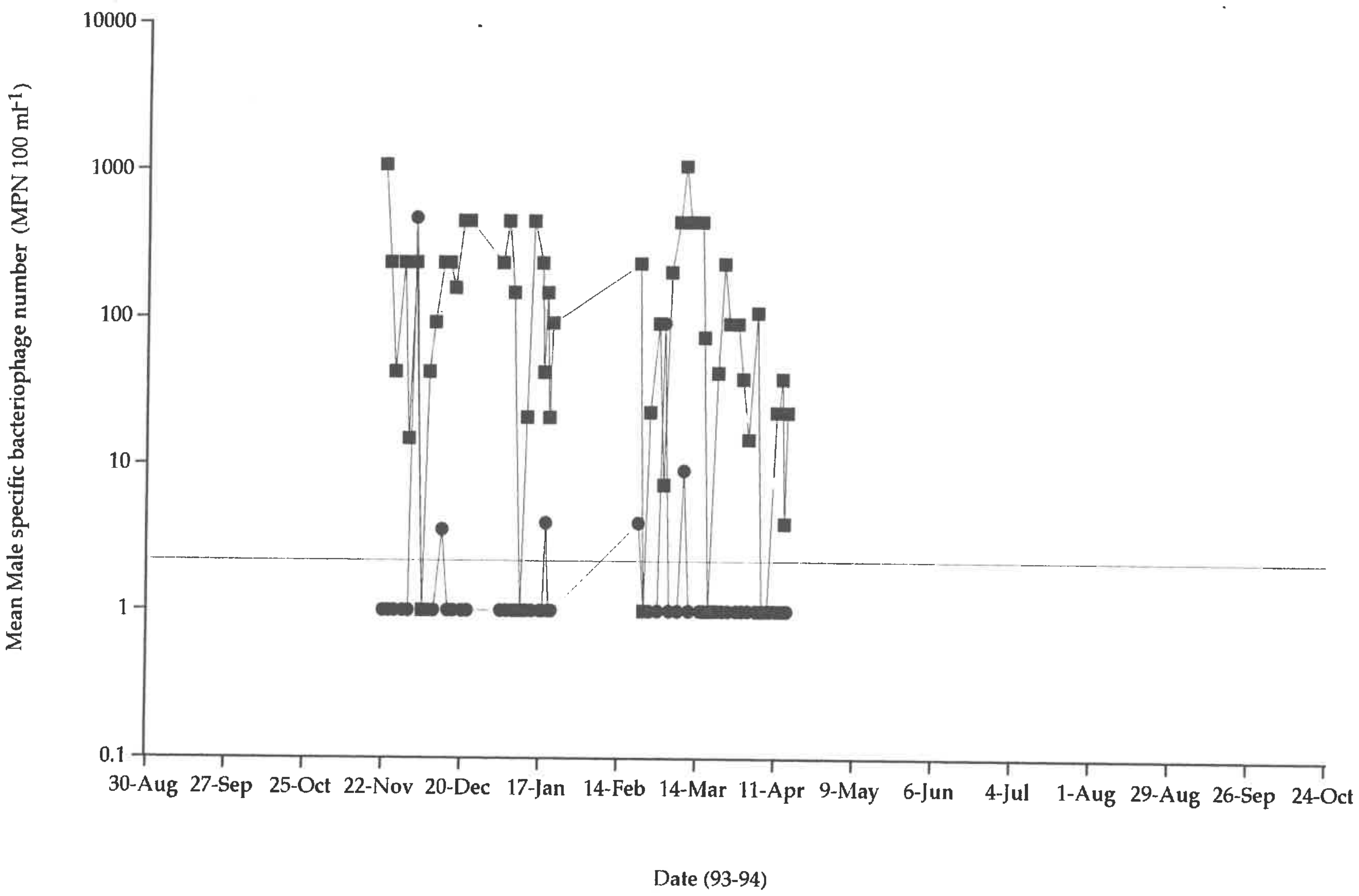
Total coliform numbers of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



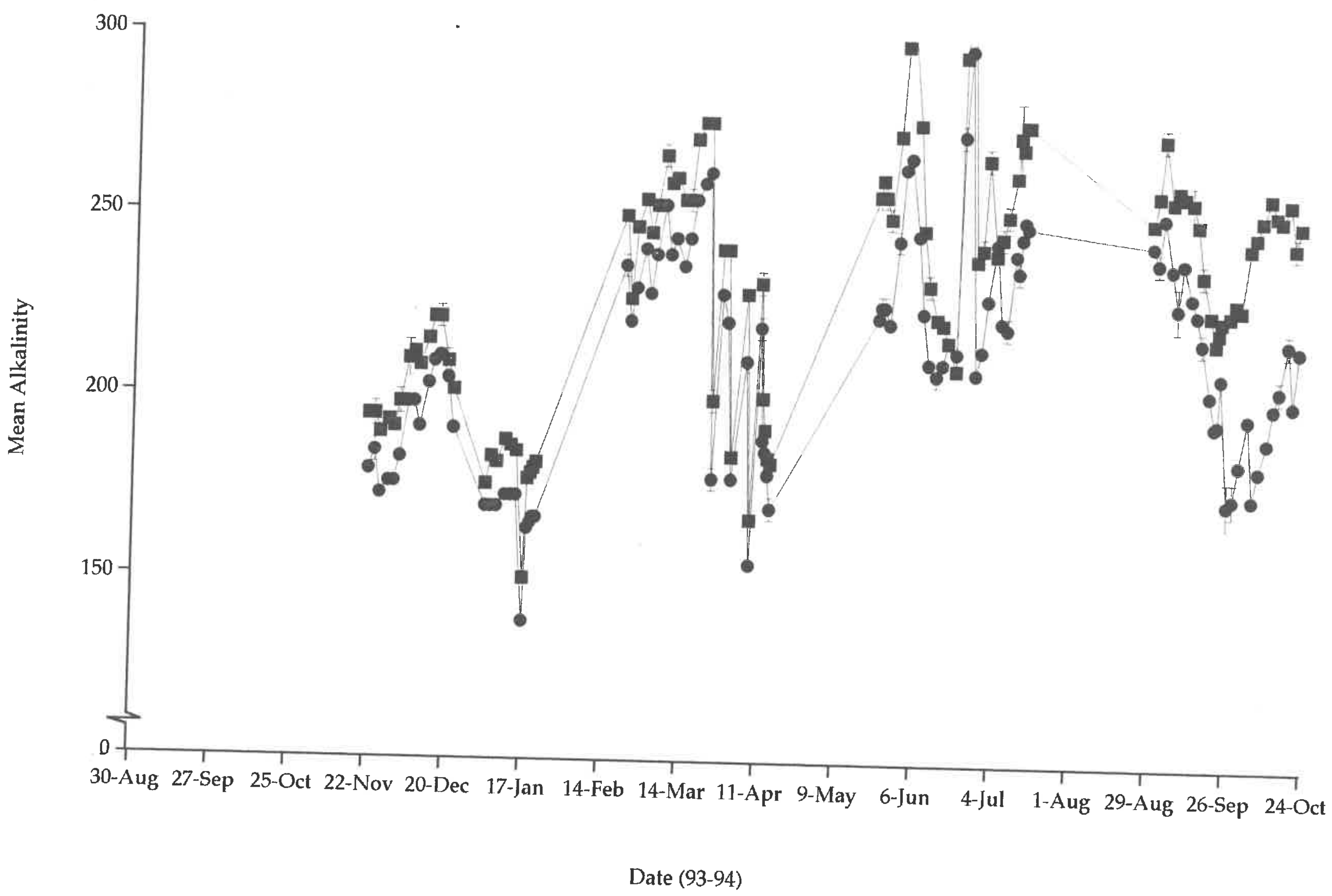
Total phosphorus concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



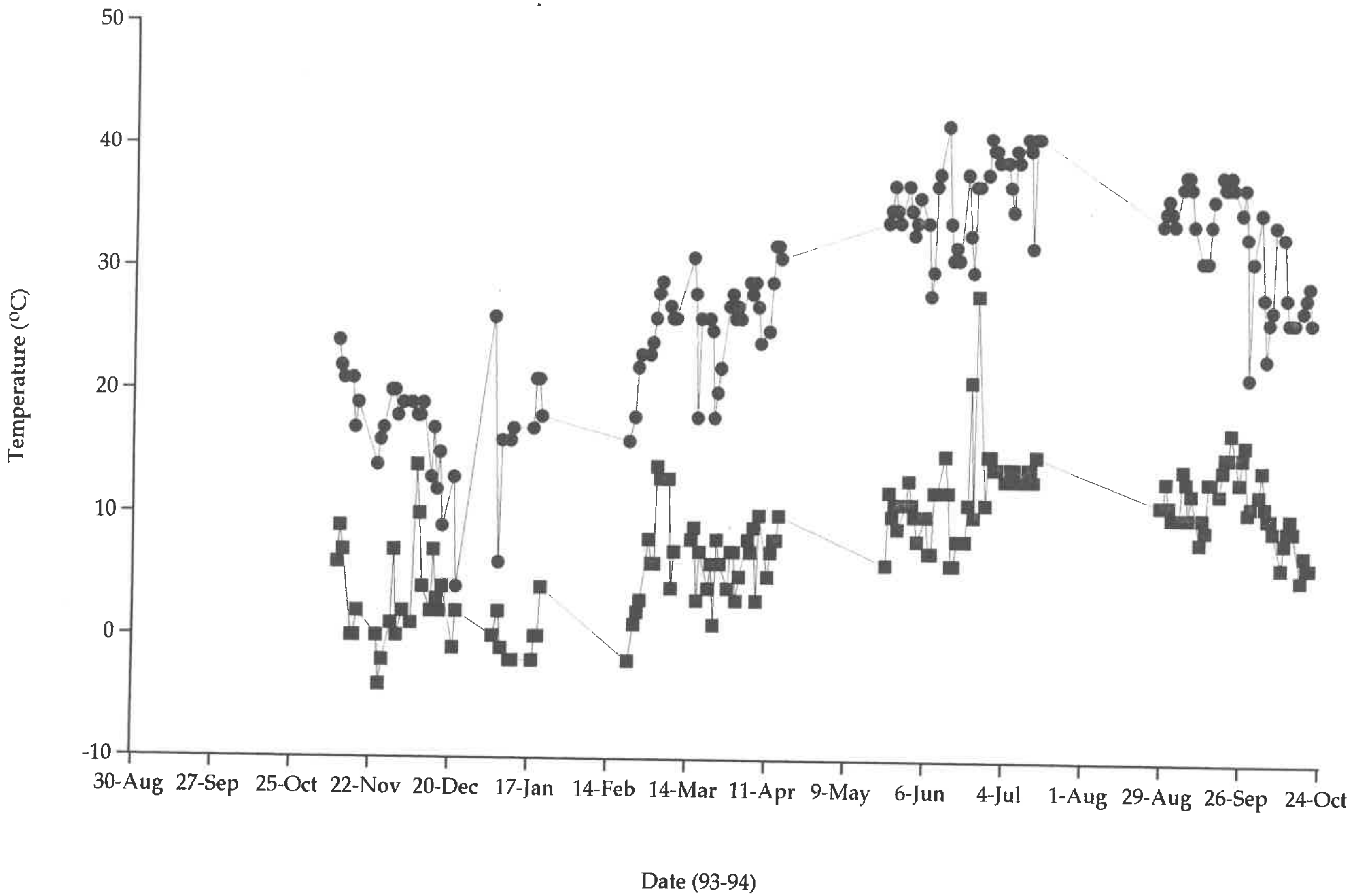
UV %-Transmittance of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



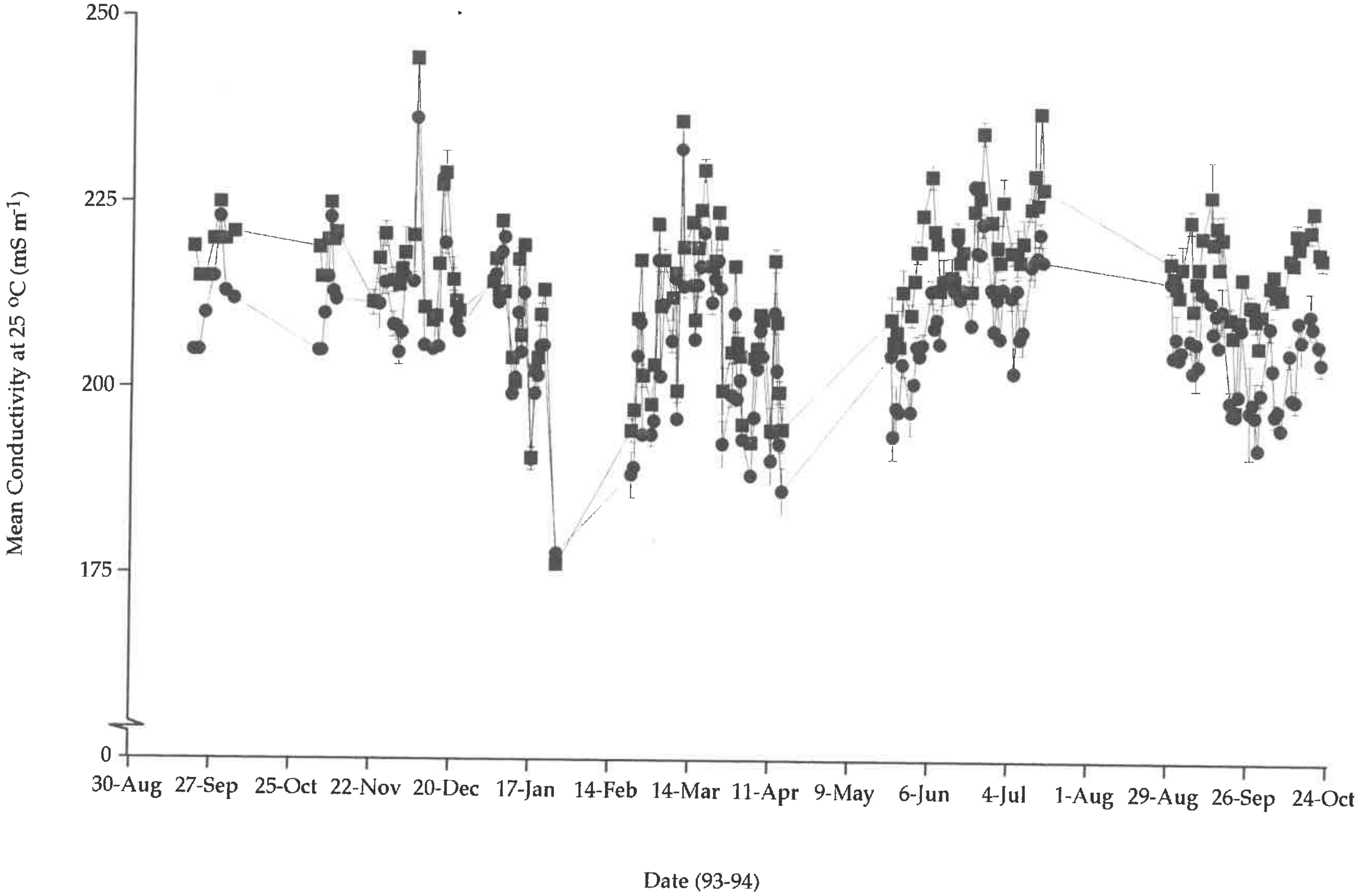
Male specific bacteriophage numbersof influent (■) and effluent (●) of the ATS/UV system.



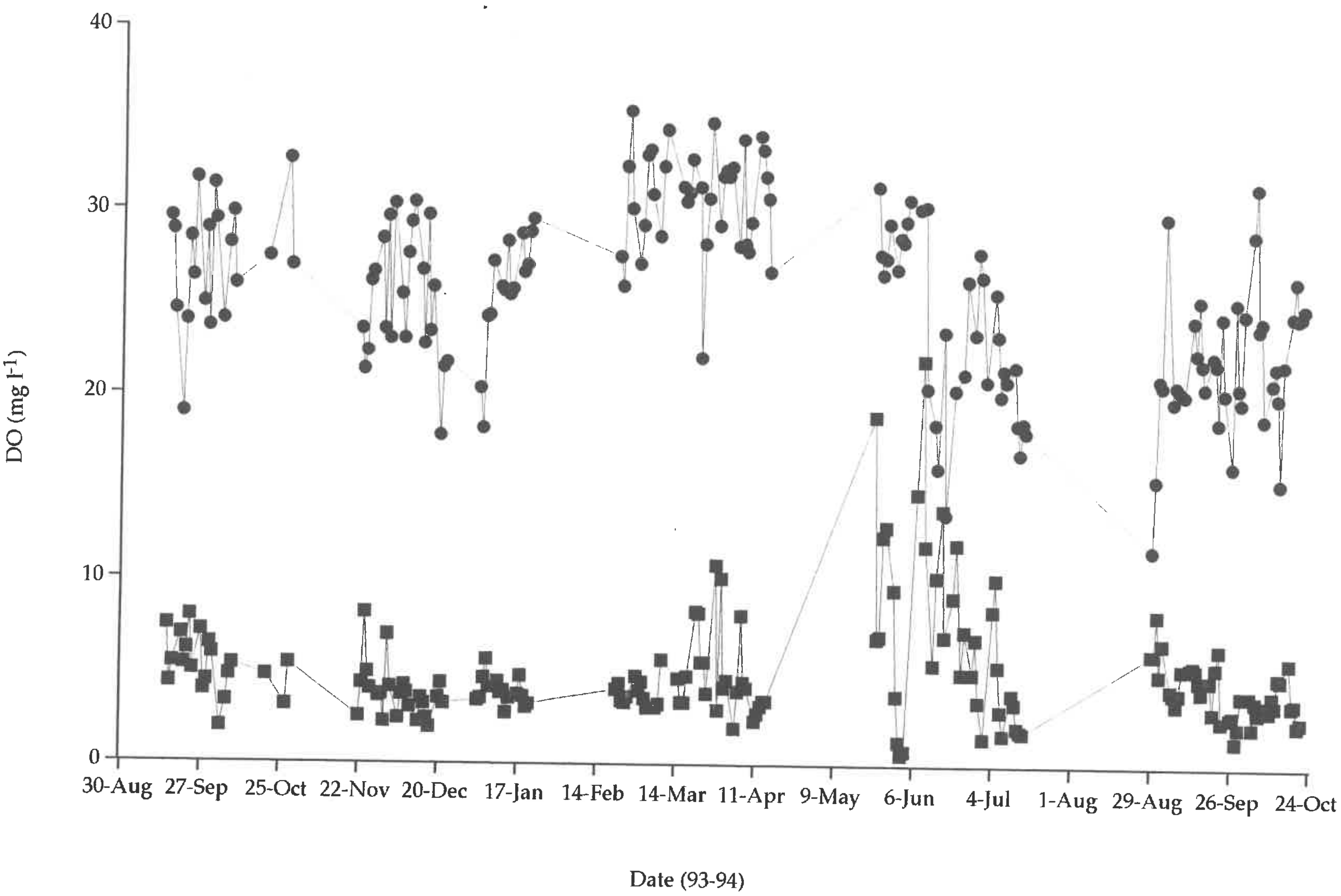
Alkalinity of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



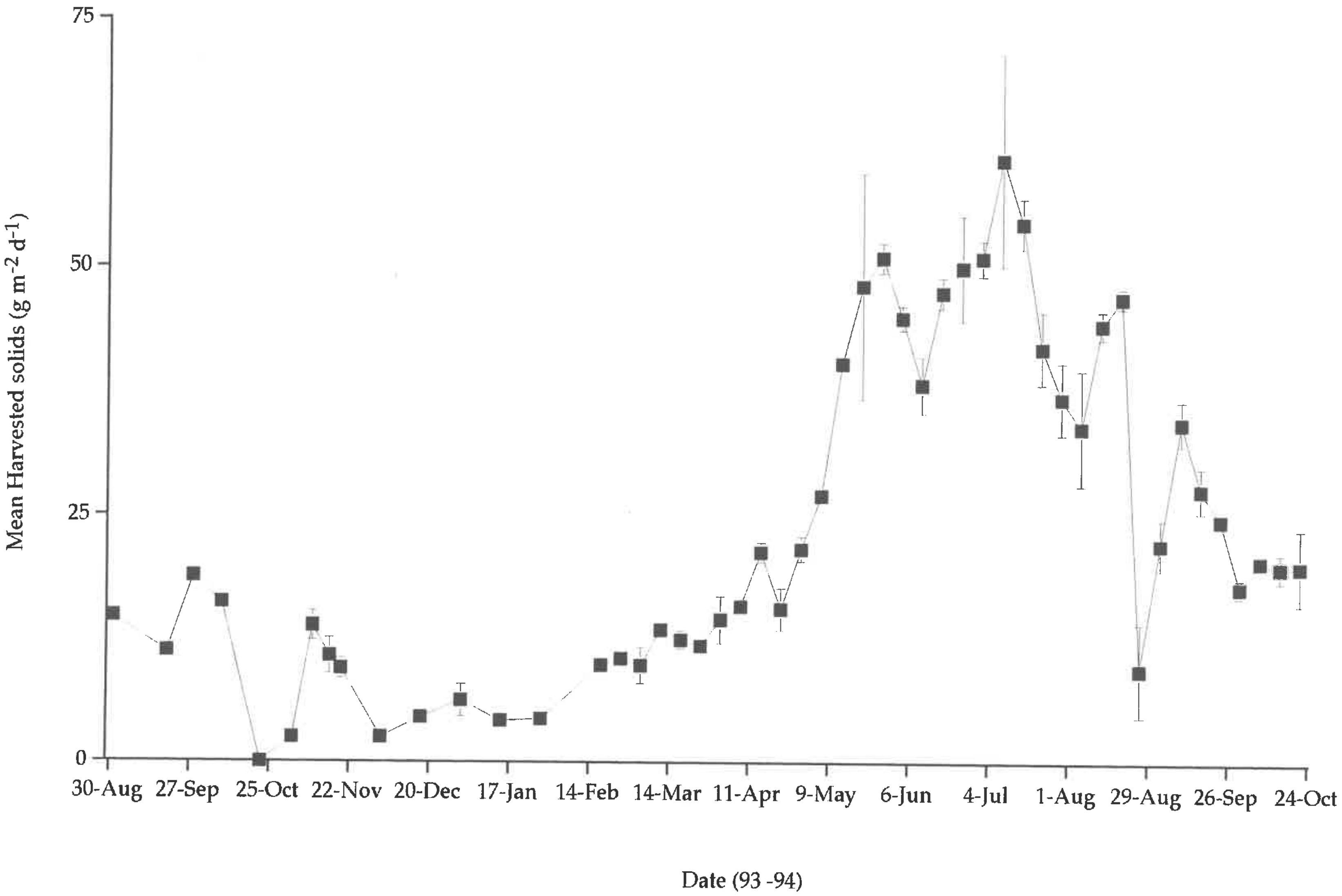
Minimum (■) and maximum (●) ambient temperature.



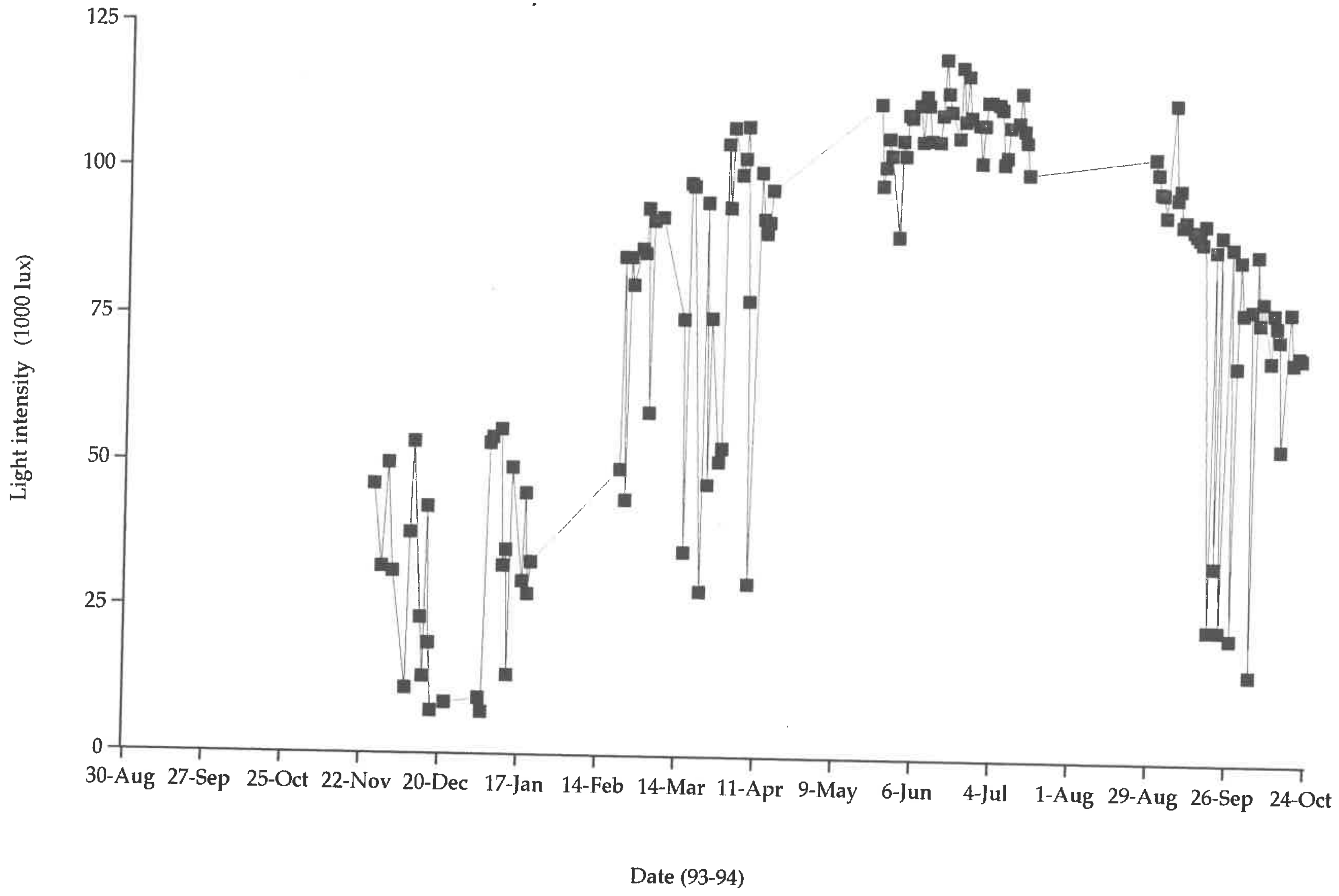
Conductivity of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



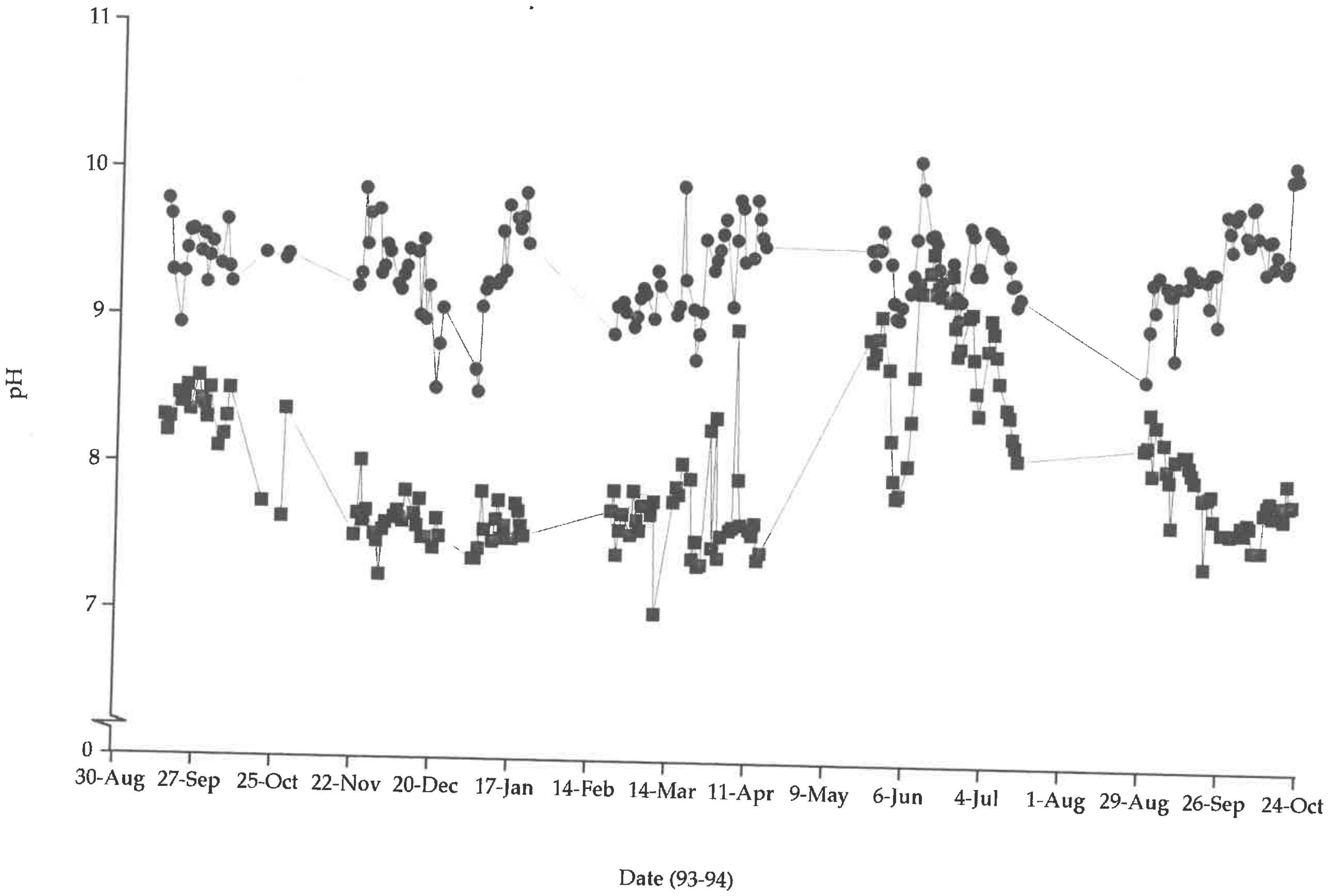
Dissolved Oxygen of influent (■) and effluent (●) of the ATS/UV system.



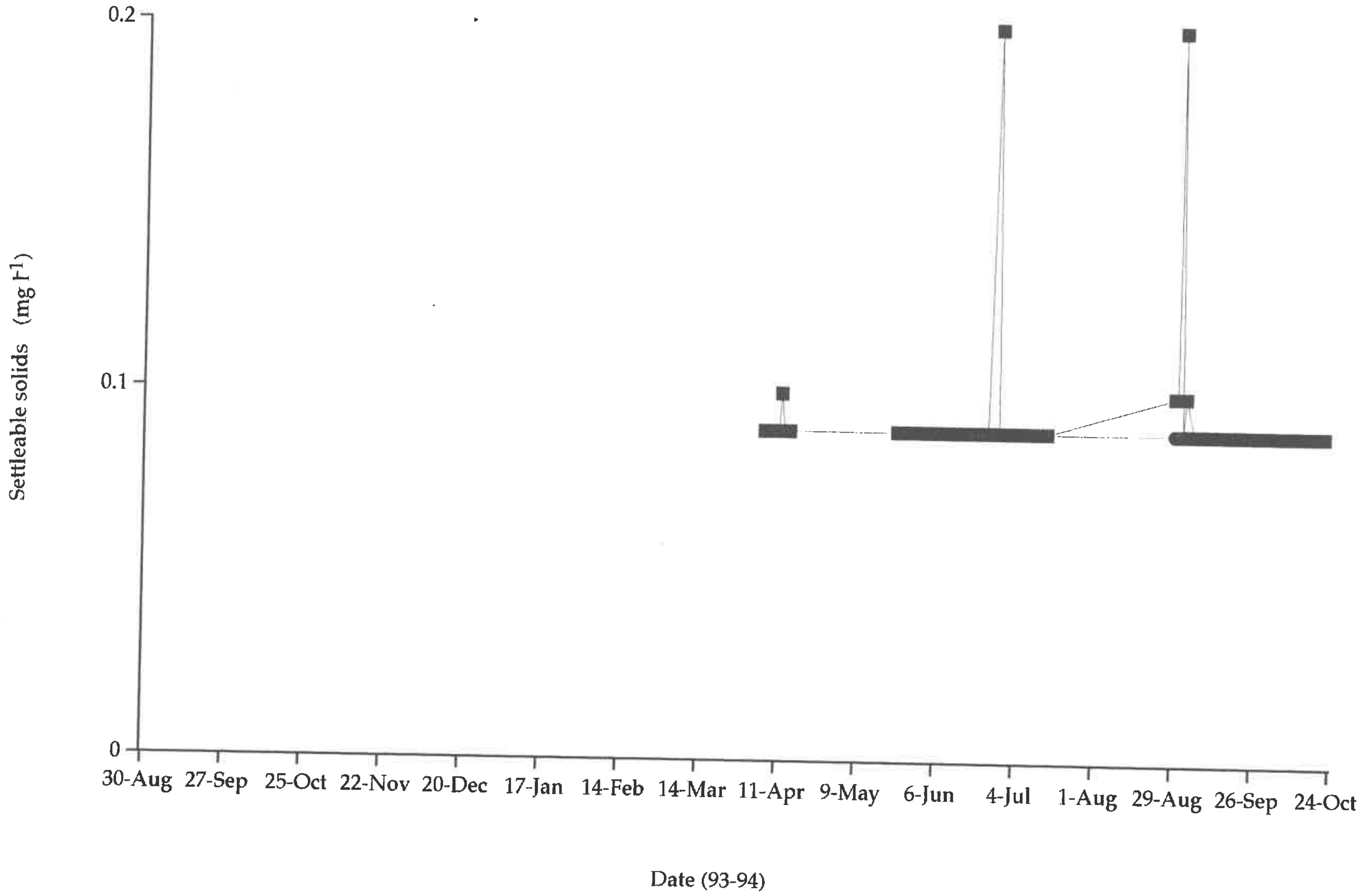
Harvested solids from the ATS. Values are means ± s.d. of two composite samples, each from five sites.



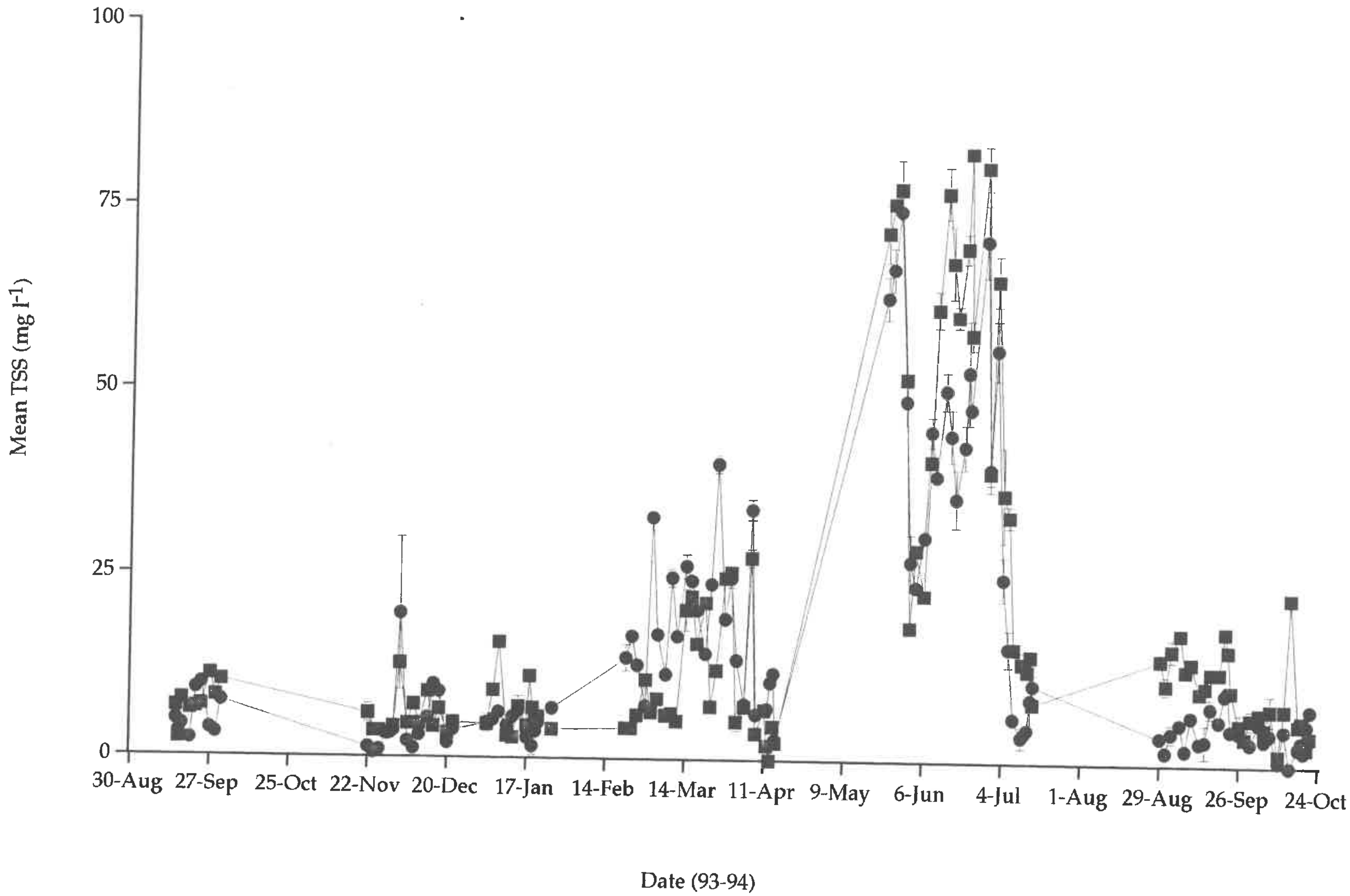
Light intensity measured at time of sampling (11.00 am) .



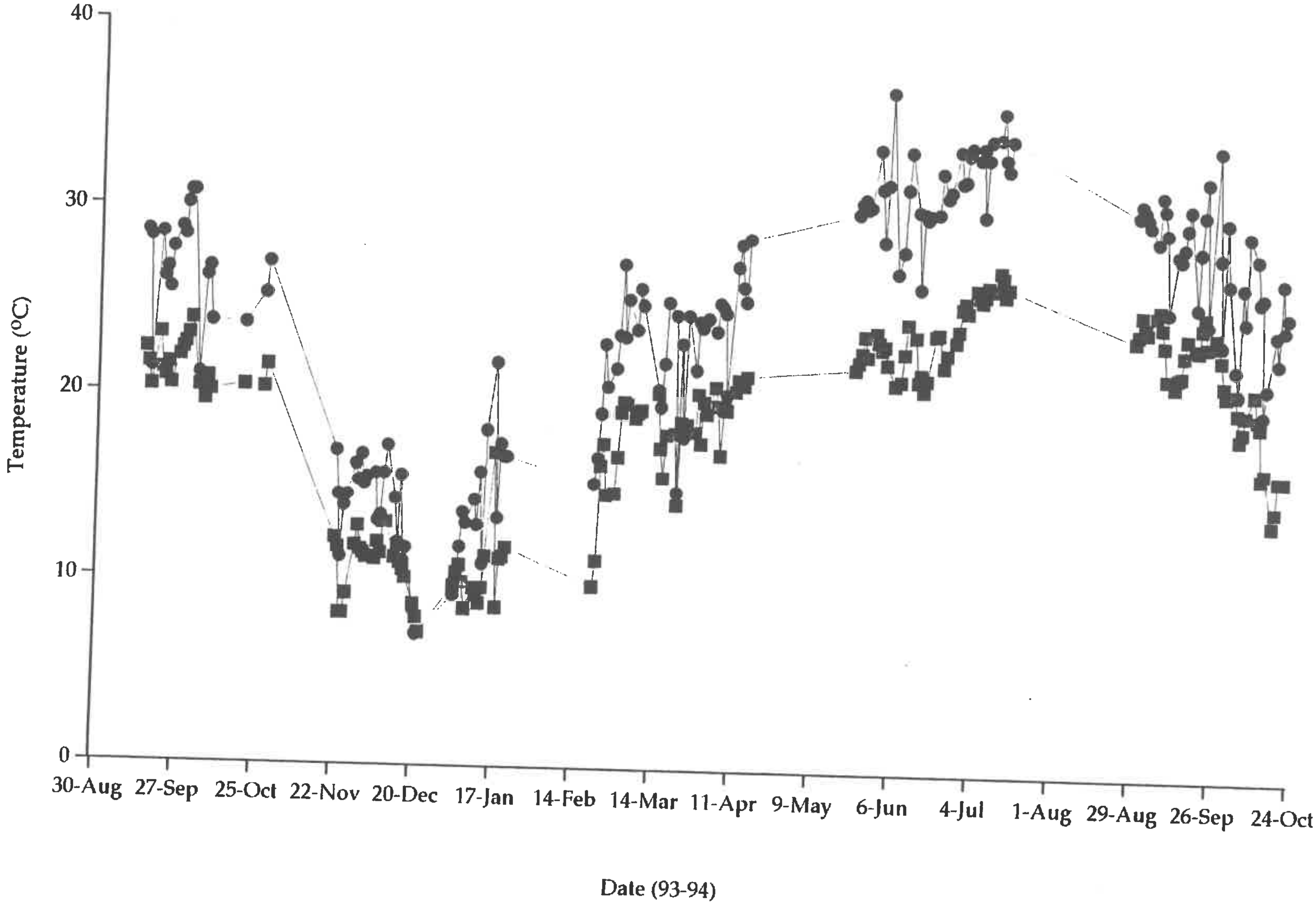
pH of influent (■) and effluent (●) of the ATS/UV system.



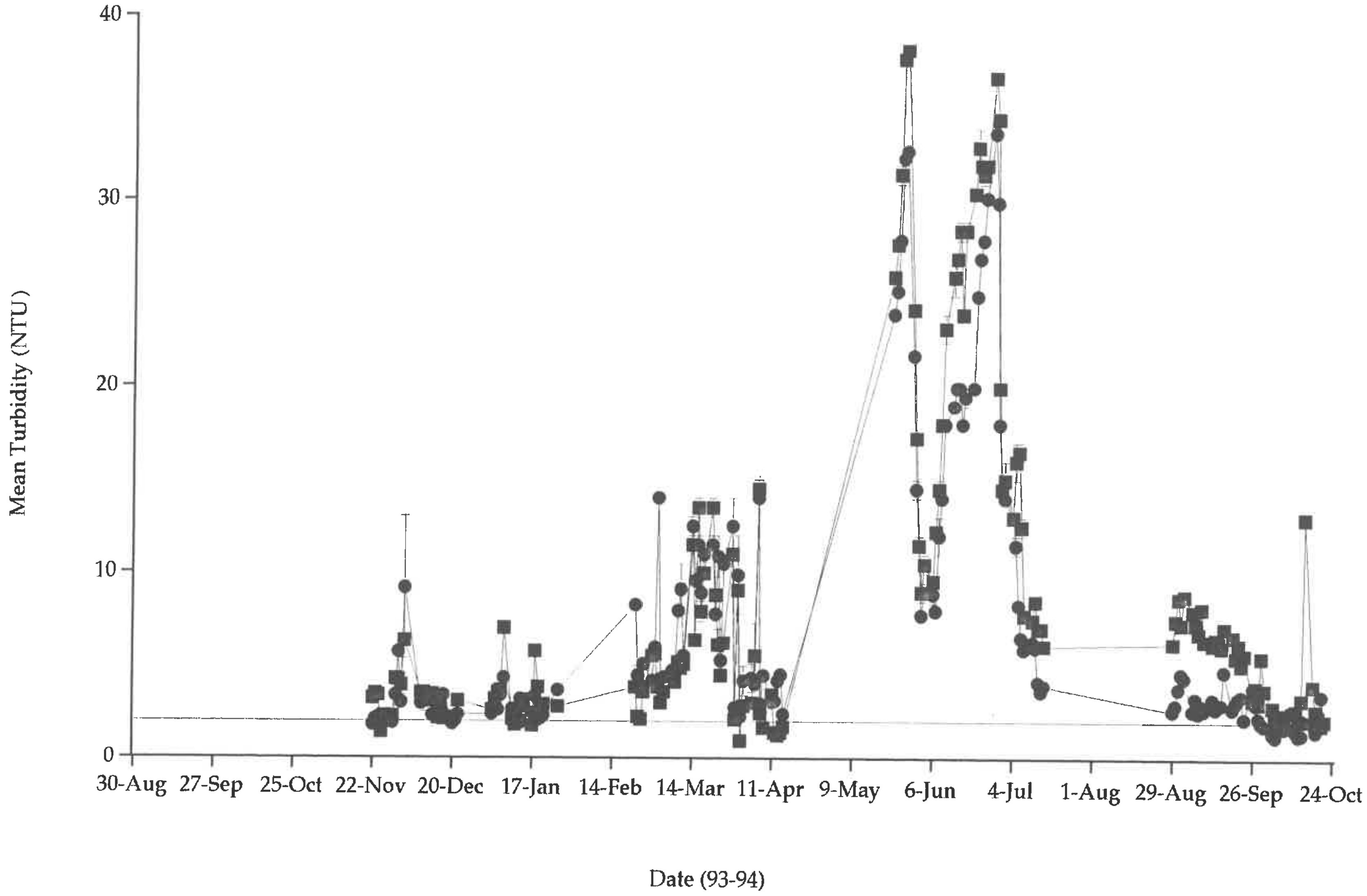
Settleable solidsof influent (■) and effluent (●) of the ATS/UV system .



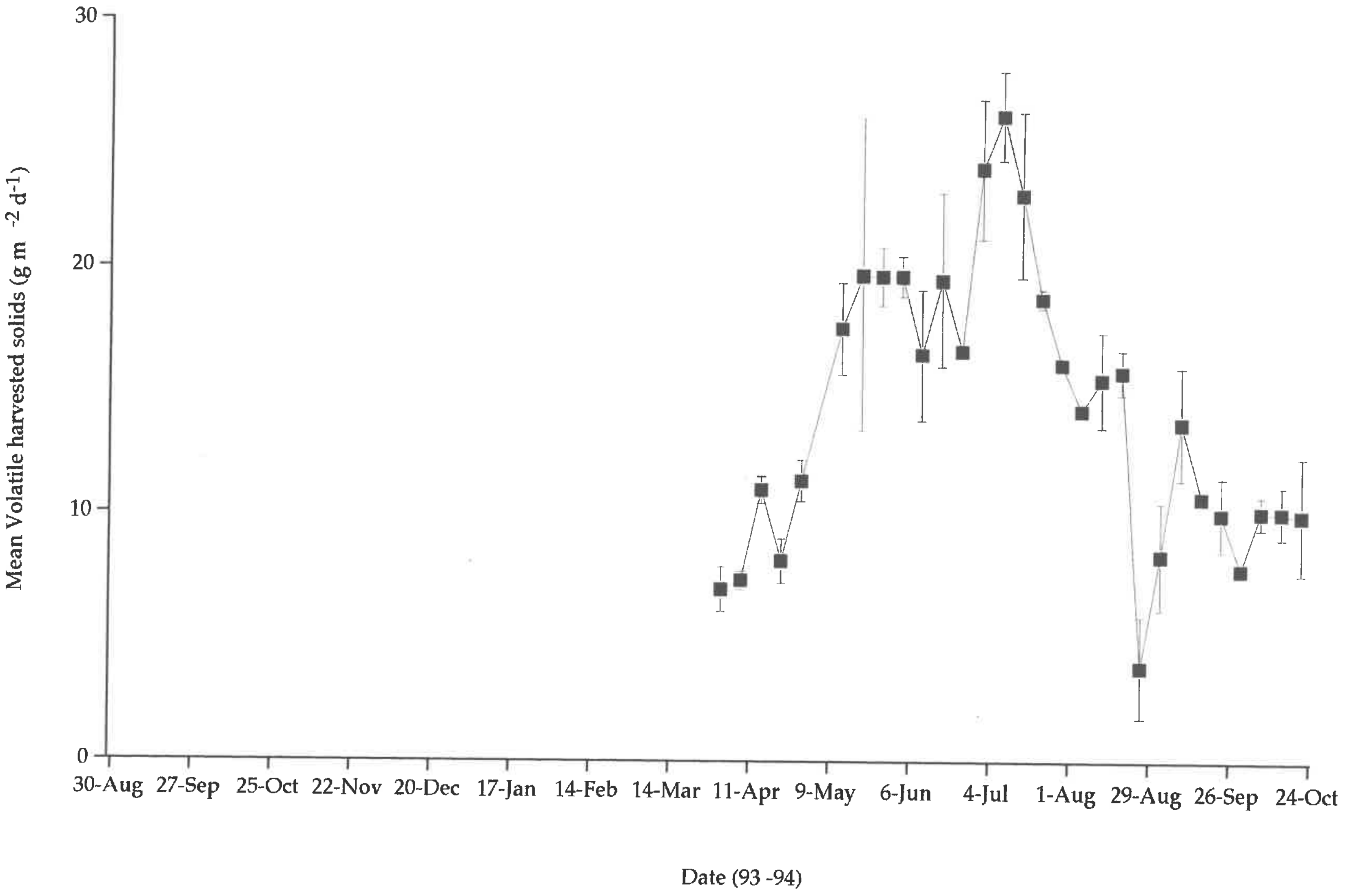
Total suspended solids of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



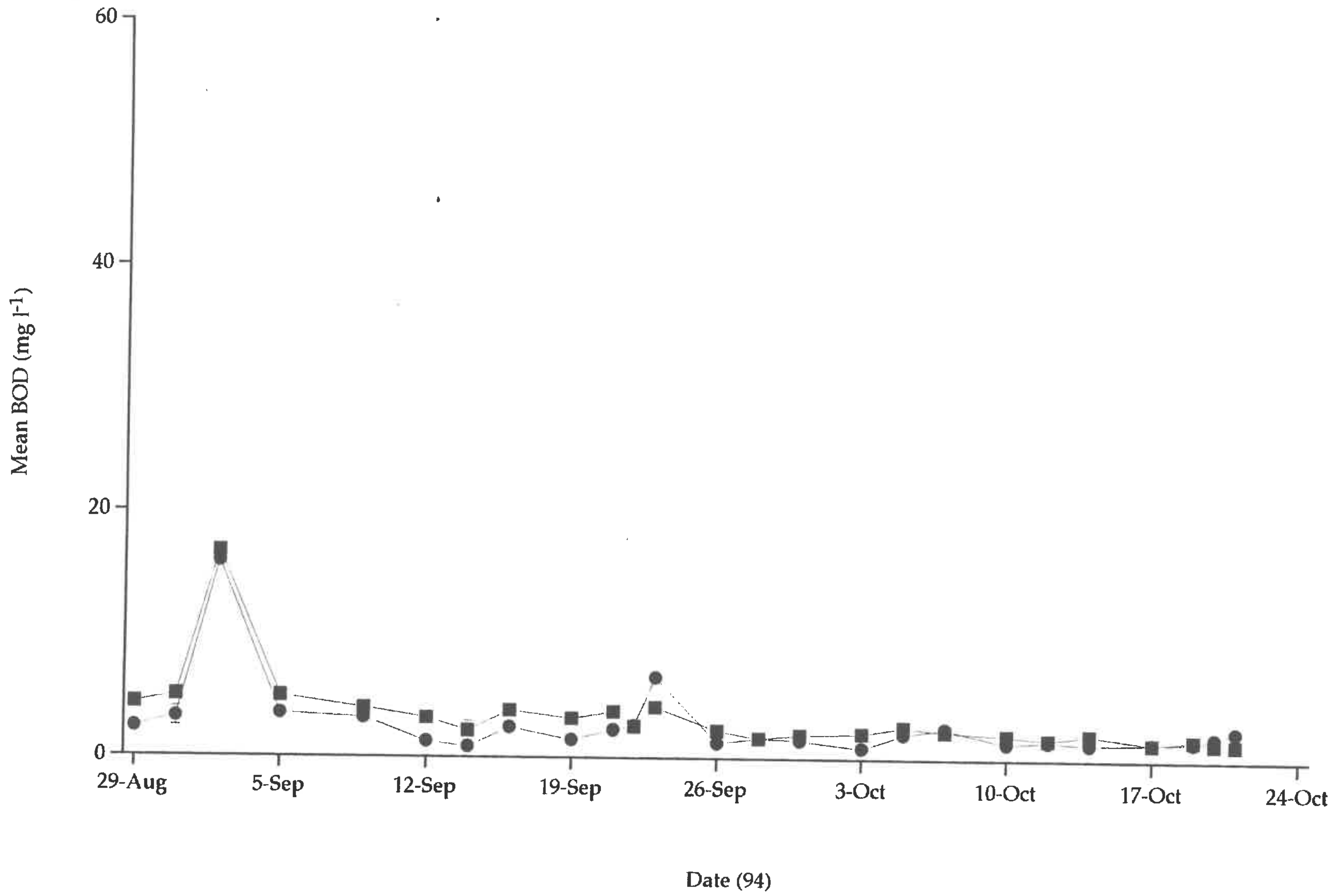
Temperature of influent (■) and effluent (●) of the ATS/UV system .



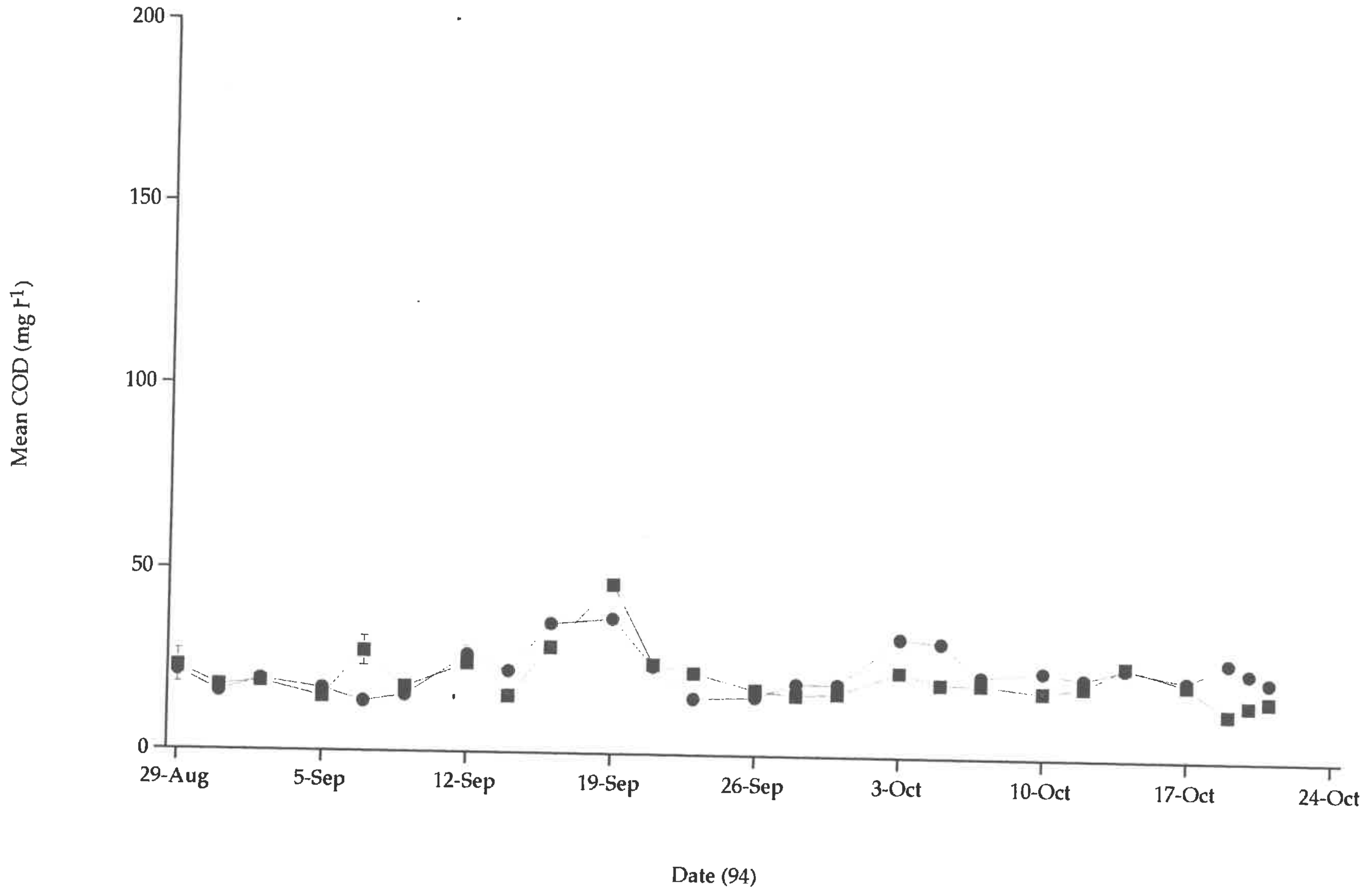
Turbidity of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



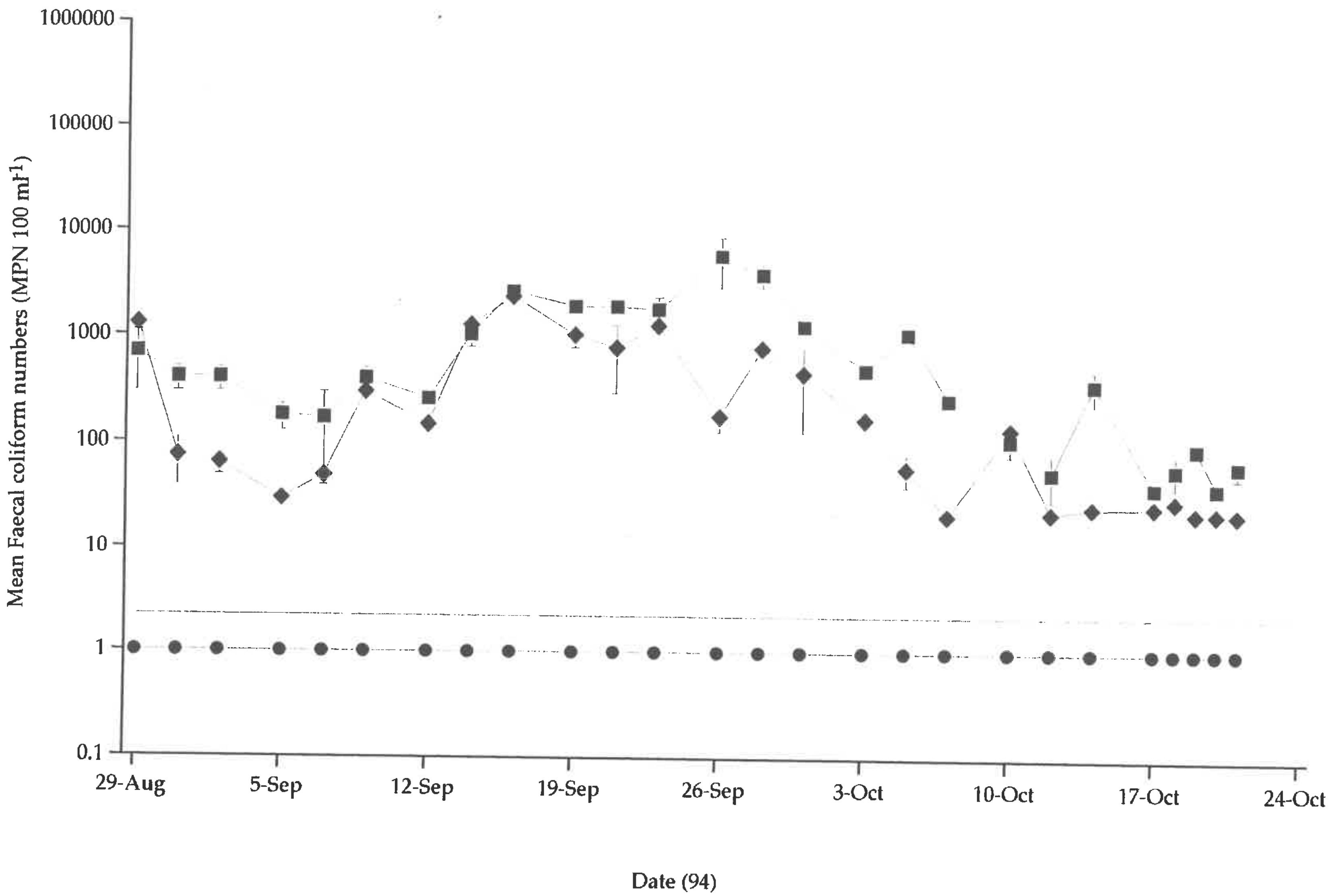
Volatile harvested solids from the ATS. Values are means ± s.d. of two composite samples, each from five sites.



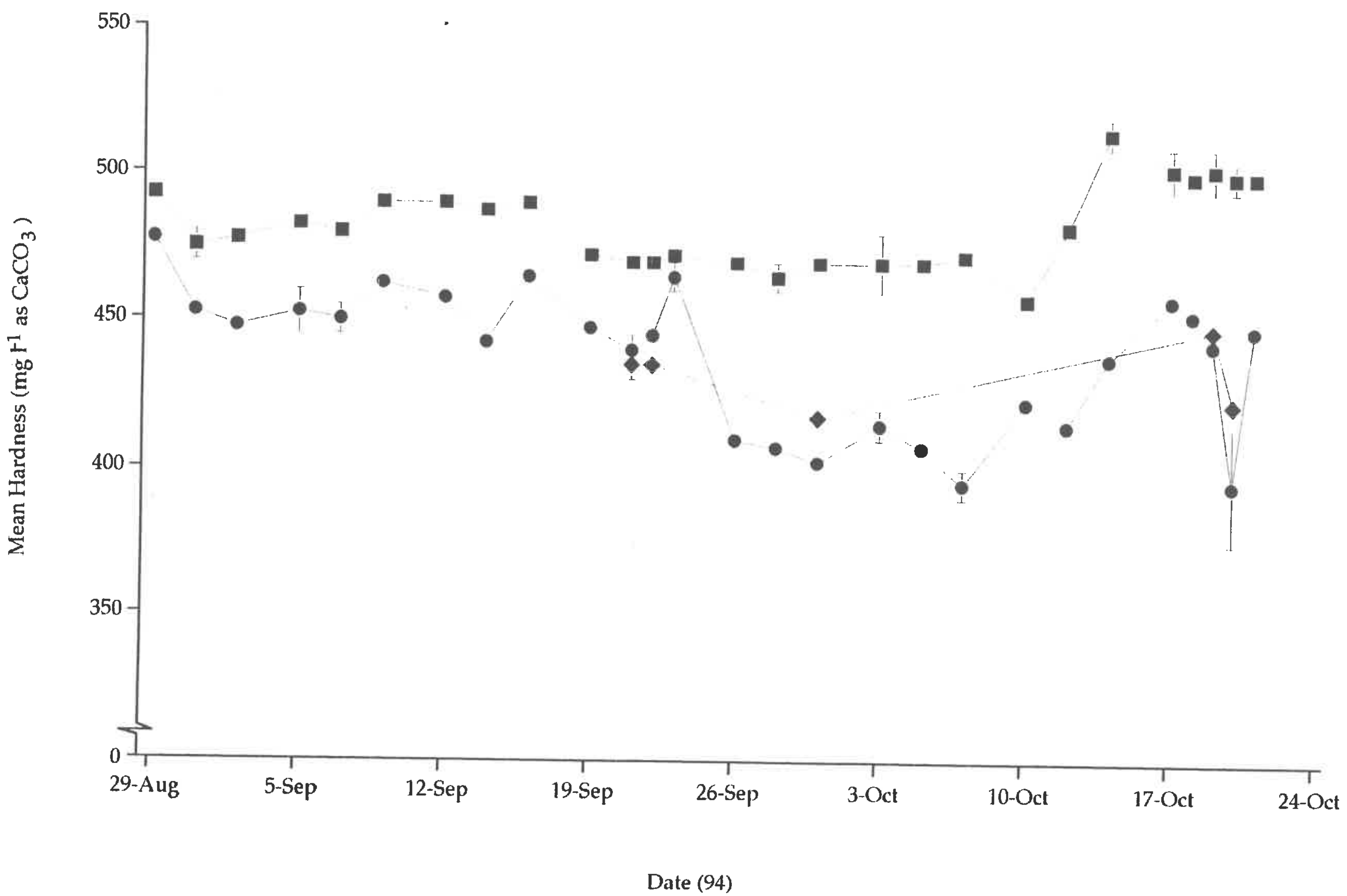
Fall quarter. Biochemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



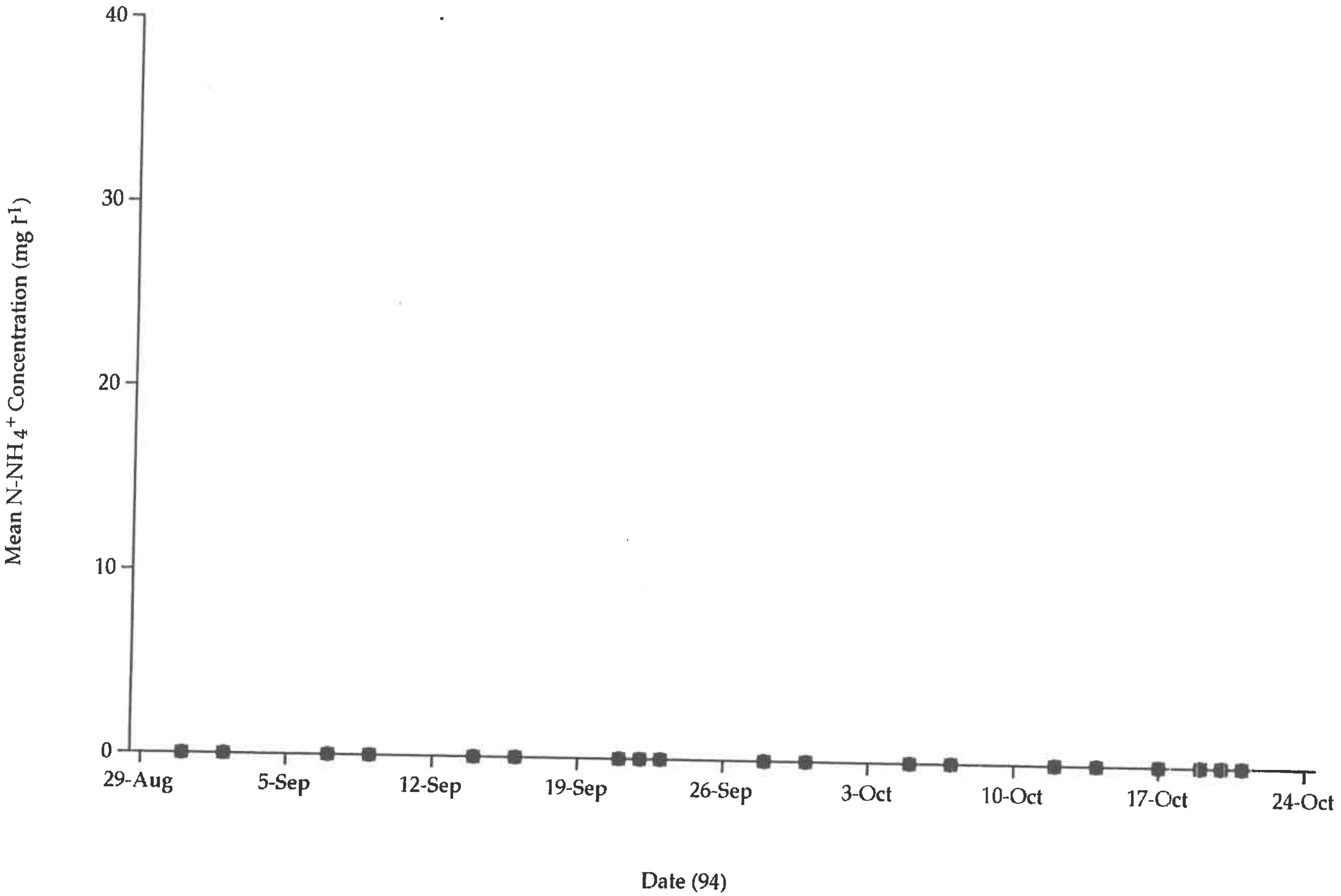
Fall quarter. Chemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



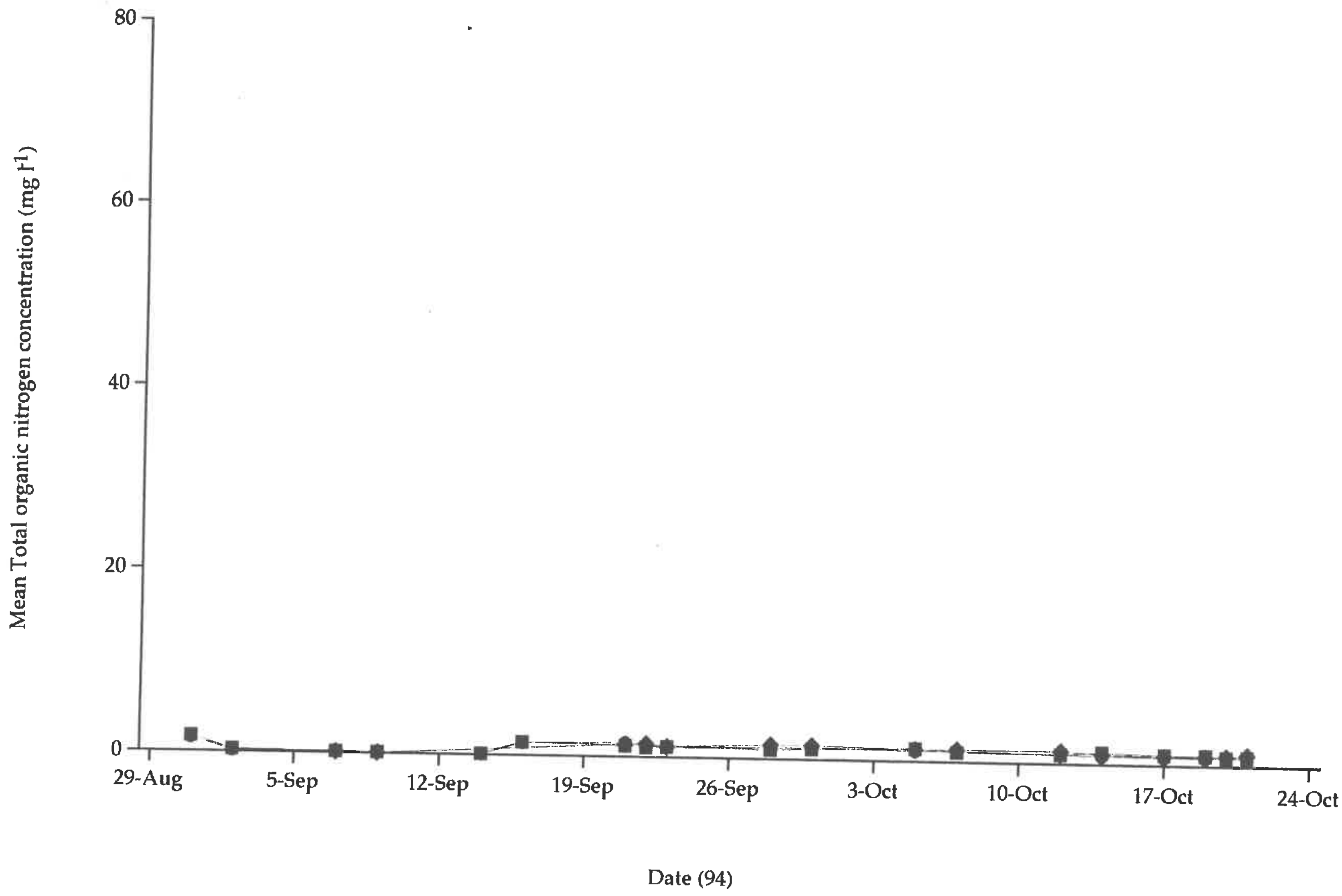
Fall quarter. Faecal coliform numbers of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



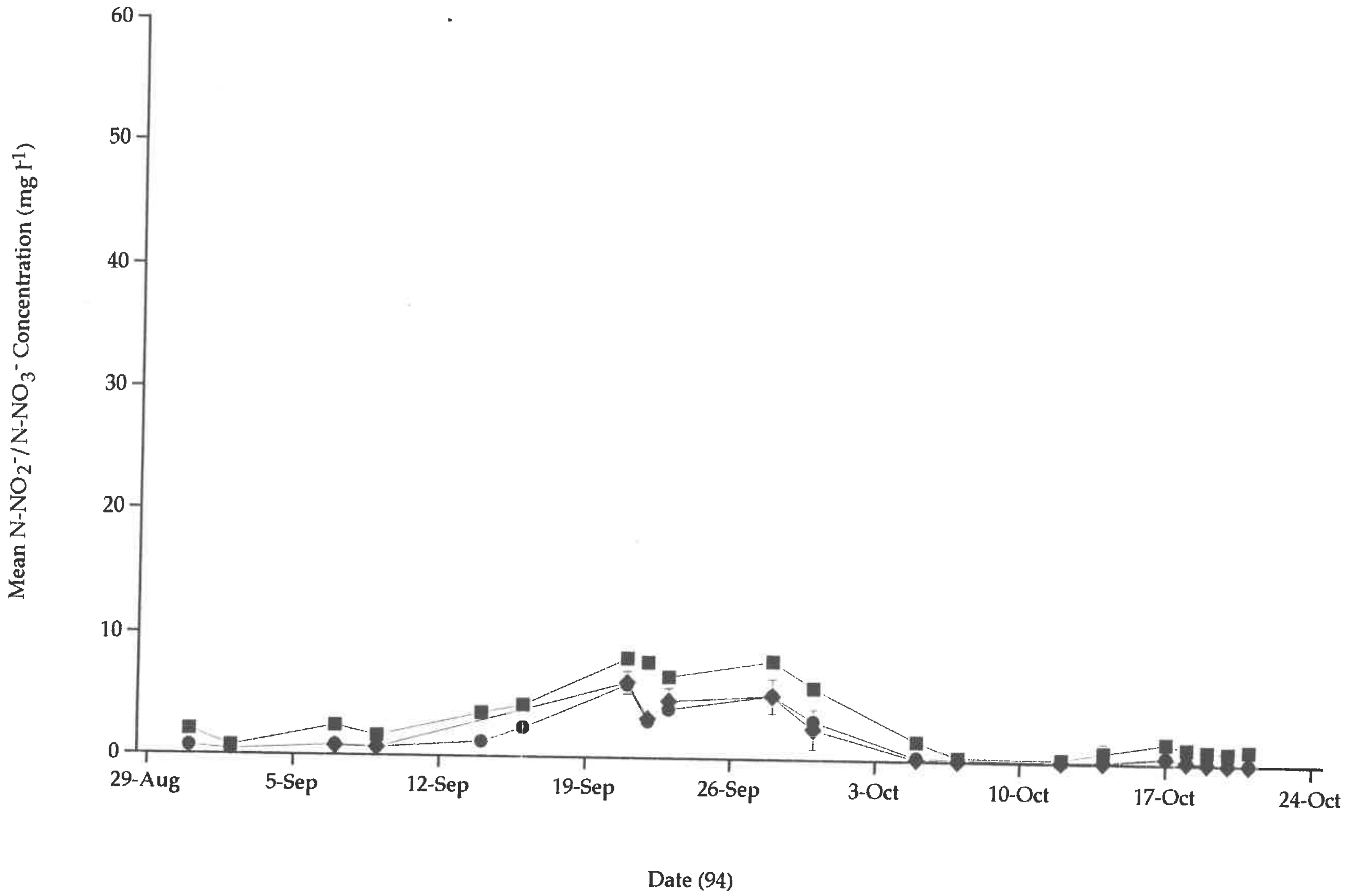
Fall quarter. **Hardness** of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



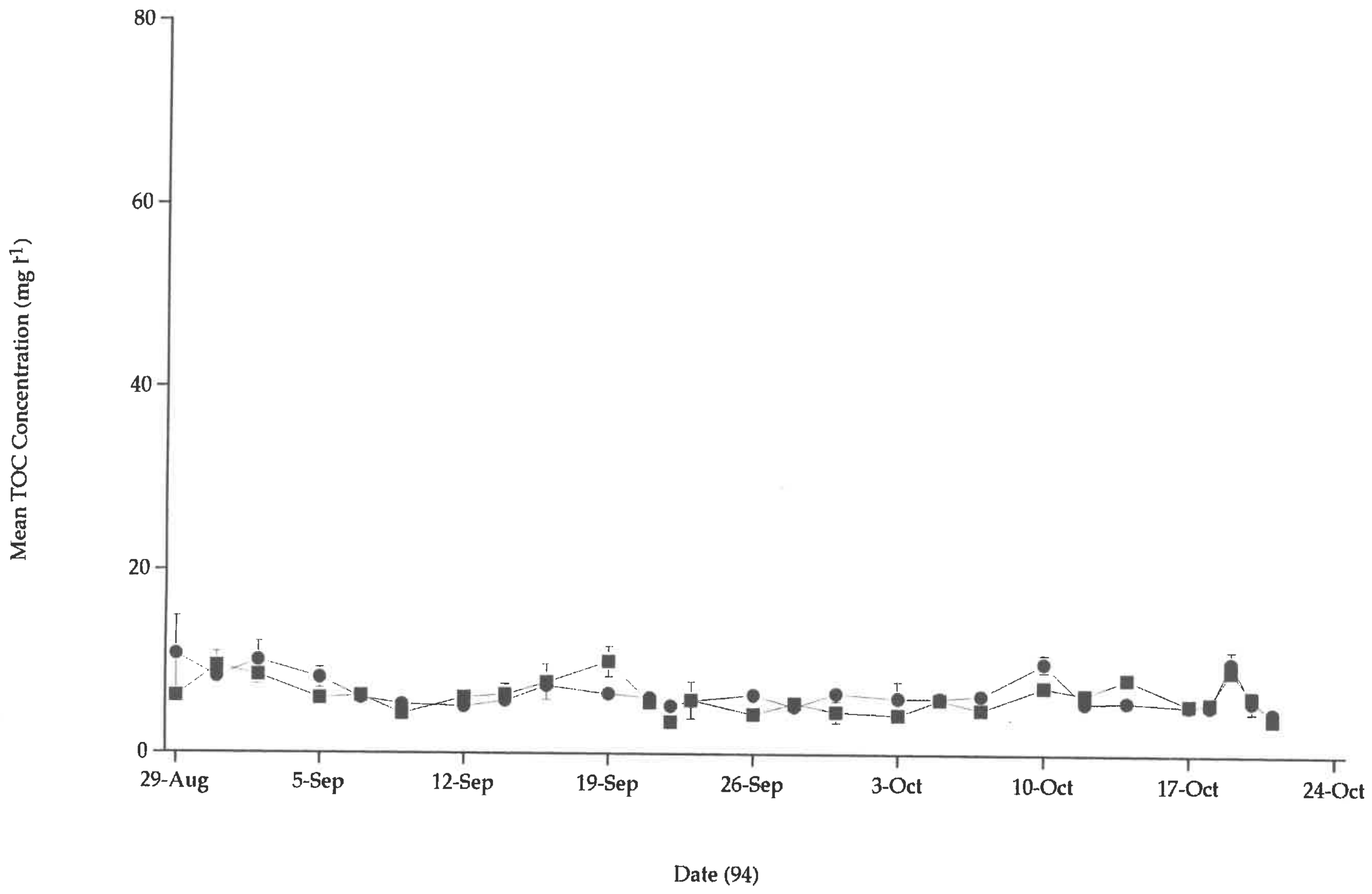
Fall quarter. Ammonium-nitrogen concentration of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



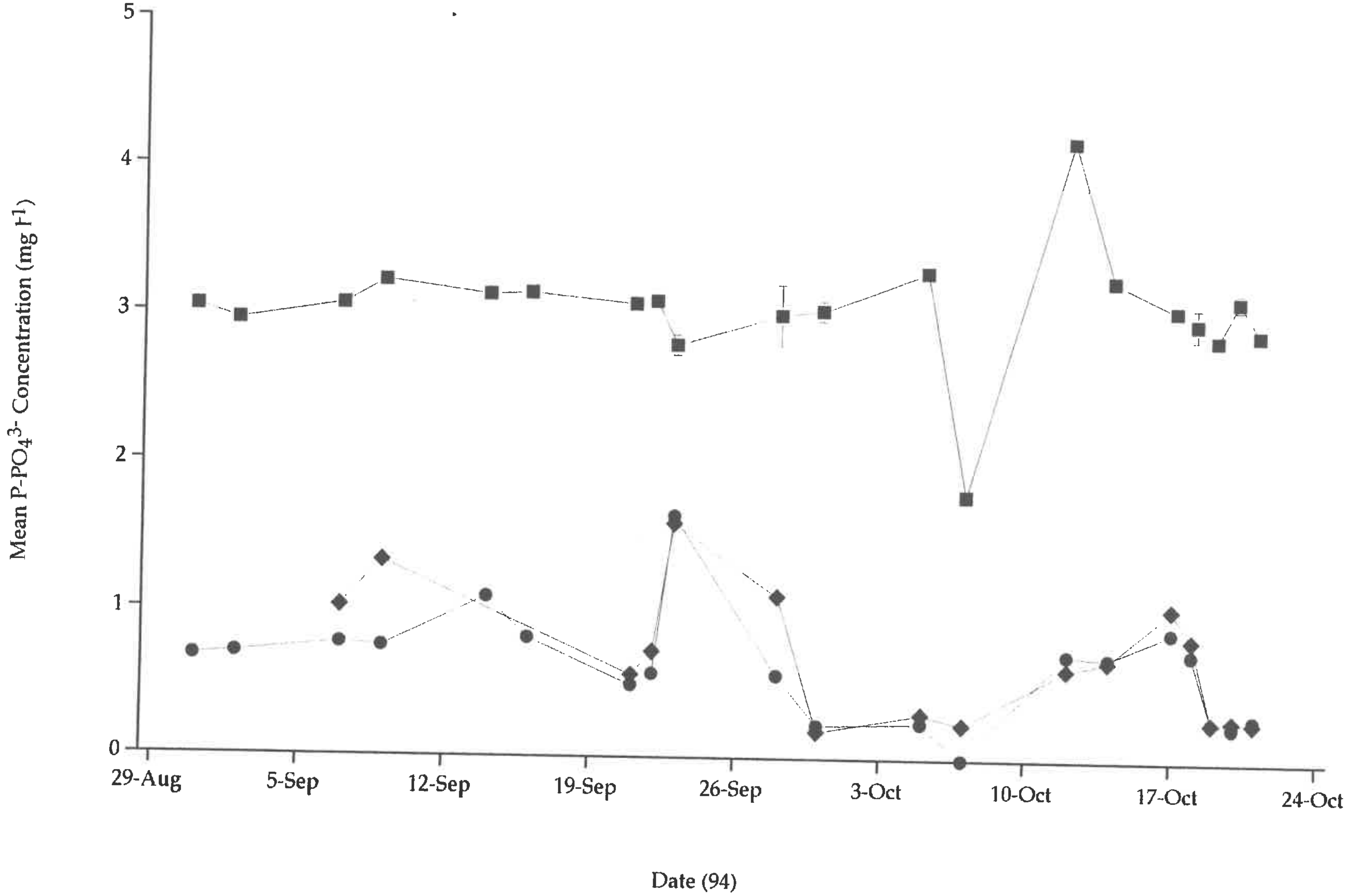
Fall quarter. Total organic nitrogen concentration of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



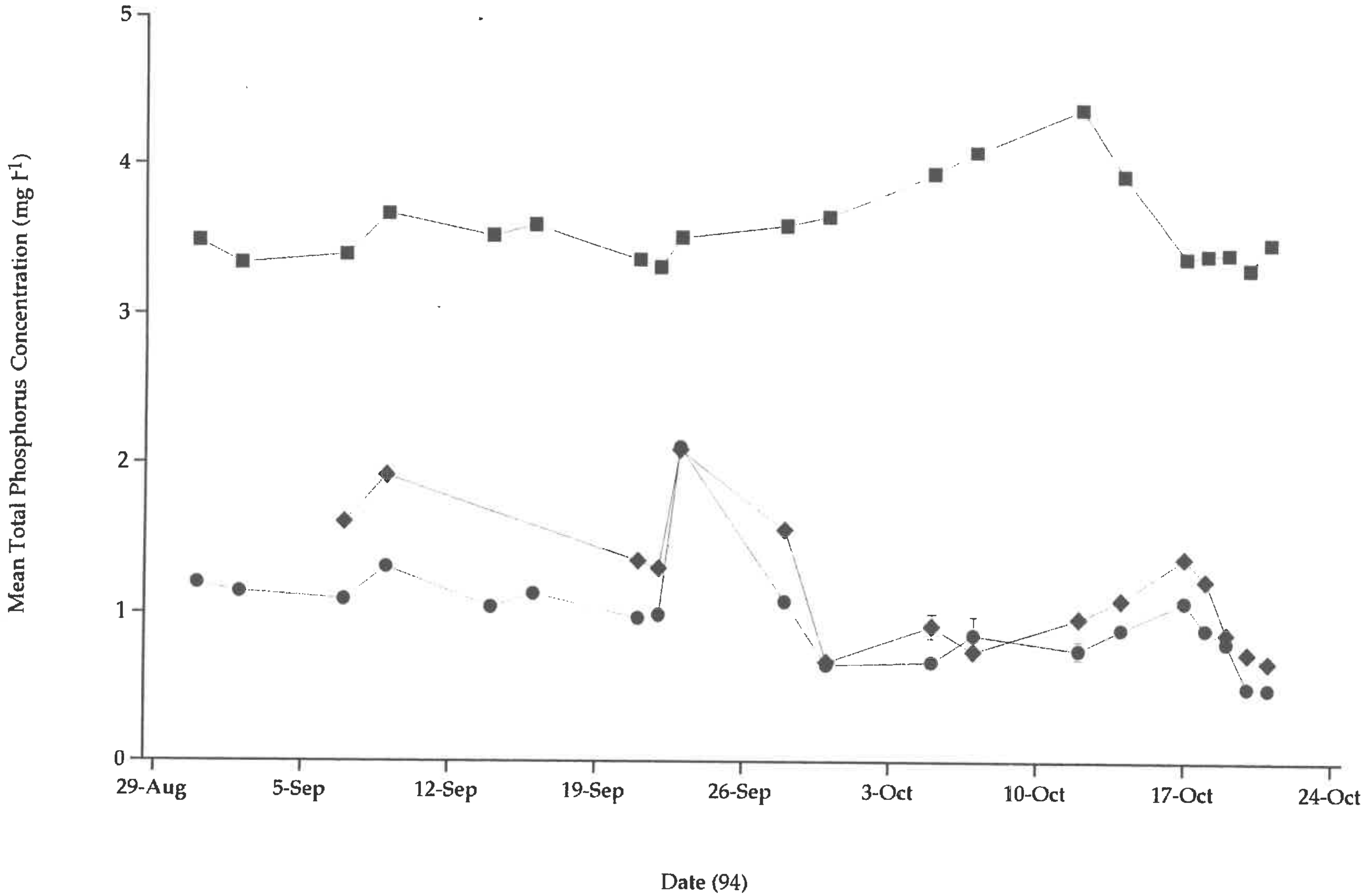
Fall quarter. Nitrite- and Nitrate-nitrogen concentration of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



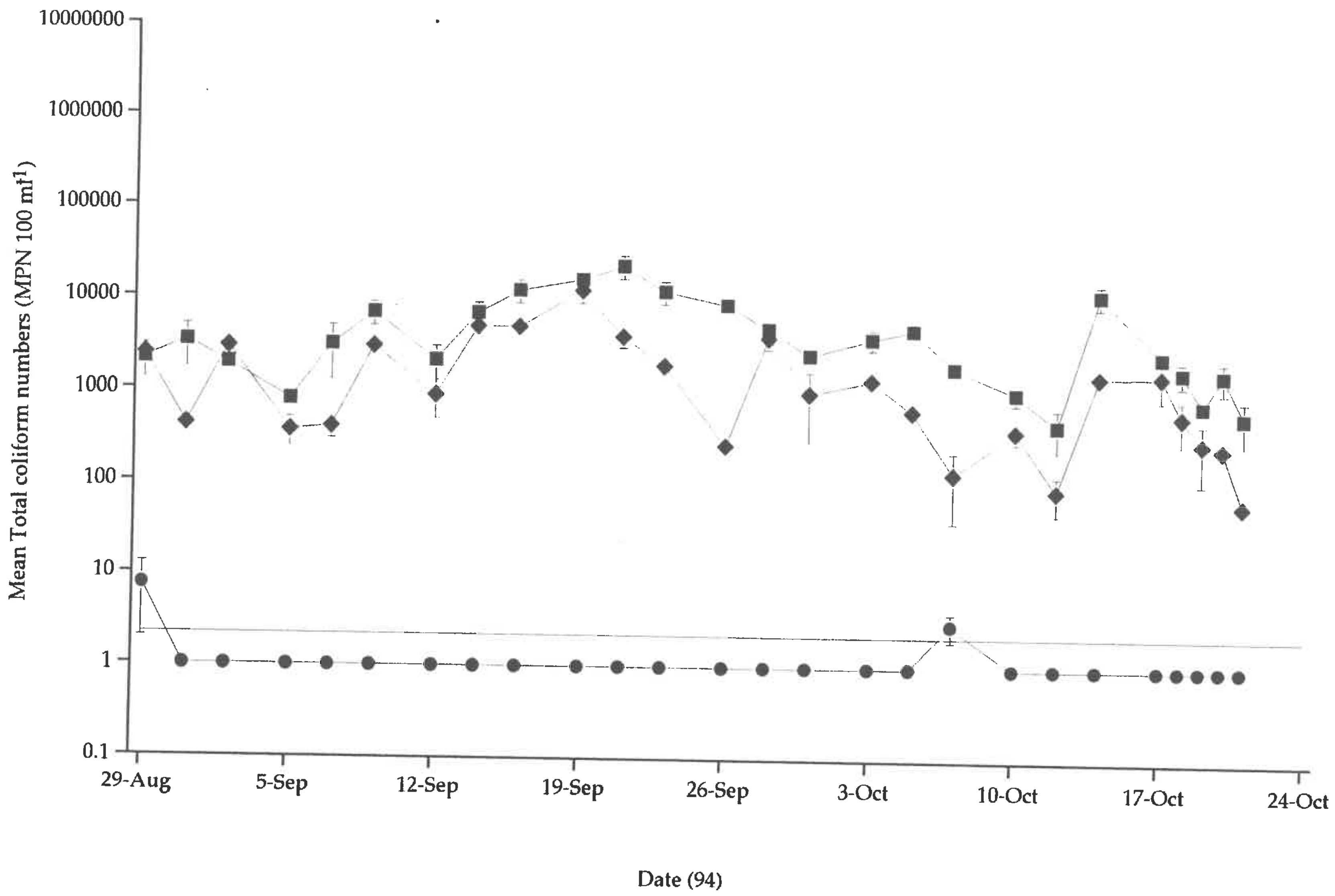
Fall quarter. Total organic carbon concentration of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples. .



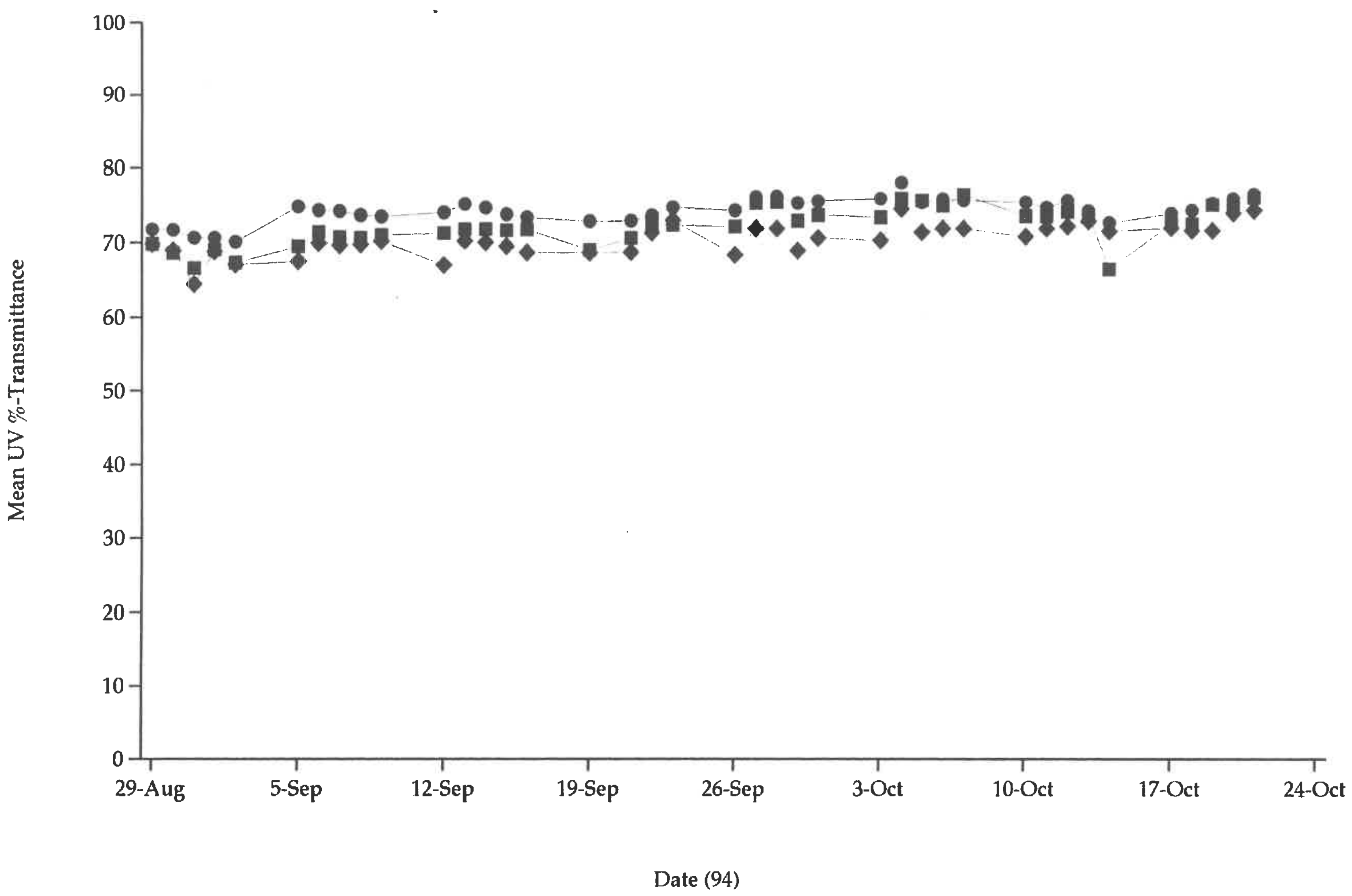
Fall quarter. Soluble reactive phosphorus concentration of influent (■), ATS effluent (◆) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



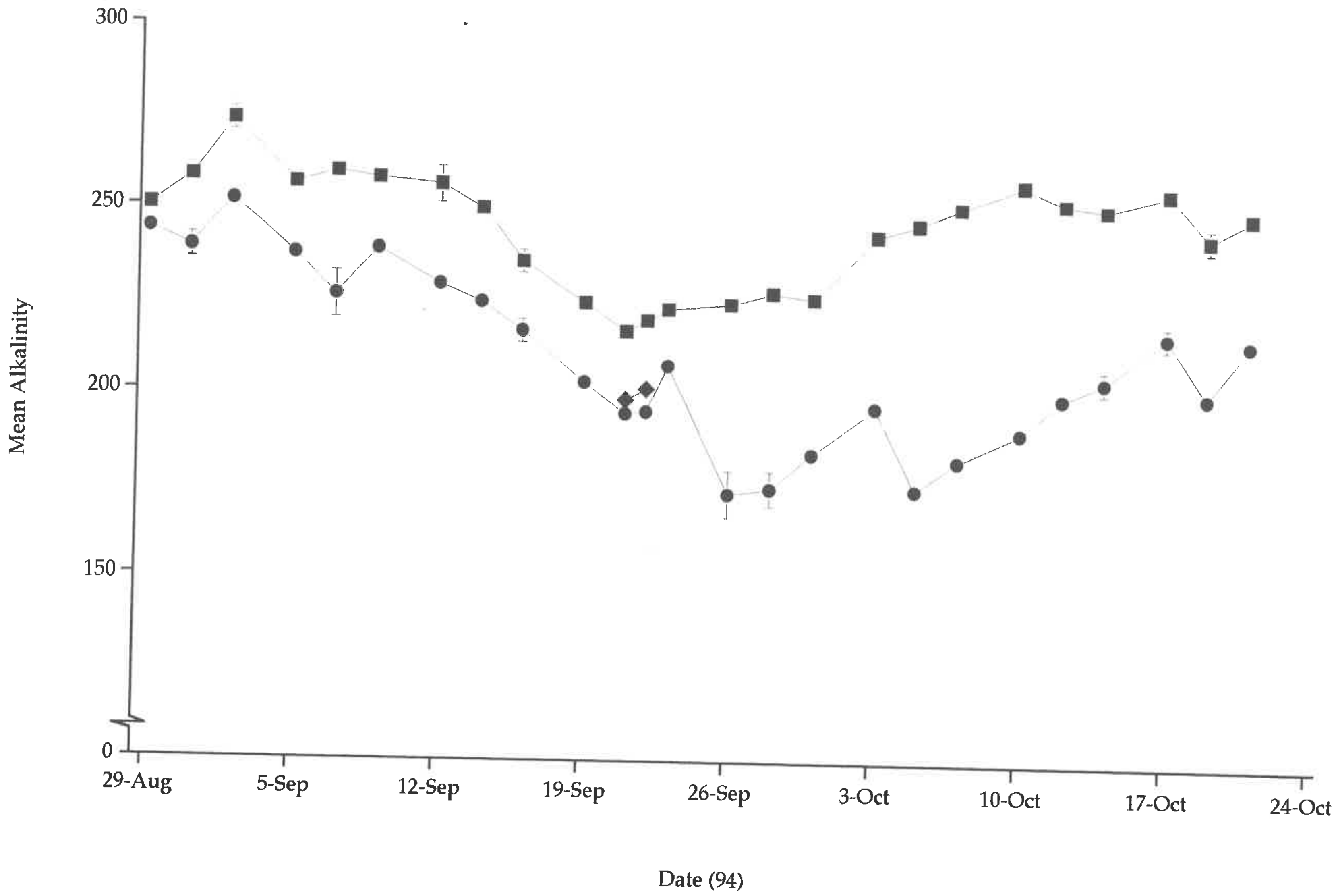
Fall quarter. Total phosphorus concentration of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



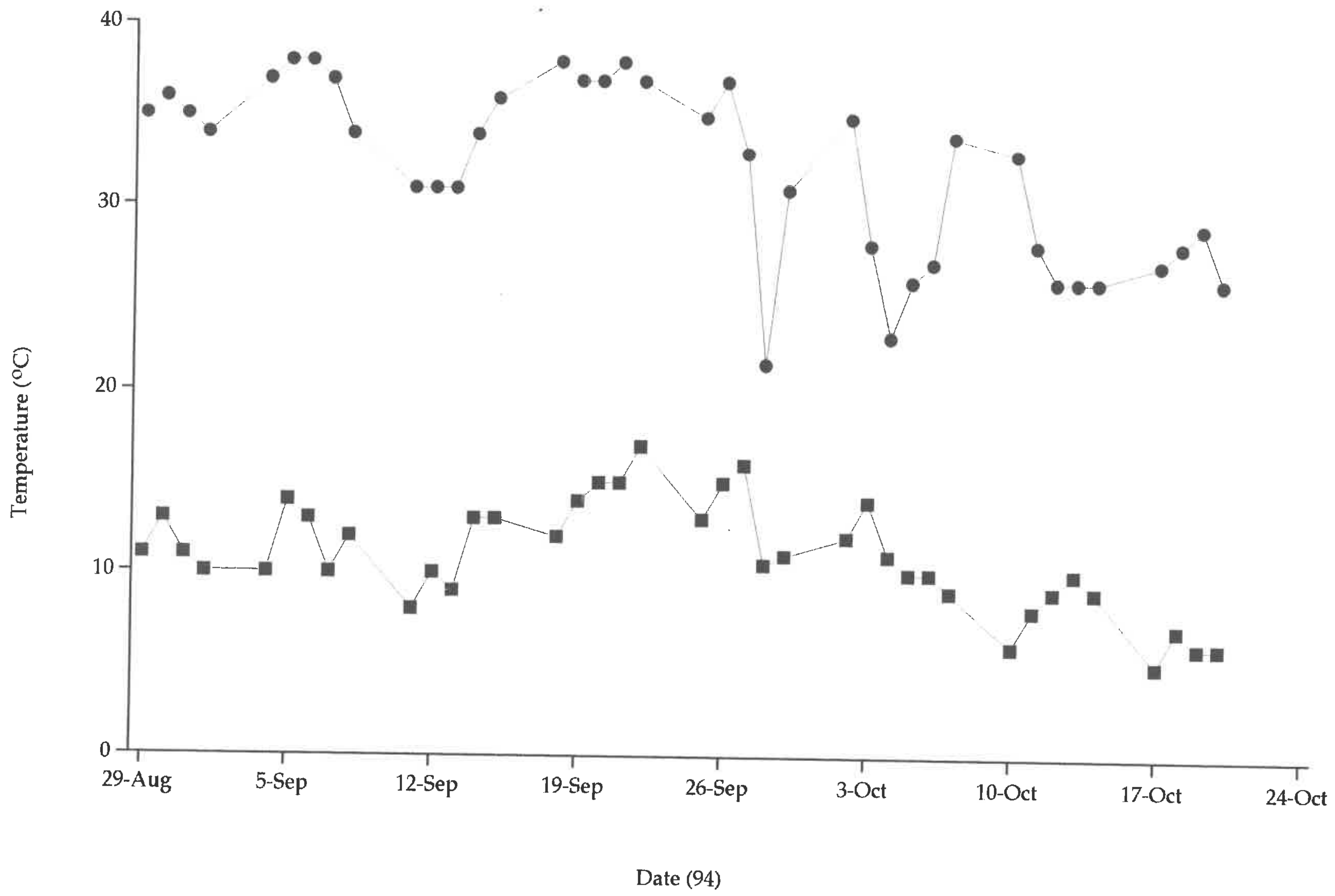
Fall quarter. Total coliform numbers of influent (■), ATS effluent (◆) and UV effluent (●) of the UV system. Values are means ± s.d. of two replicate samples.



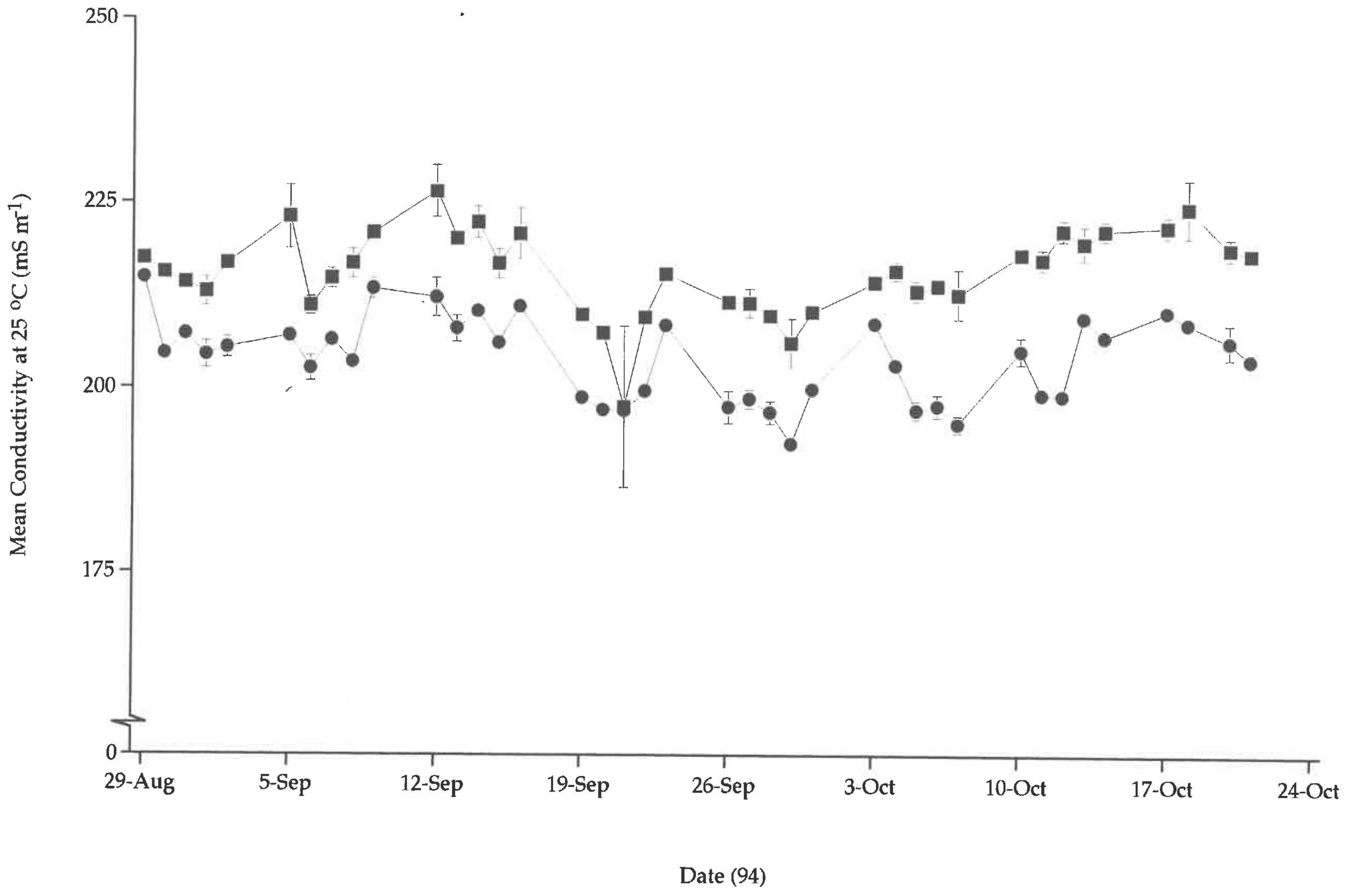
Fall quarter. UV %-Transmittance of influent (■), ATS effluent and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



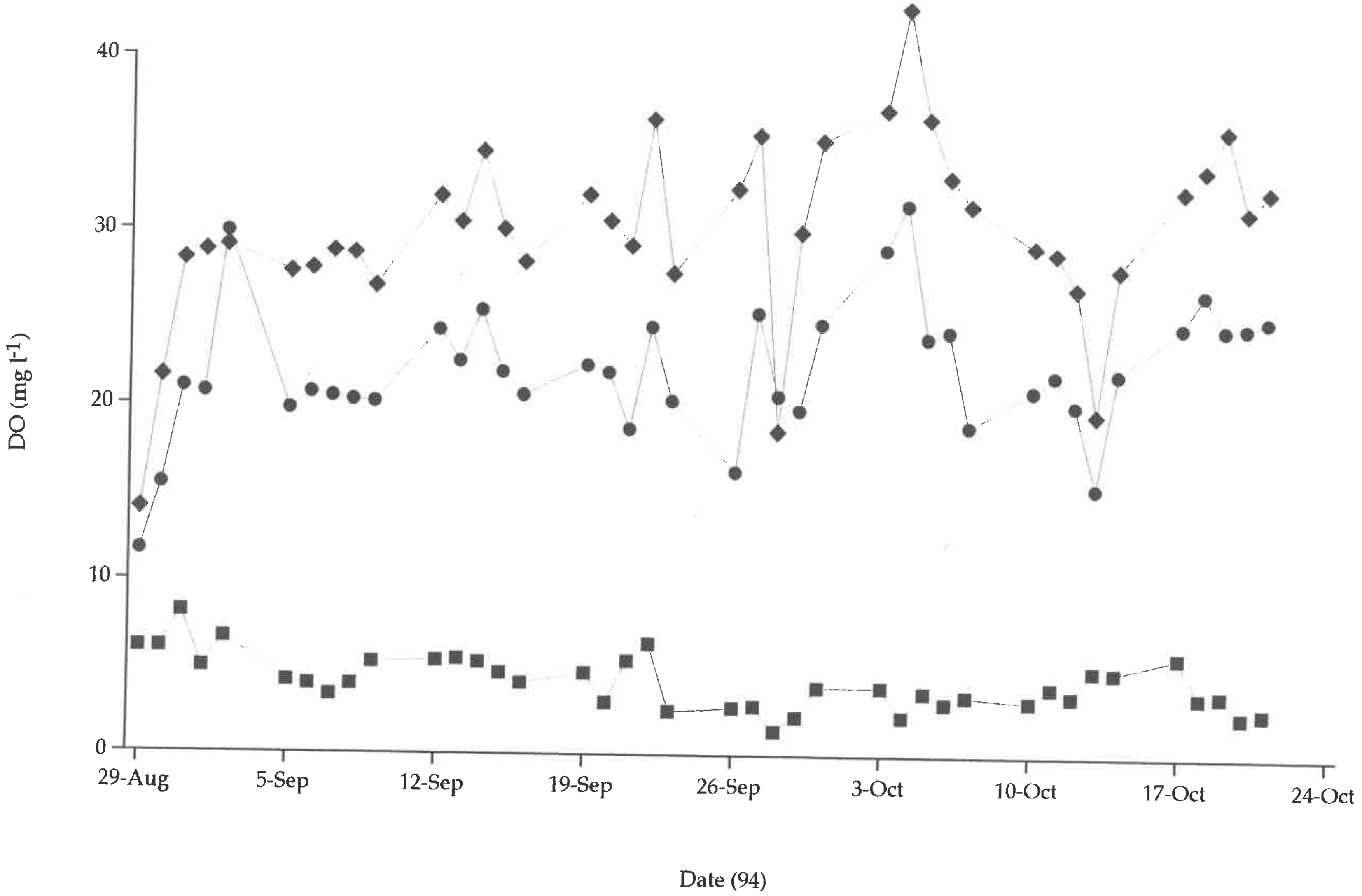
Fall quarter. **Alkalinity** of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



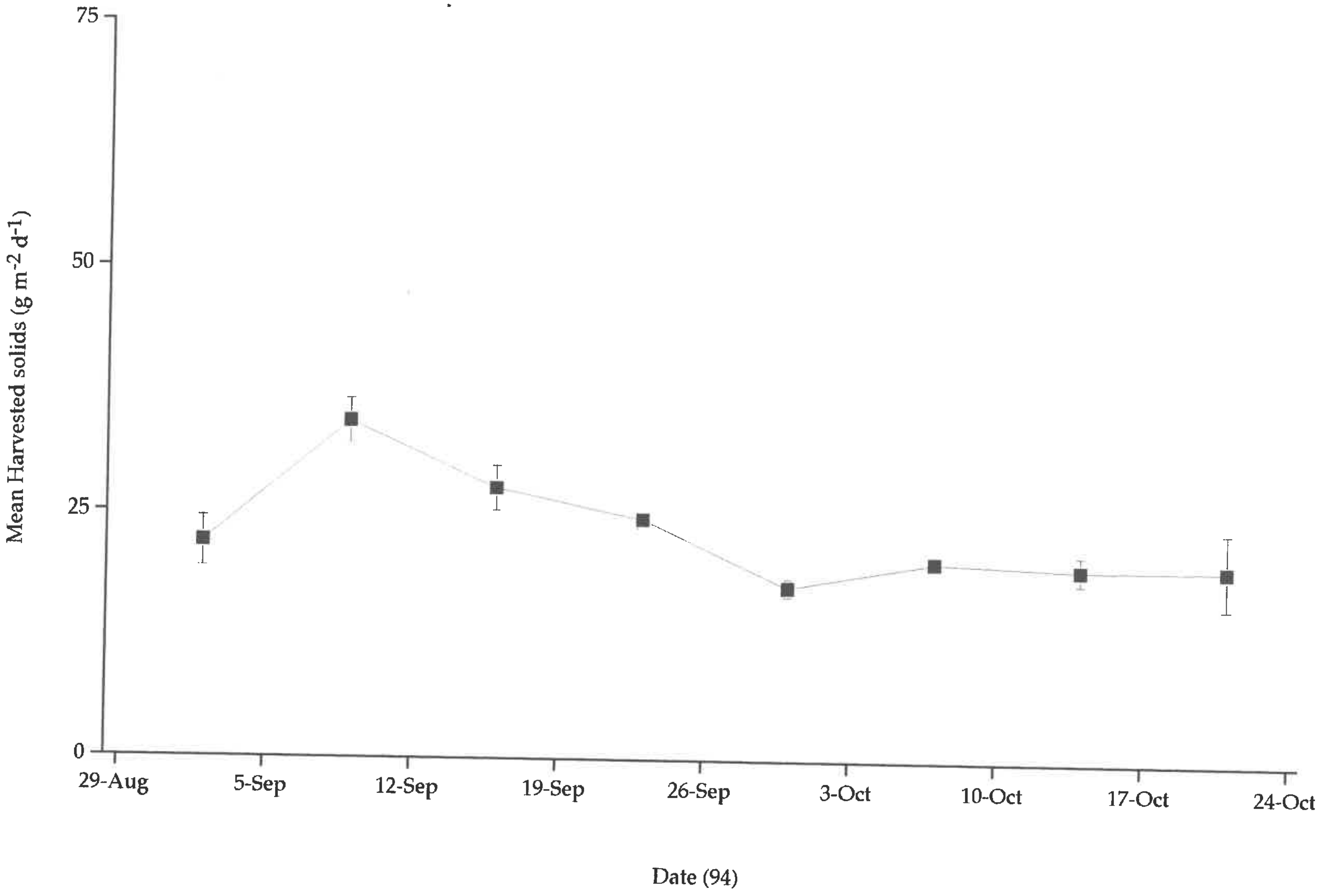
Fall quarter. Minimum (■) and maximum (●) ambient temperature.



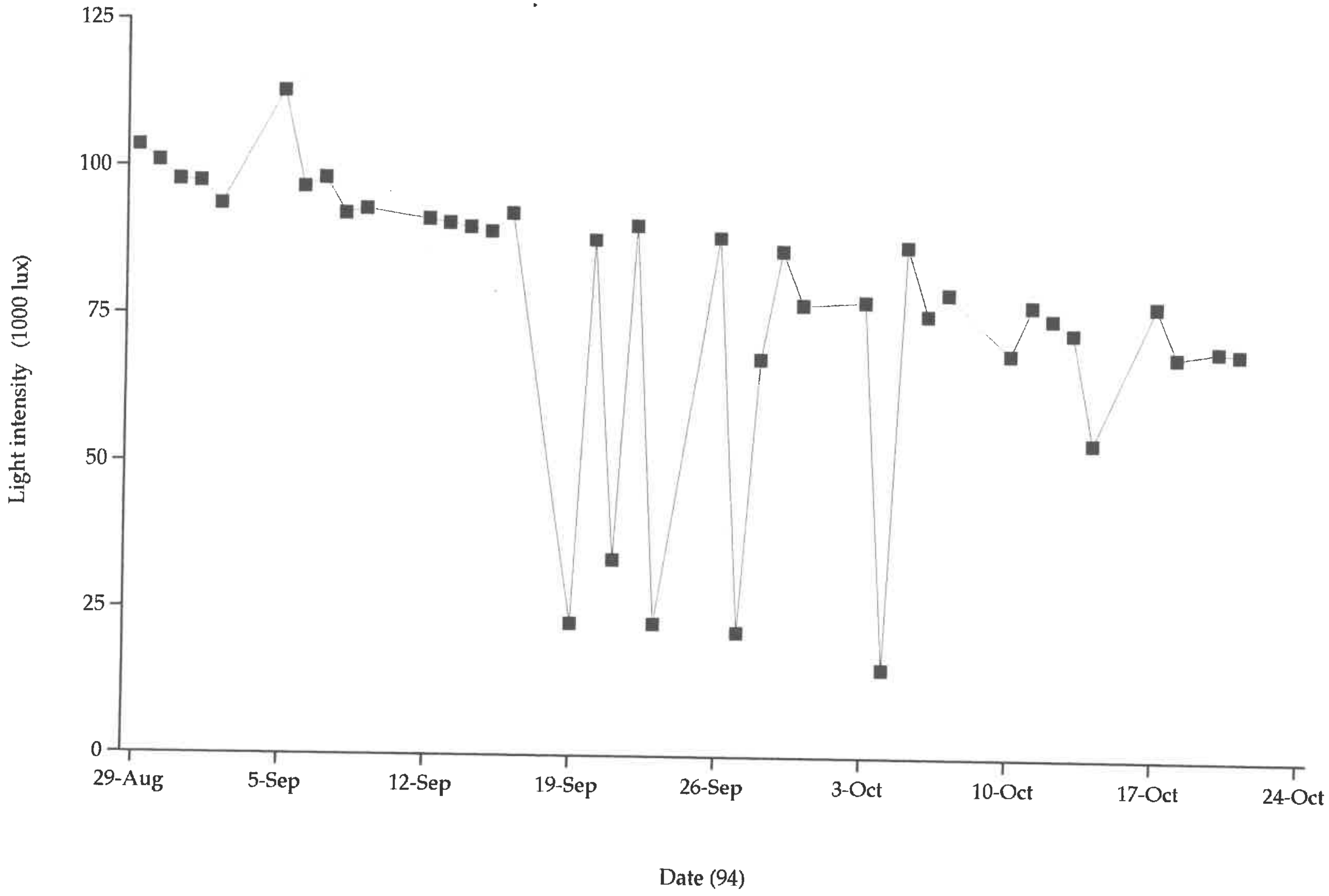
Fall quarter. Conductivity of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



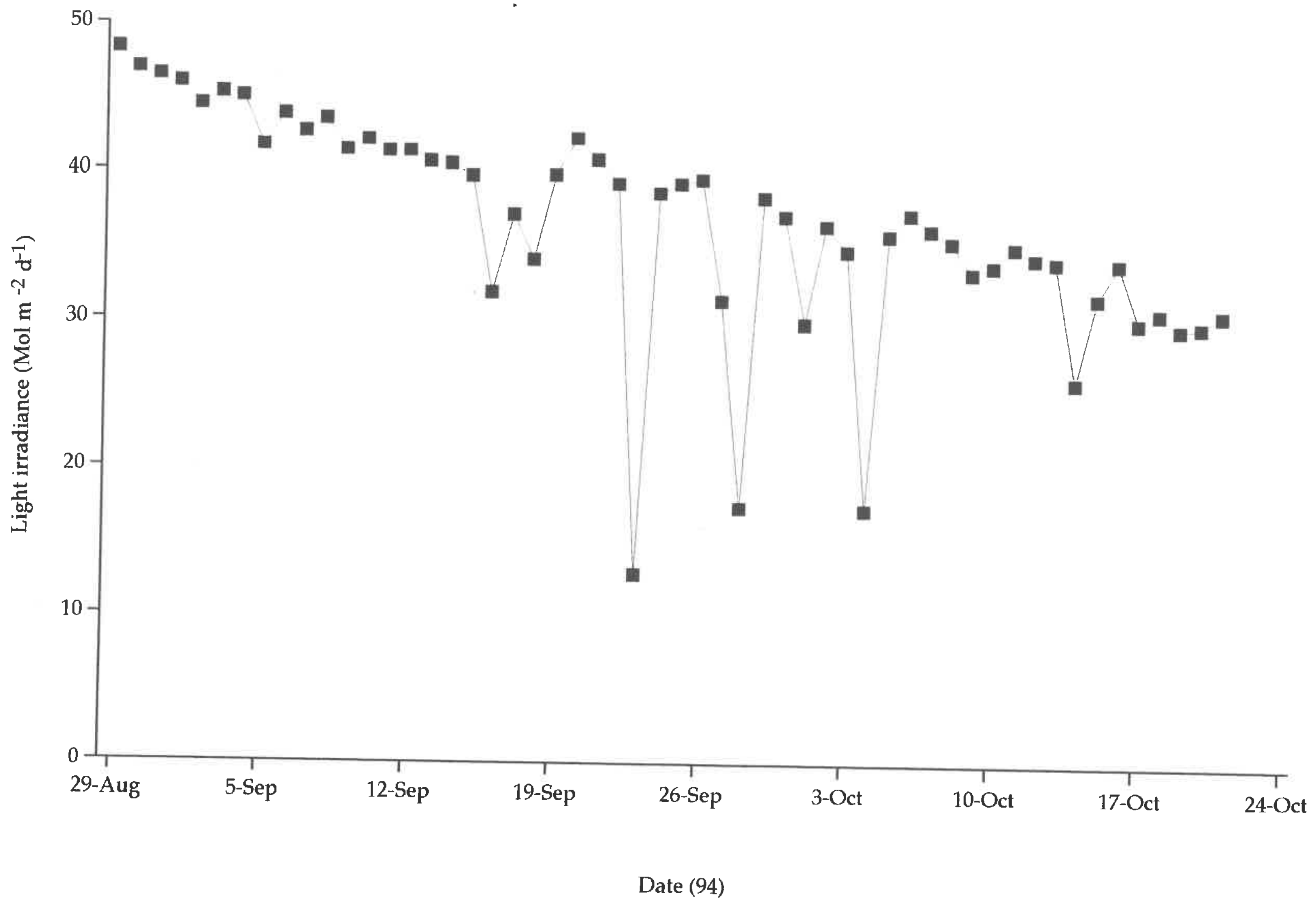
Fall quarter. Dissolved Oxygen of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system.



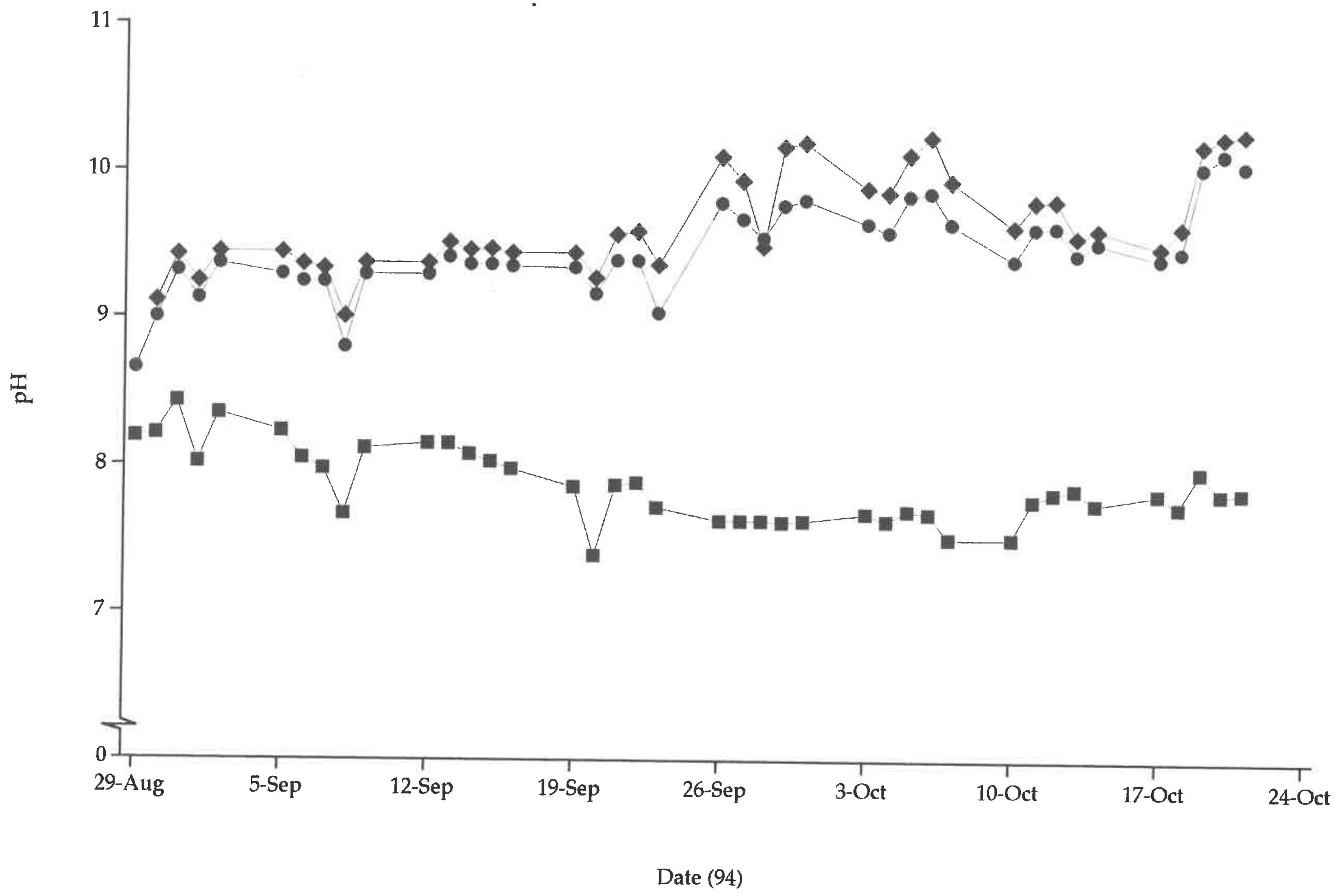
Fall quarter. Harvested solids from the ATS. Values are means ± s.d. of two composite samples, each from five sites.



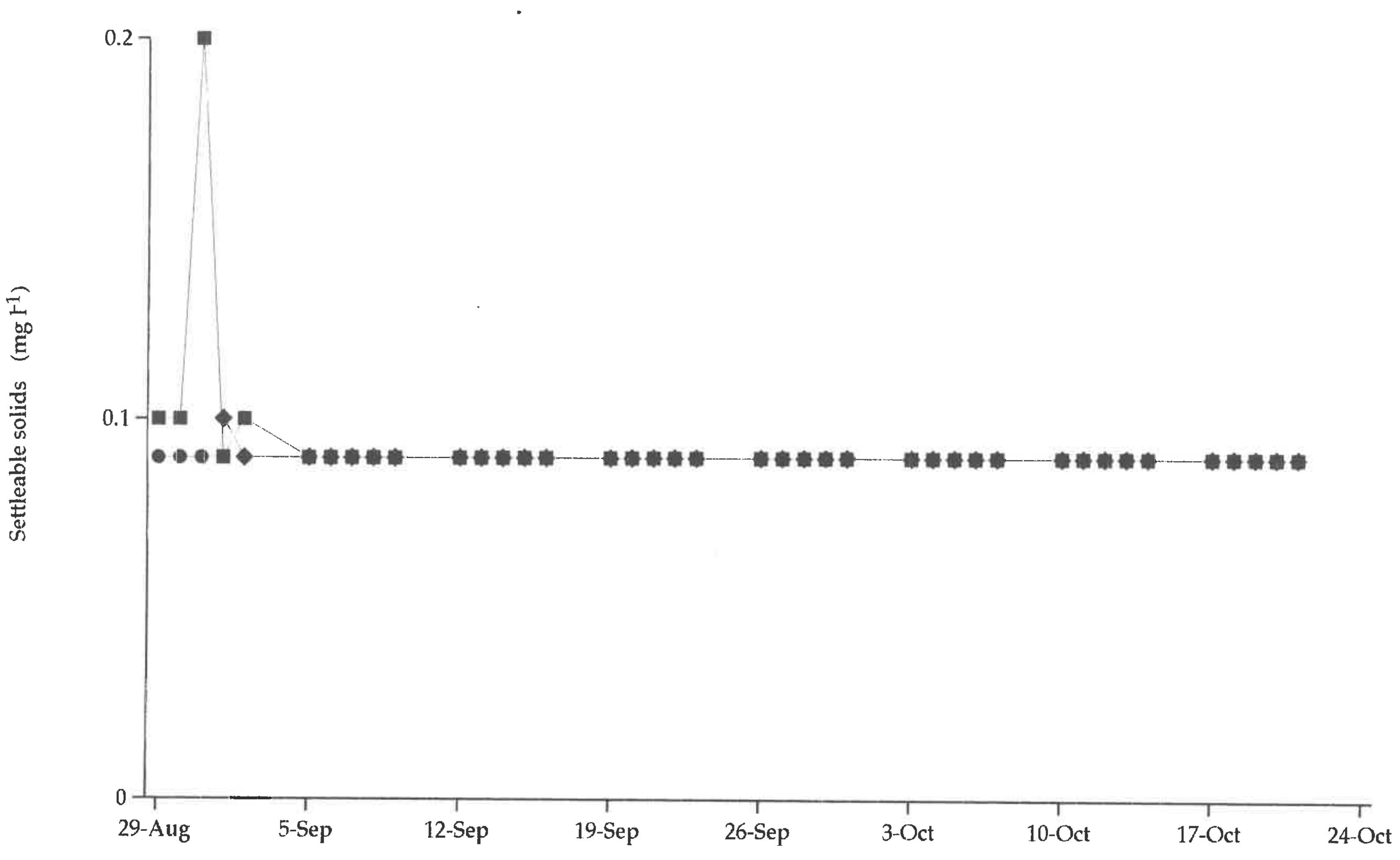
Fall quarter. Light intensity measured at time of sampling (11.00 am) .



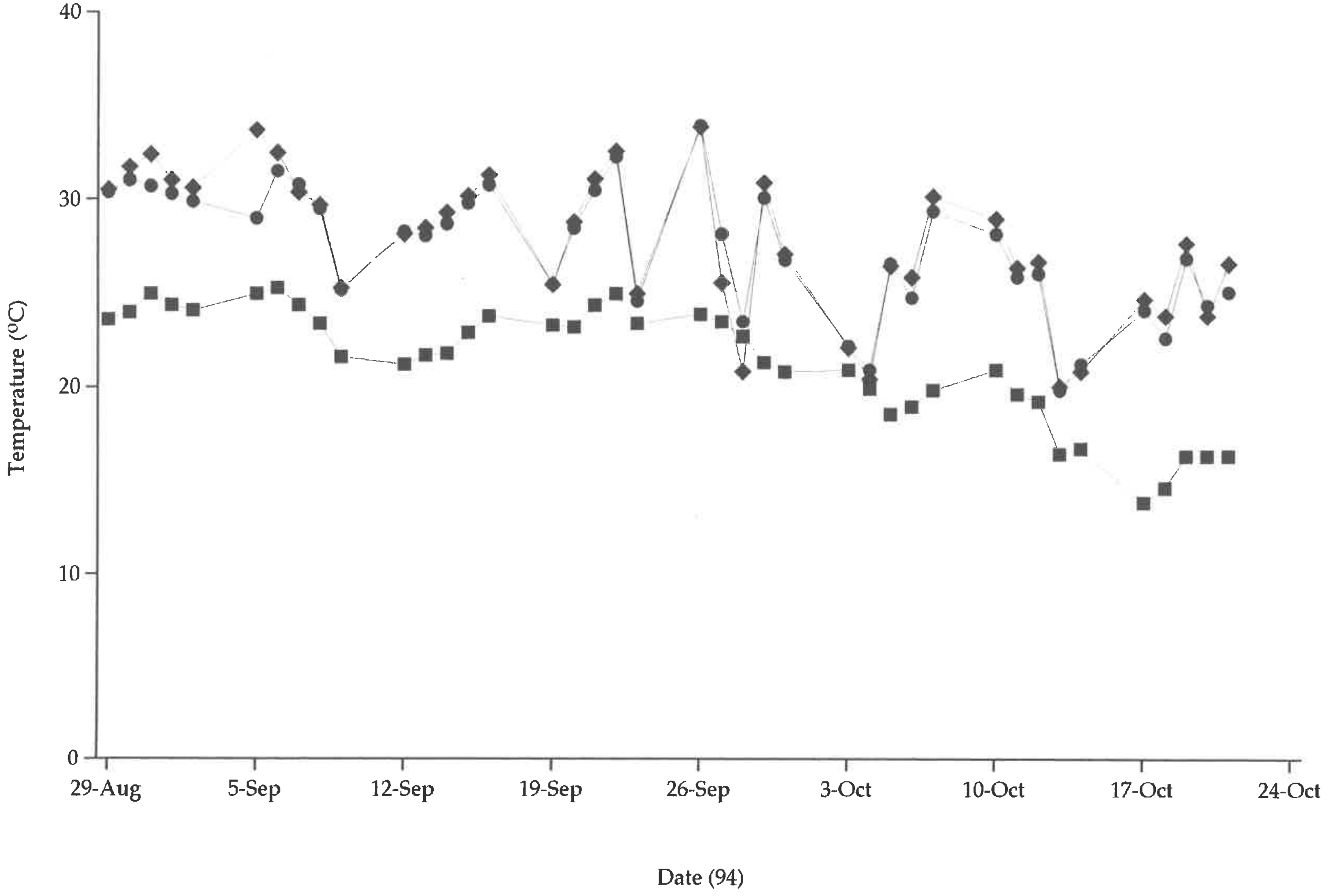
Fall quarter. Total daily light irradiance.



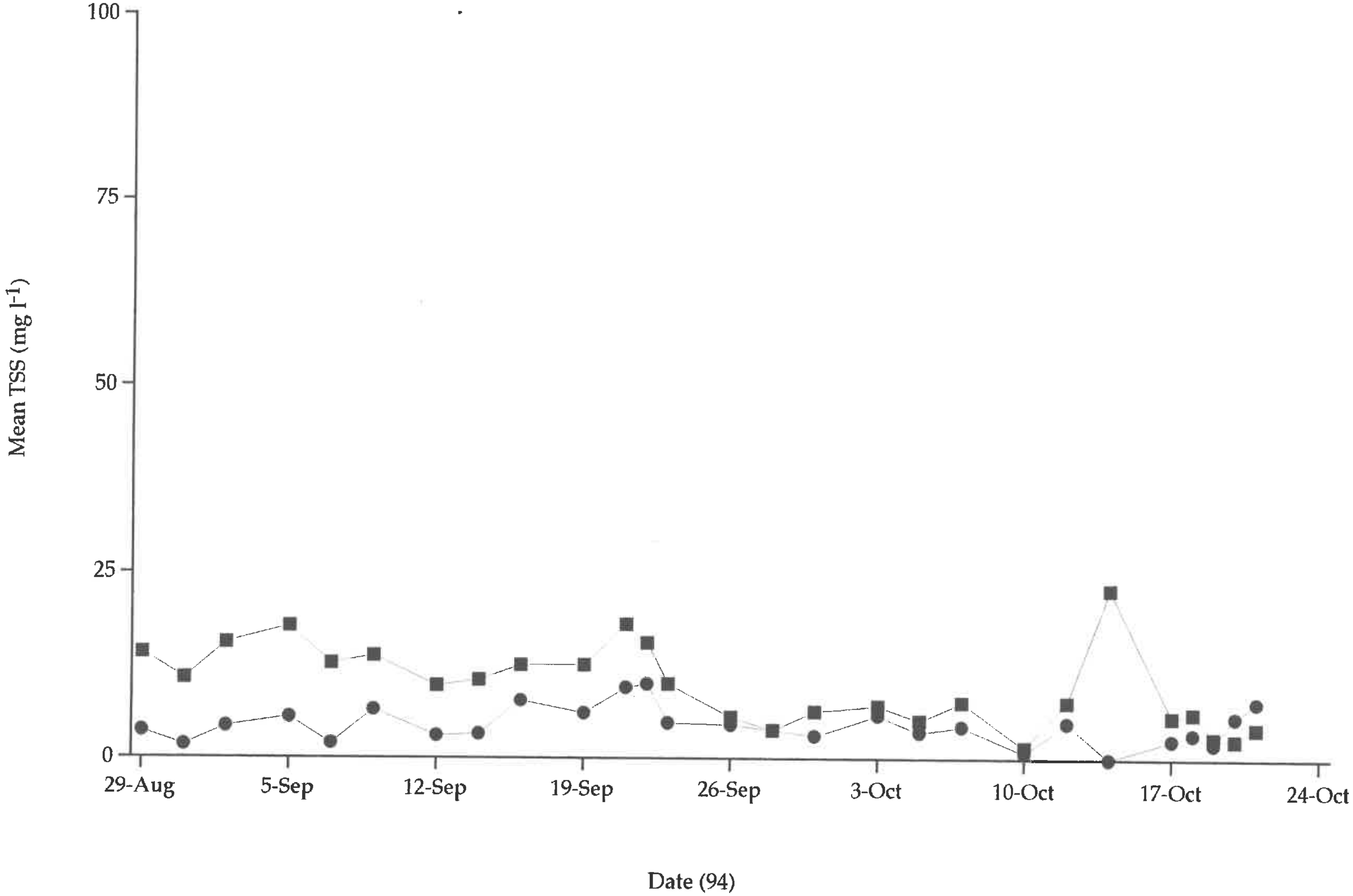
Fall quarter. pH of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system.



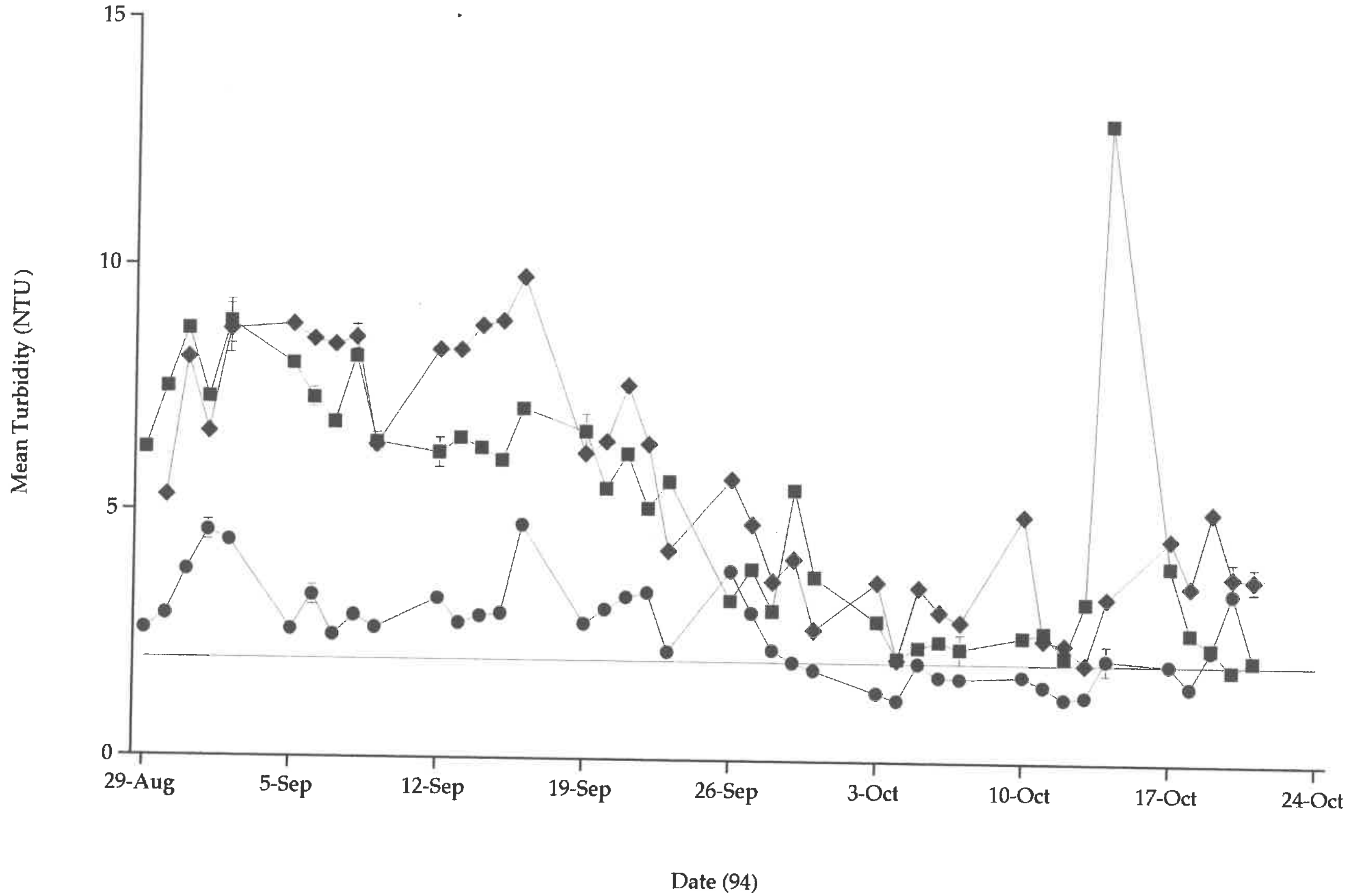
Fall quarter. Settleable solids of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system.



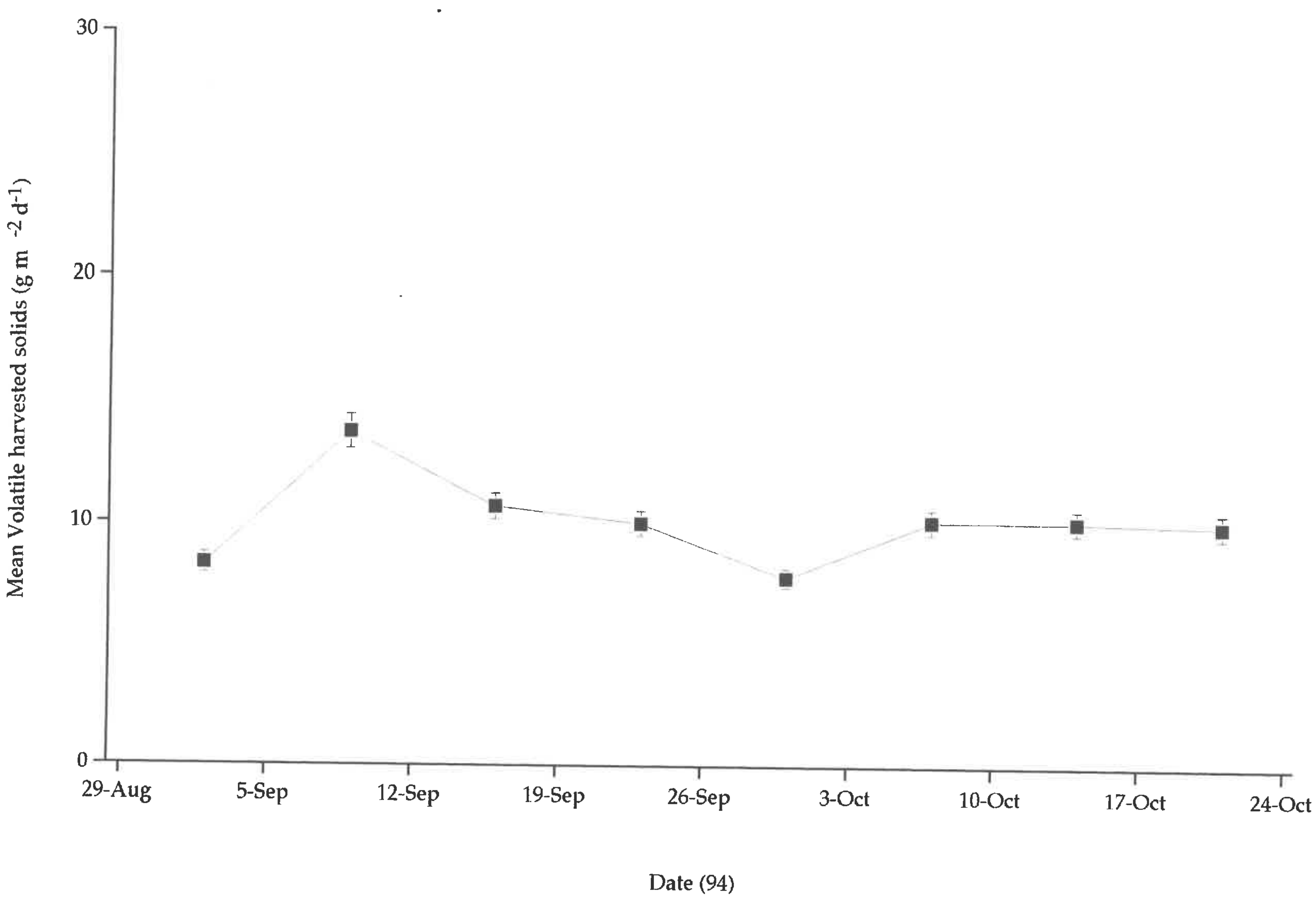
Fall quarter. Temperature of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system.



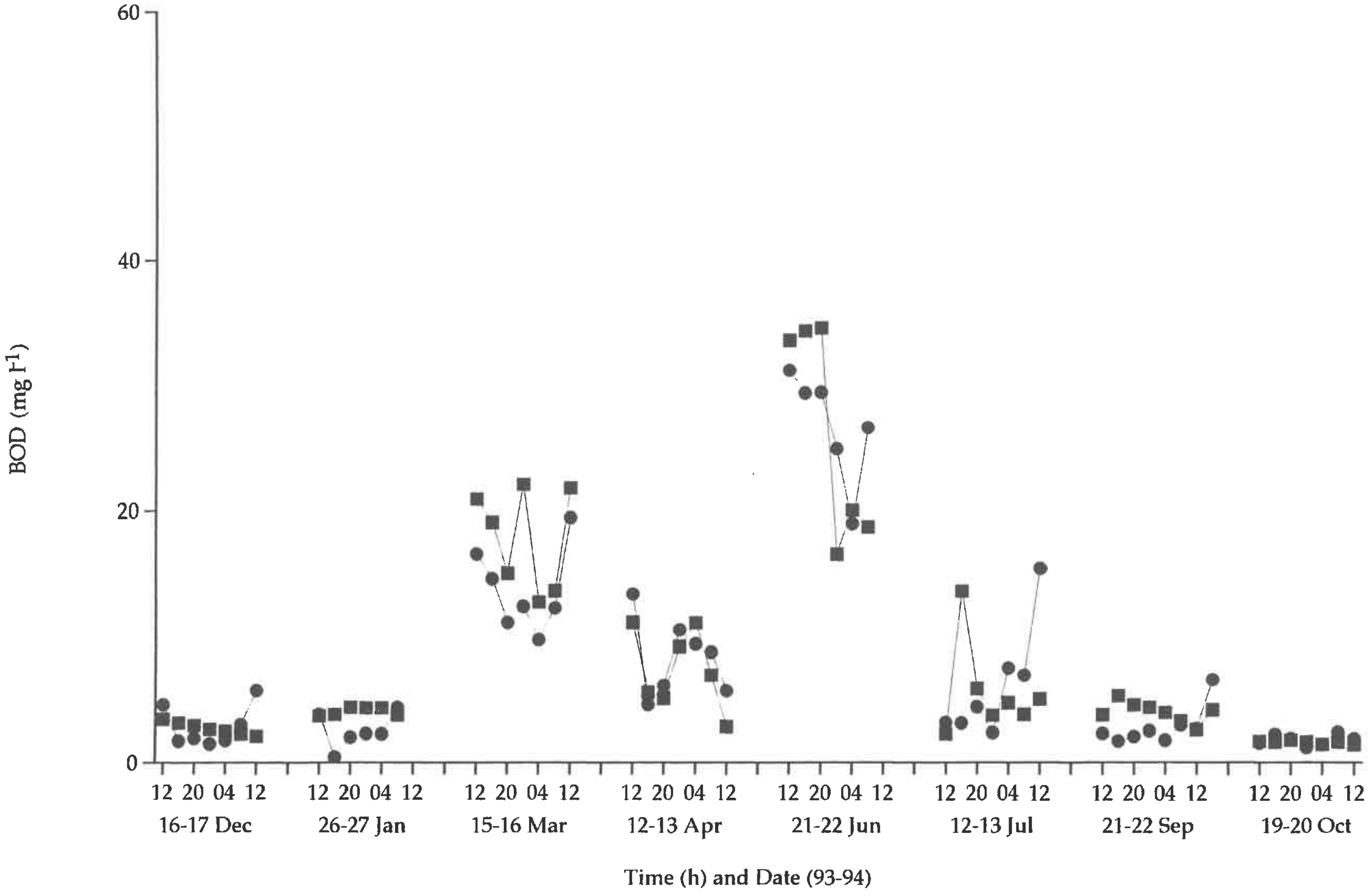
Fall quarter. Total suspended solids of influent (■) and effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



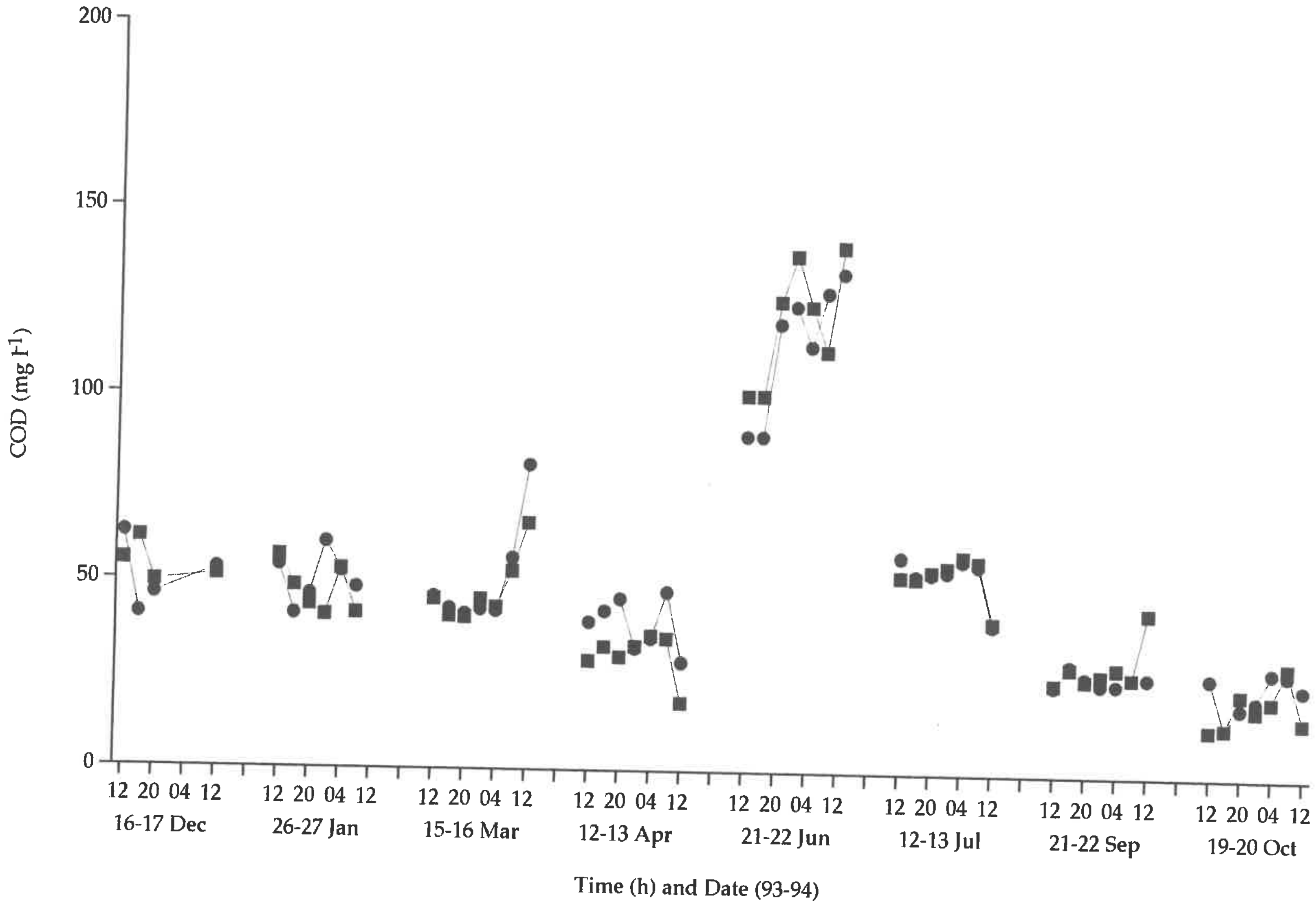
Fall quarter. Turbidity of influent (■), ATS effluent (◆) and UV effluent (●) of the ATS/UV system. Values are means ± s.d. of two replicate samples.



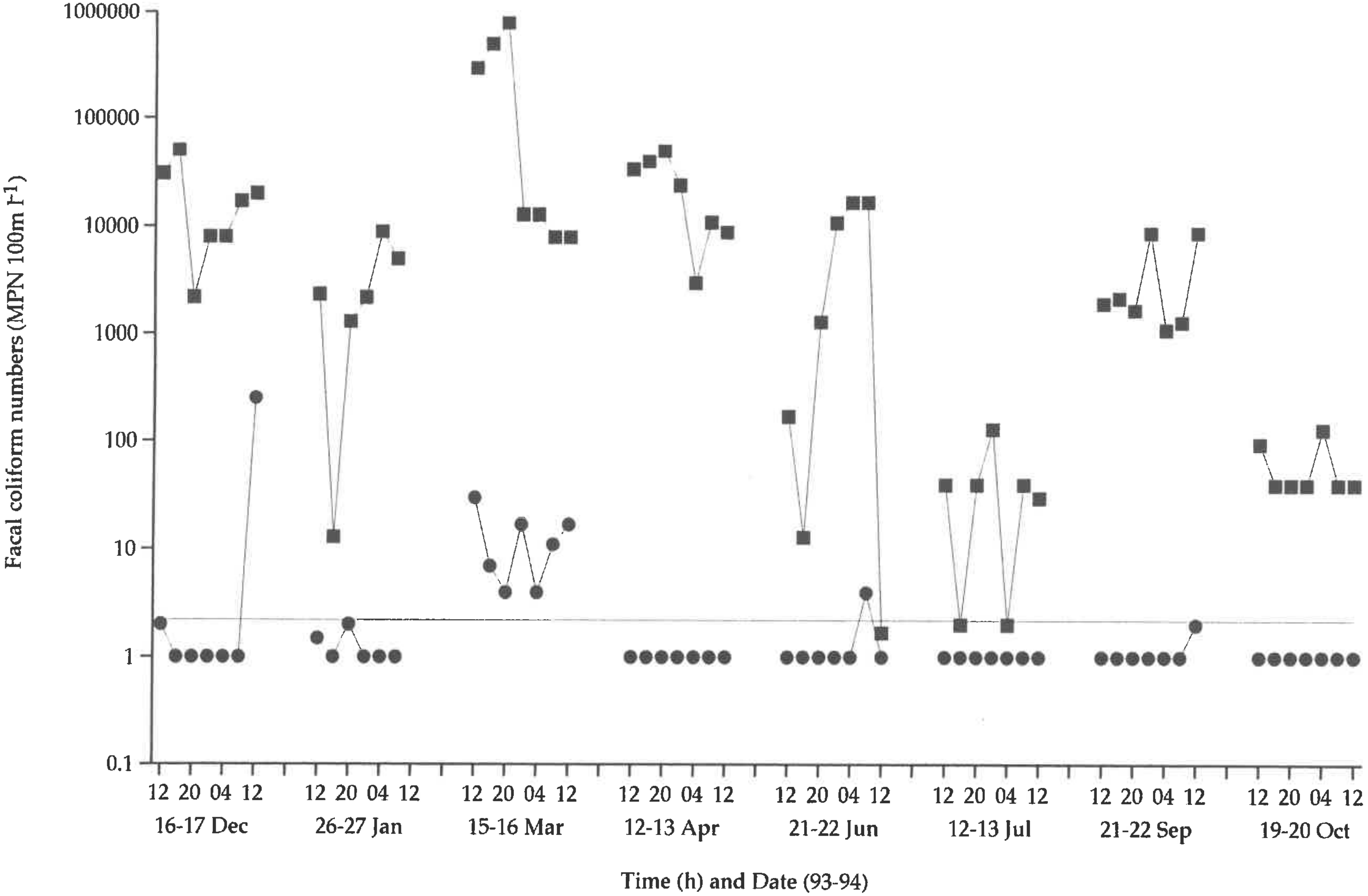
Fall quarter. Volatile harvested solids from the ATS. Values are means ± s.d. of two composite samples, each from five sites.



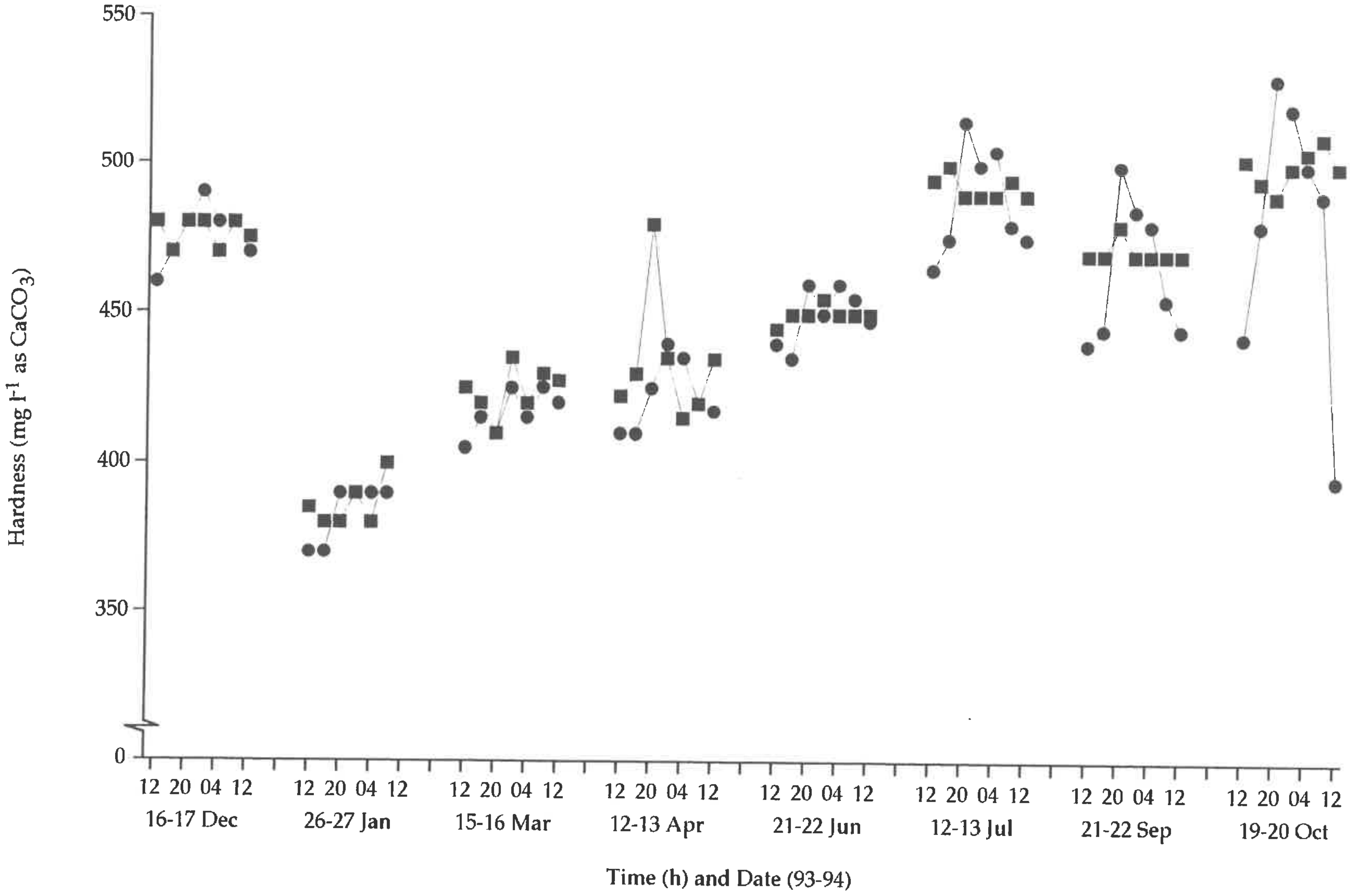
24 hour variation in biochemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system.



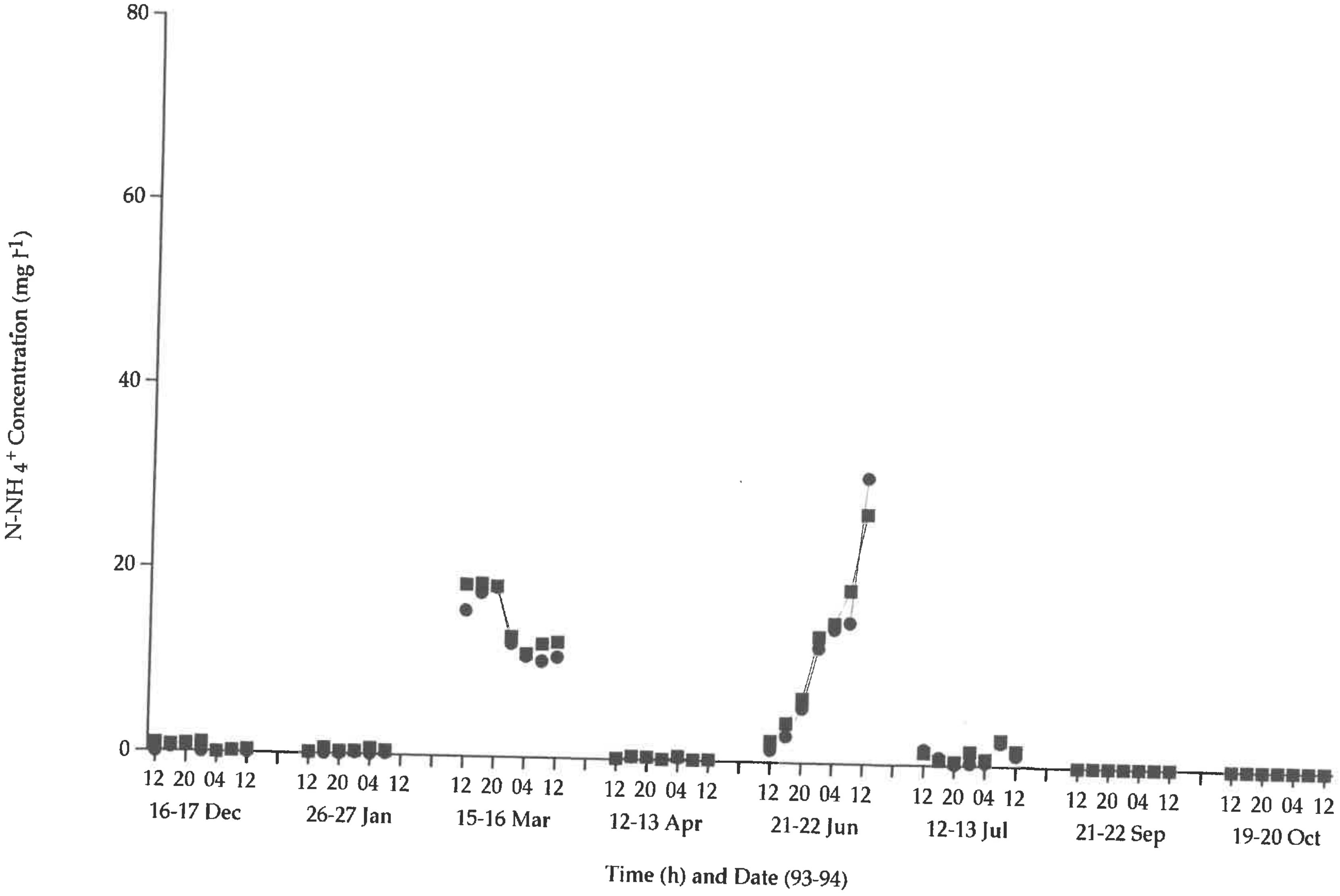
24 hour variation in chemical oxygen demand of influent (■) and effluent (●) of the ATS/UV system.



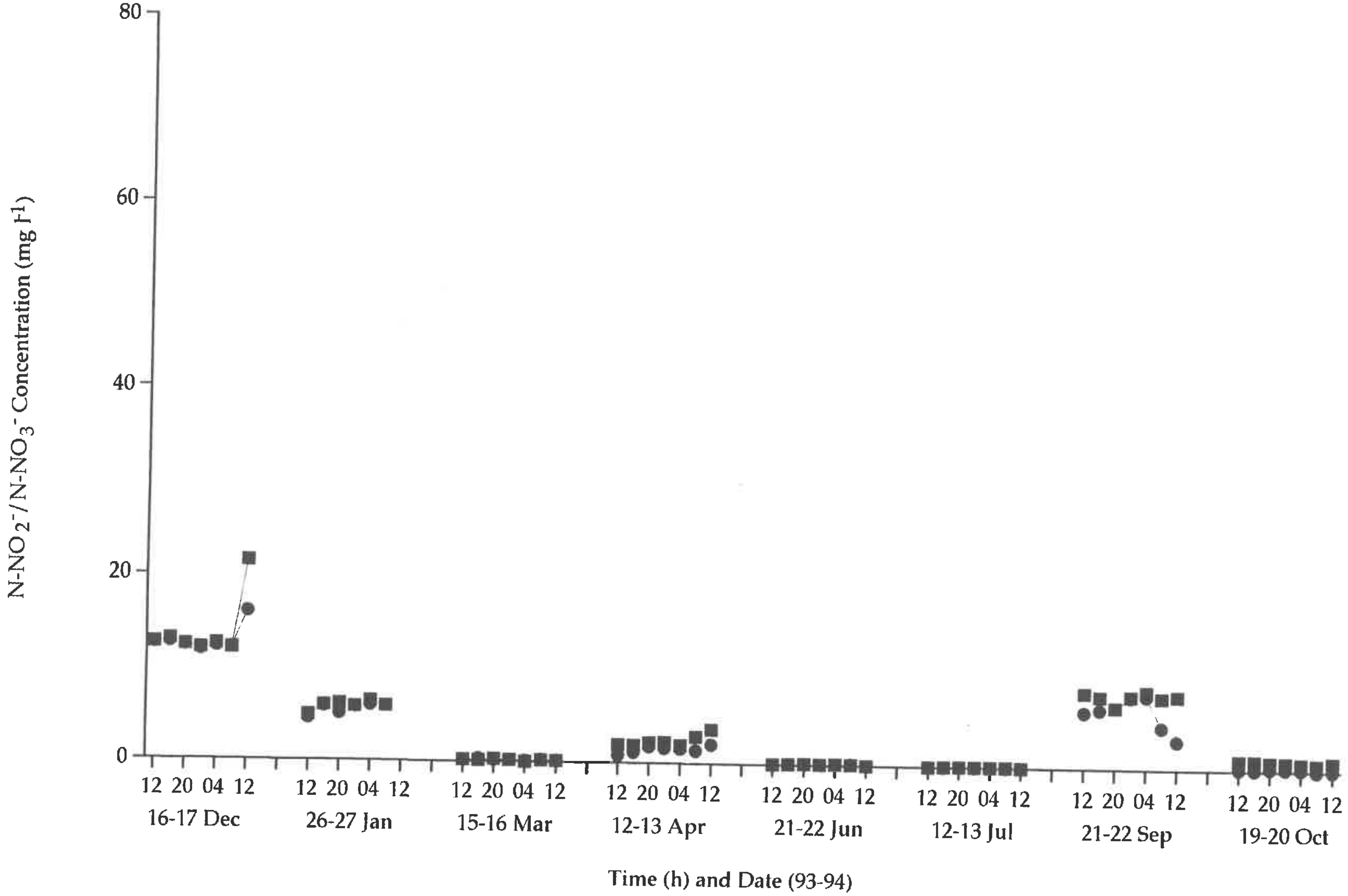
24 hour variation in faecal coliform numbers of influent (■) and effluent (●) of the UV system.



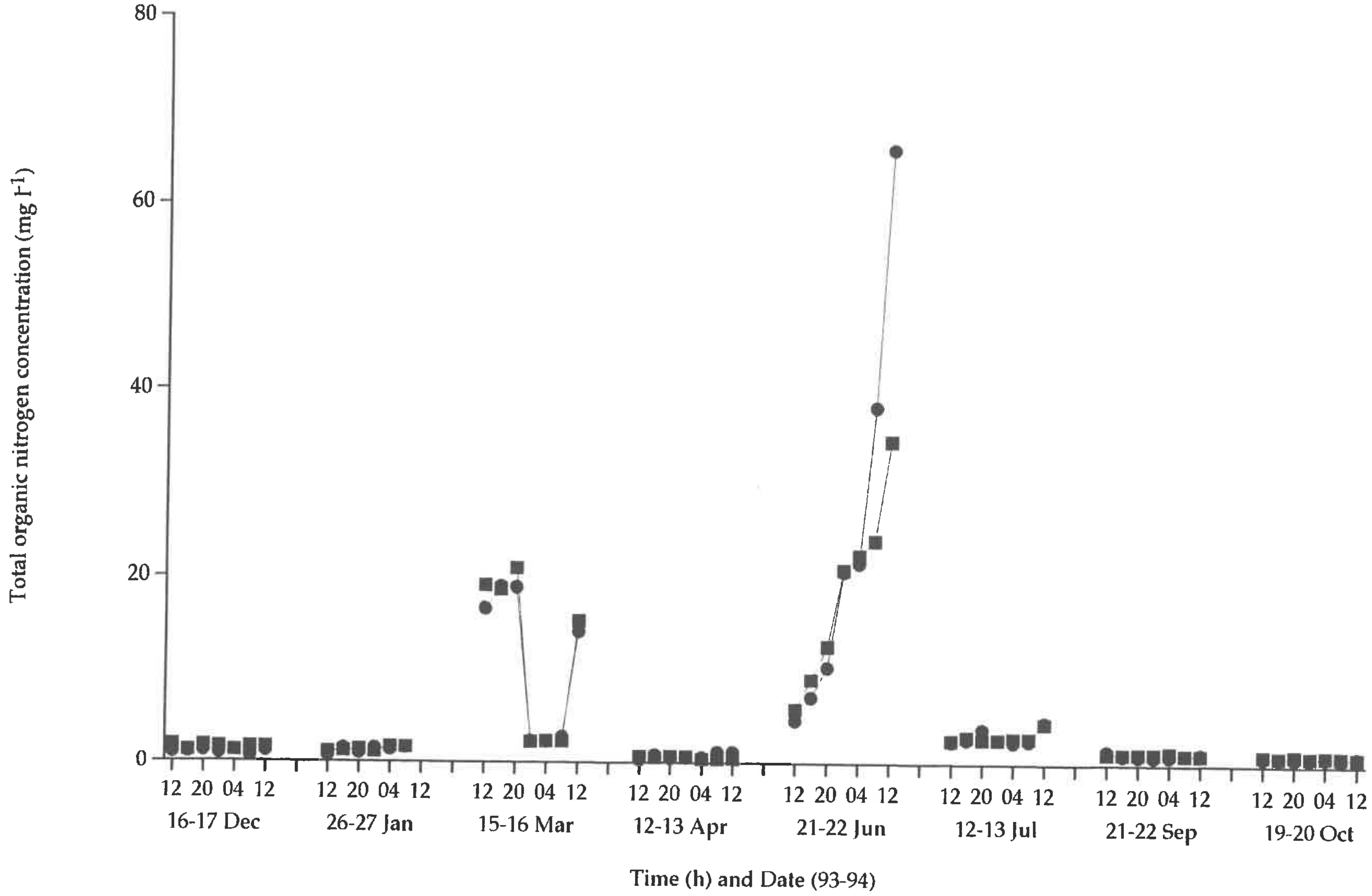
24 hour variation in hardness of influent (■) and effluent (●) of the ATS/UV system.



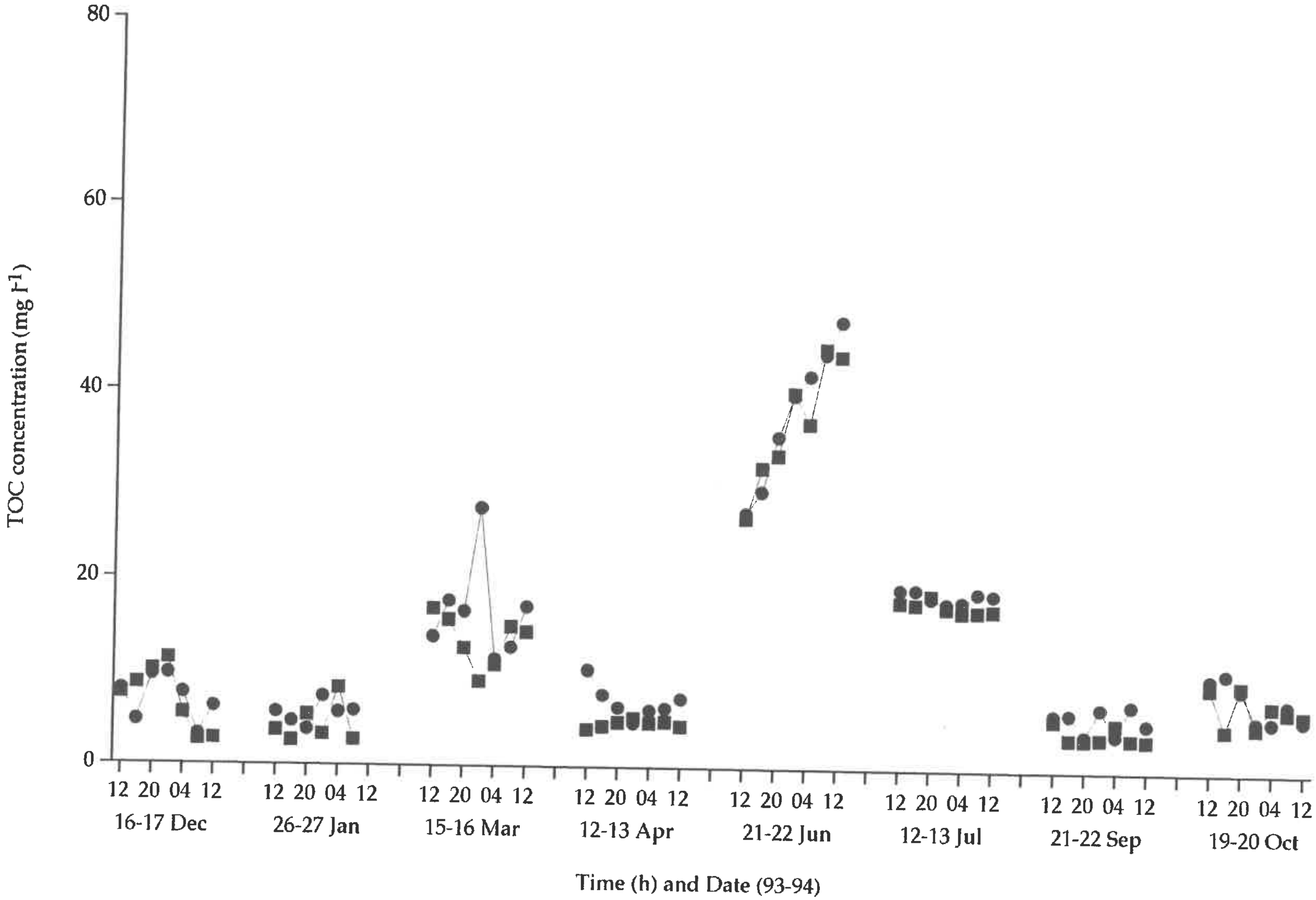
24 hour variation in ammonium-nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system.



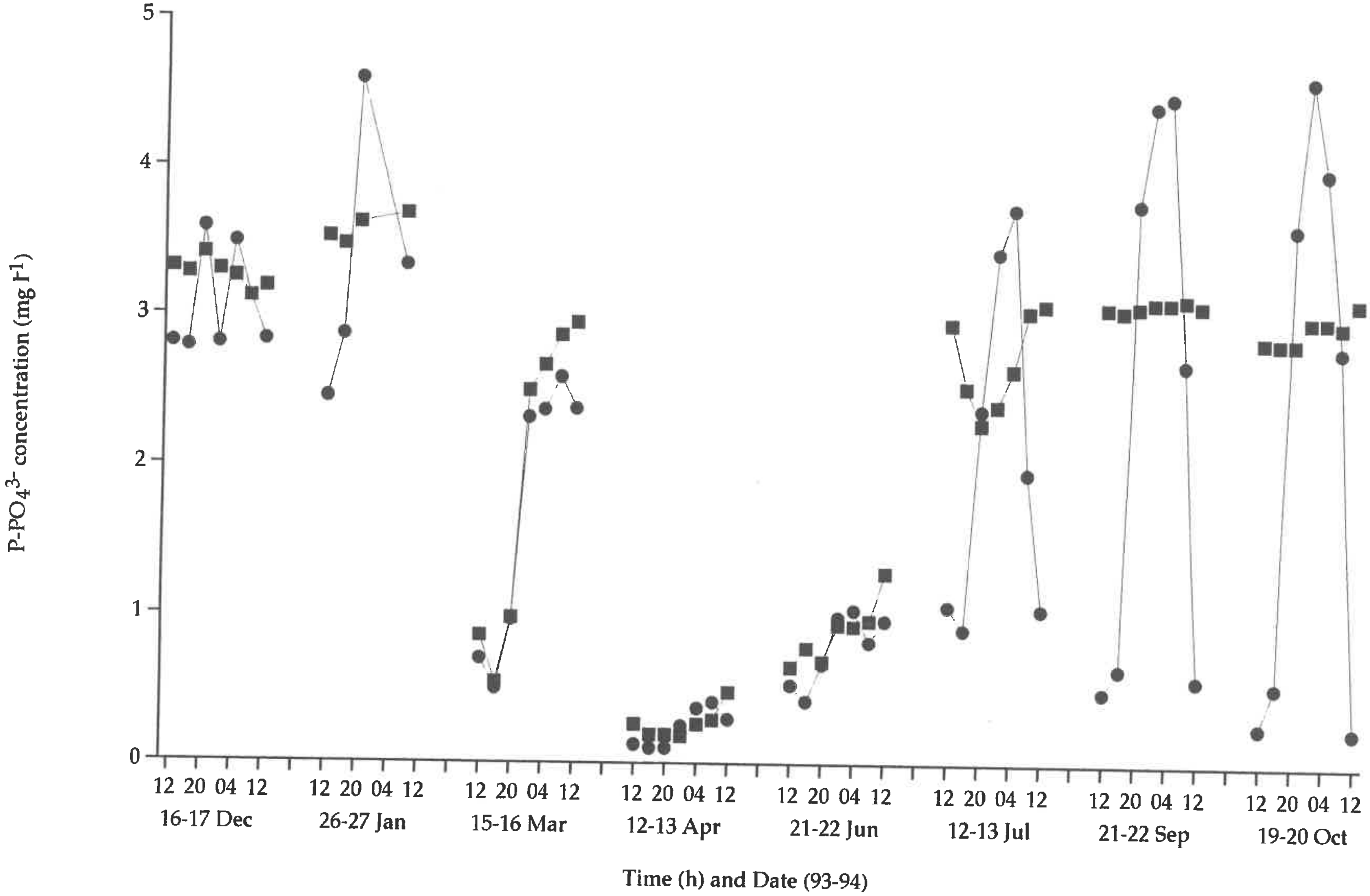
24 hour variation in nitrite- and nitrate-nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system.



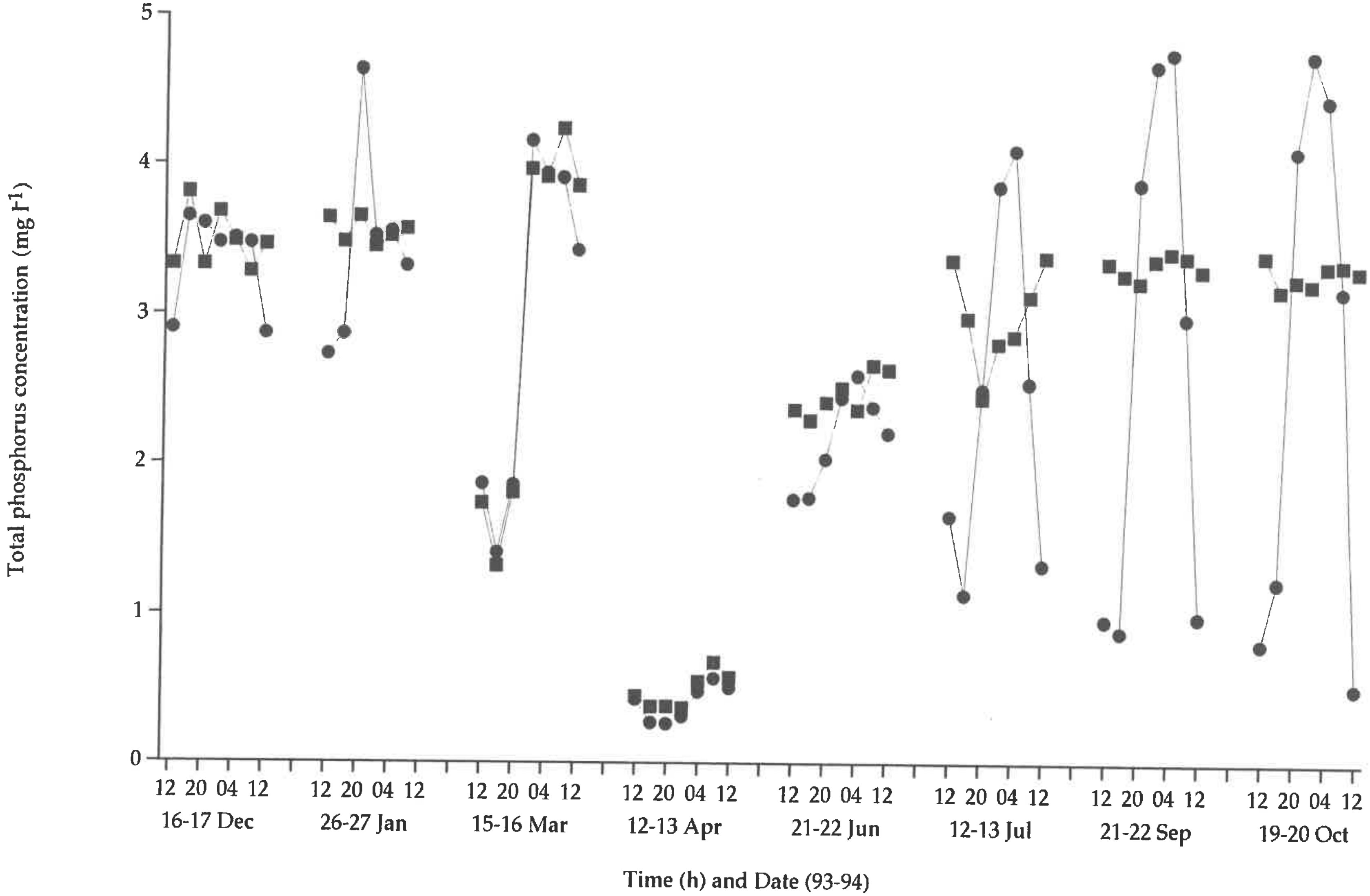
24 hour variation in total organic nitrogen concentration of influent (■) and effluent (●) of the ATS/UV system.



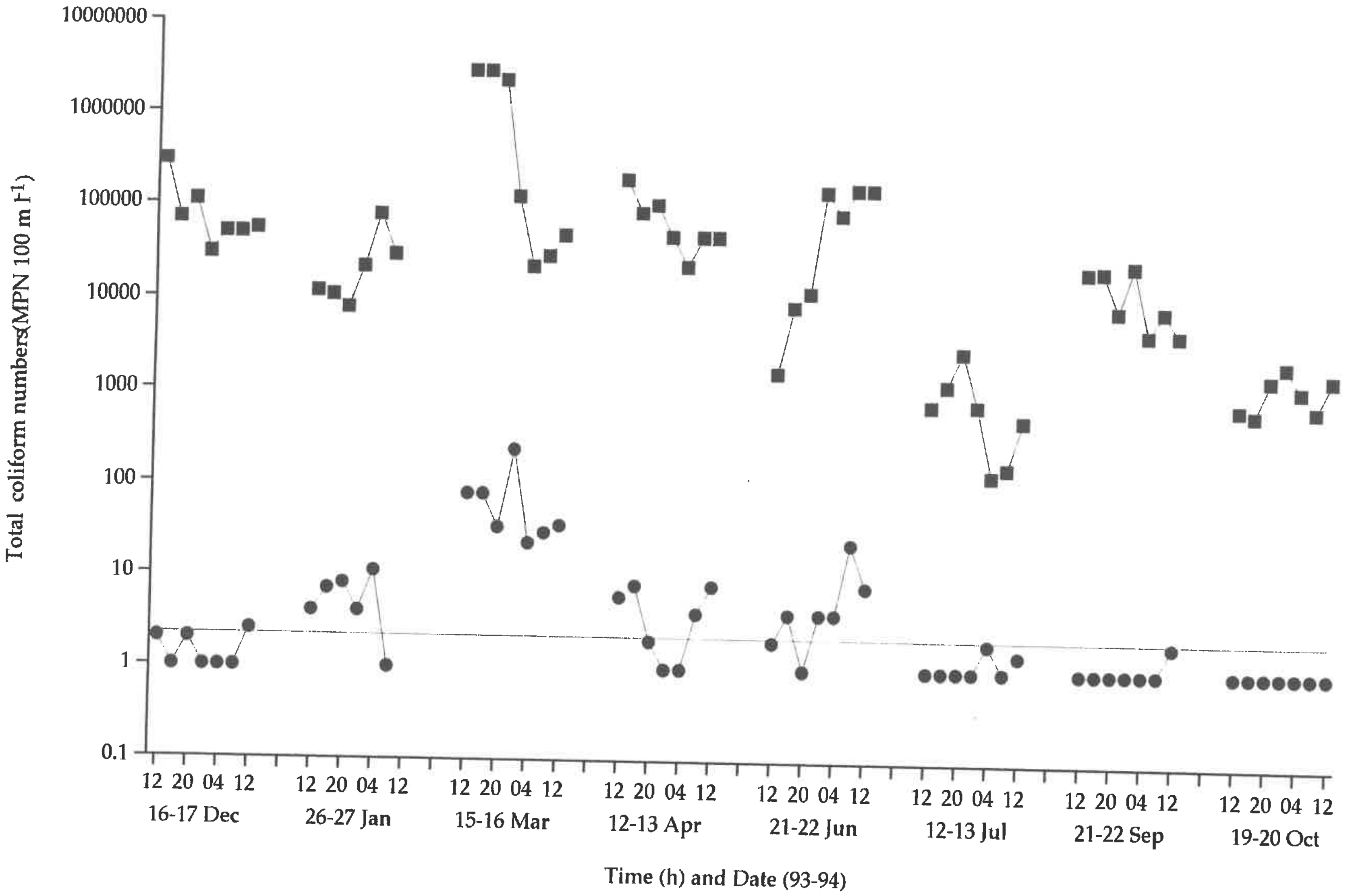
24 hour variation in total organic carbon of influent (■) and effluent (●) of the ATS/UV system.



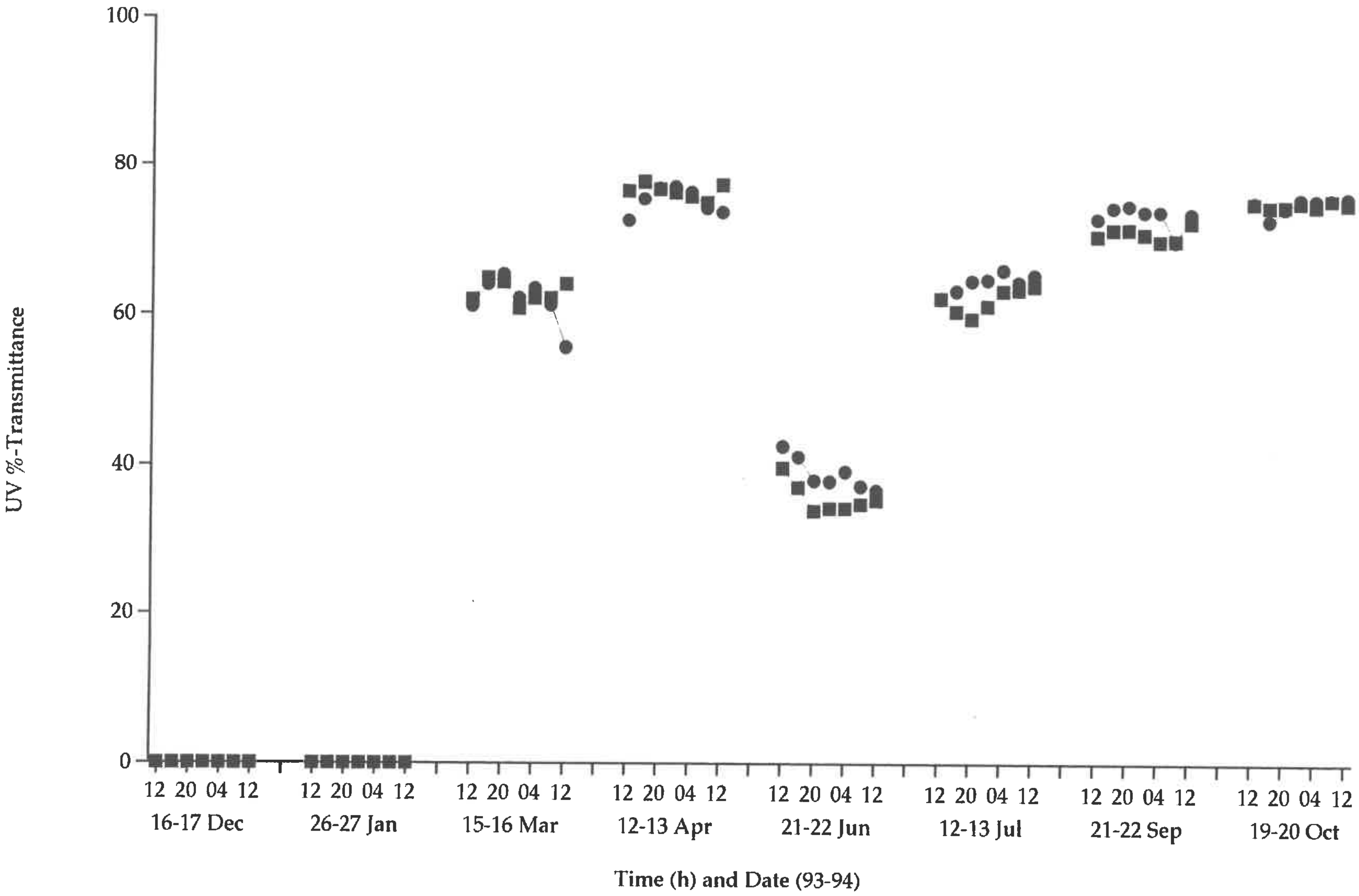
24 hour variation in soluble reactive phosphorus concentration of influent (■) and effluent (●) of the ATS/UV system.



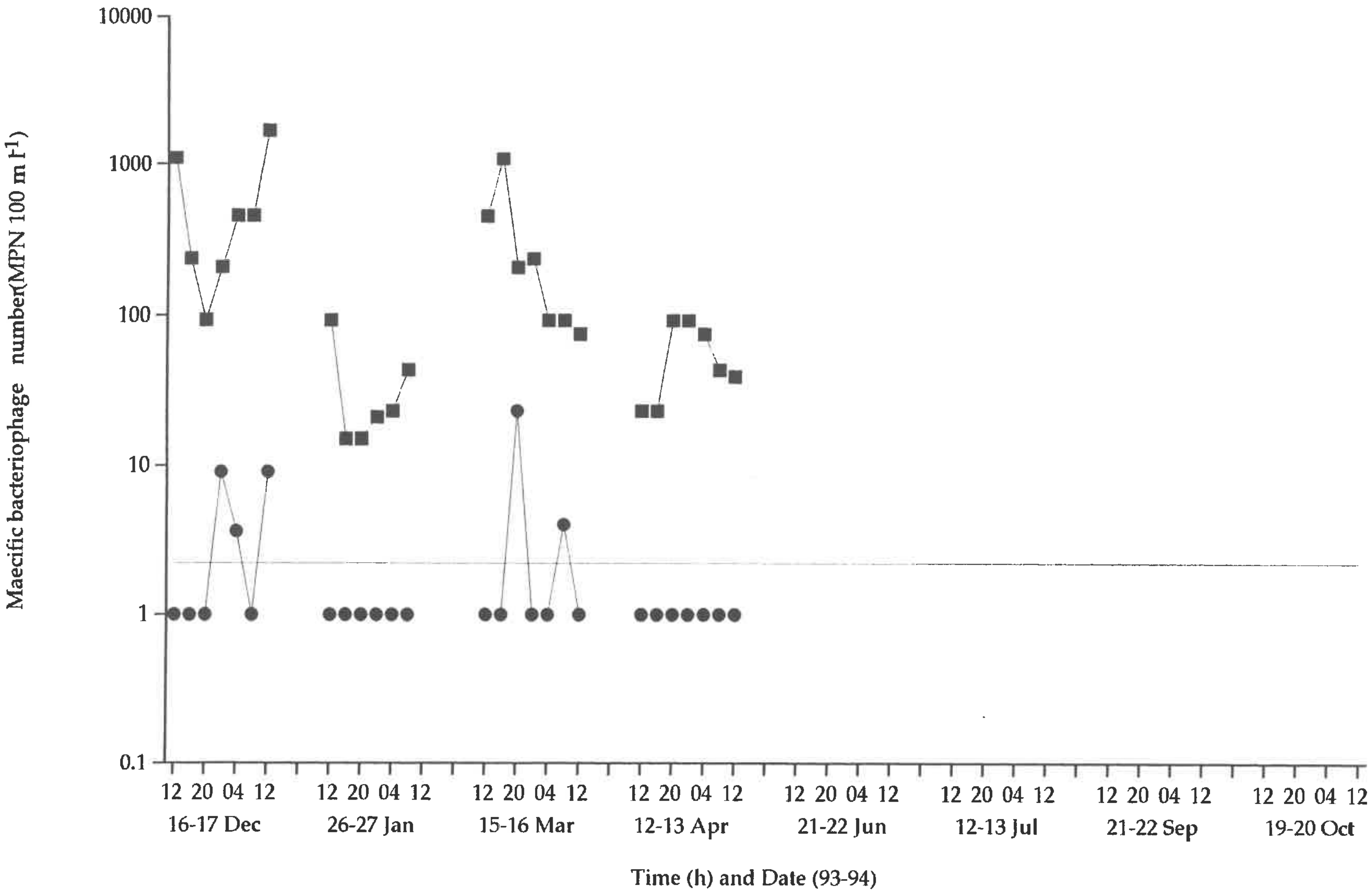
24 hour variation in total phosphorus concentration of influent (■) and effluent (●) of the ATS/UV system.



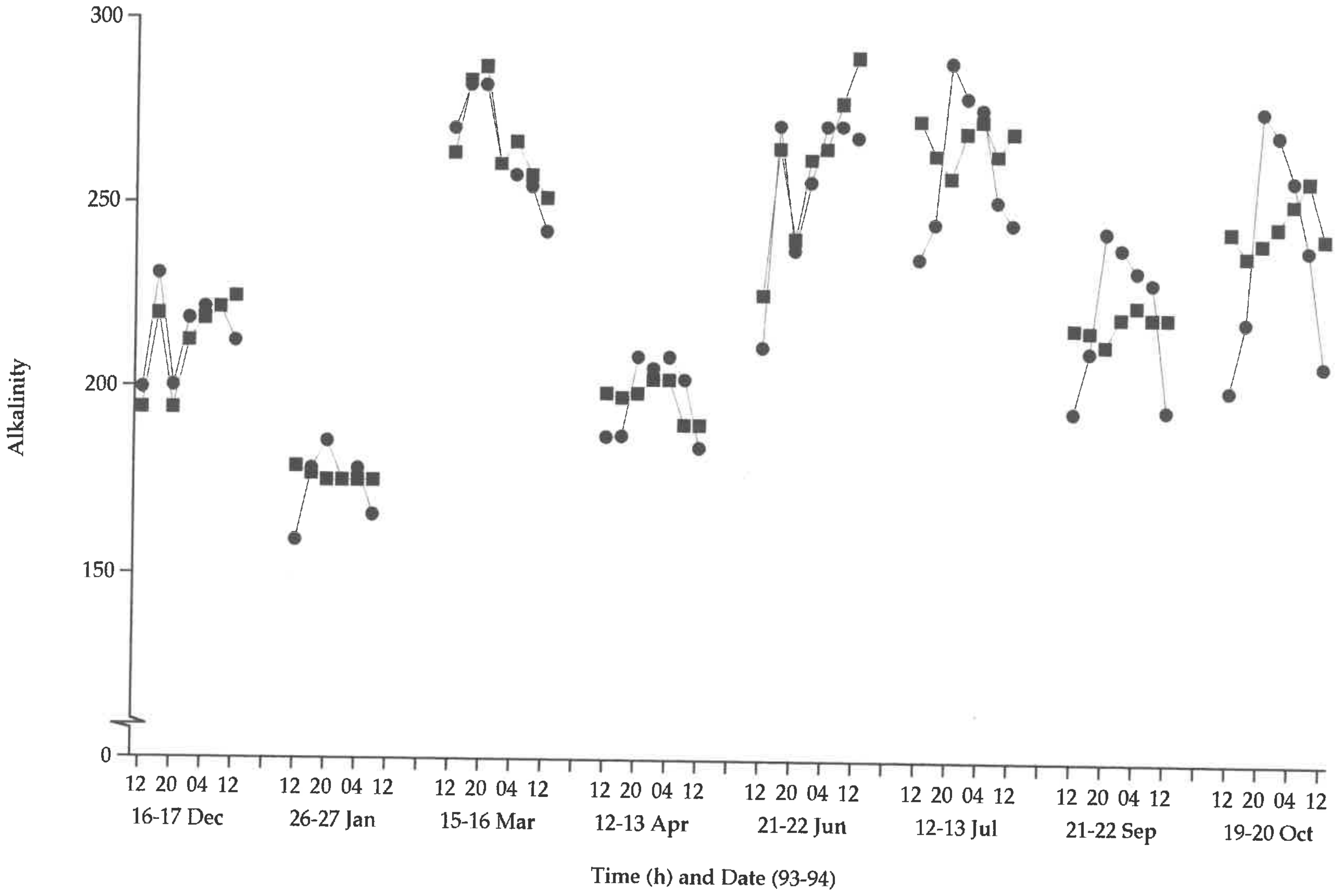
24 hour variation in total coliform numbers of influent (■) and effluent (●) of the UV system.



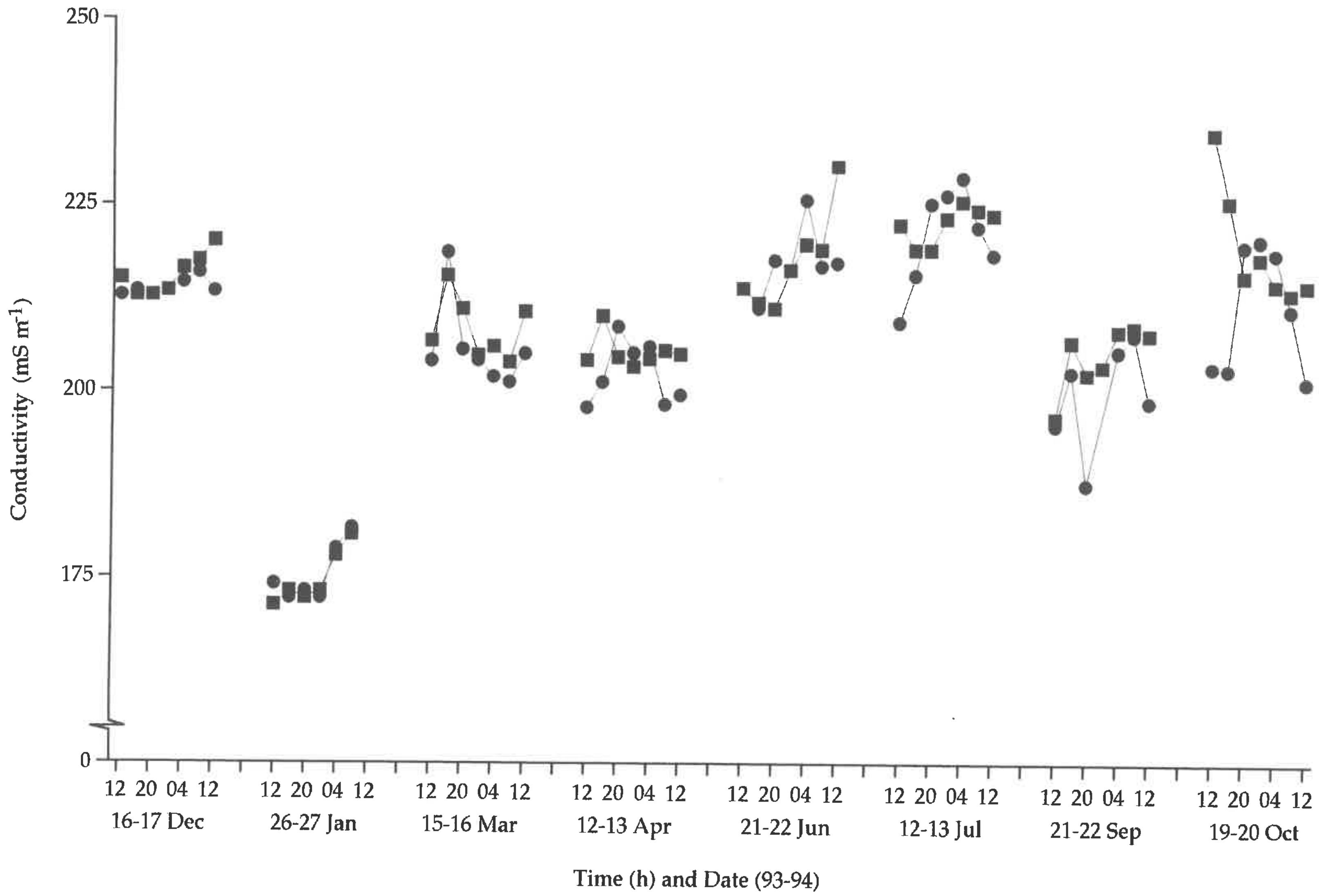
24 hour variation in UV %-transmittance of influent (■) and effluent (●) of the ATS/UV system.



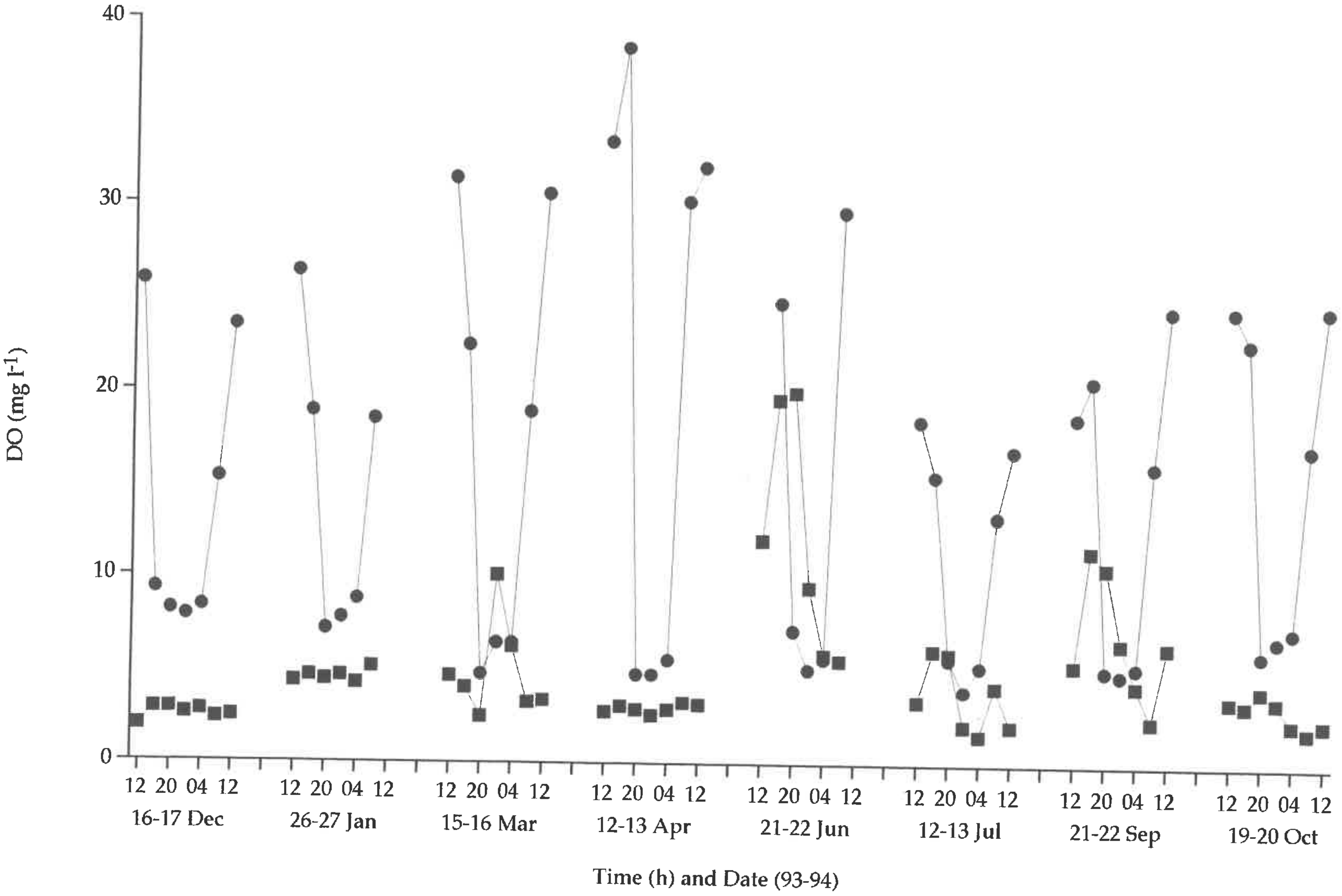
24 hour variation in male specific bacteriophage numbers of influent (■) and effluent (●) of the UV system.



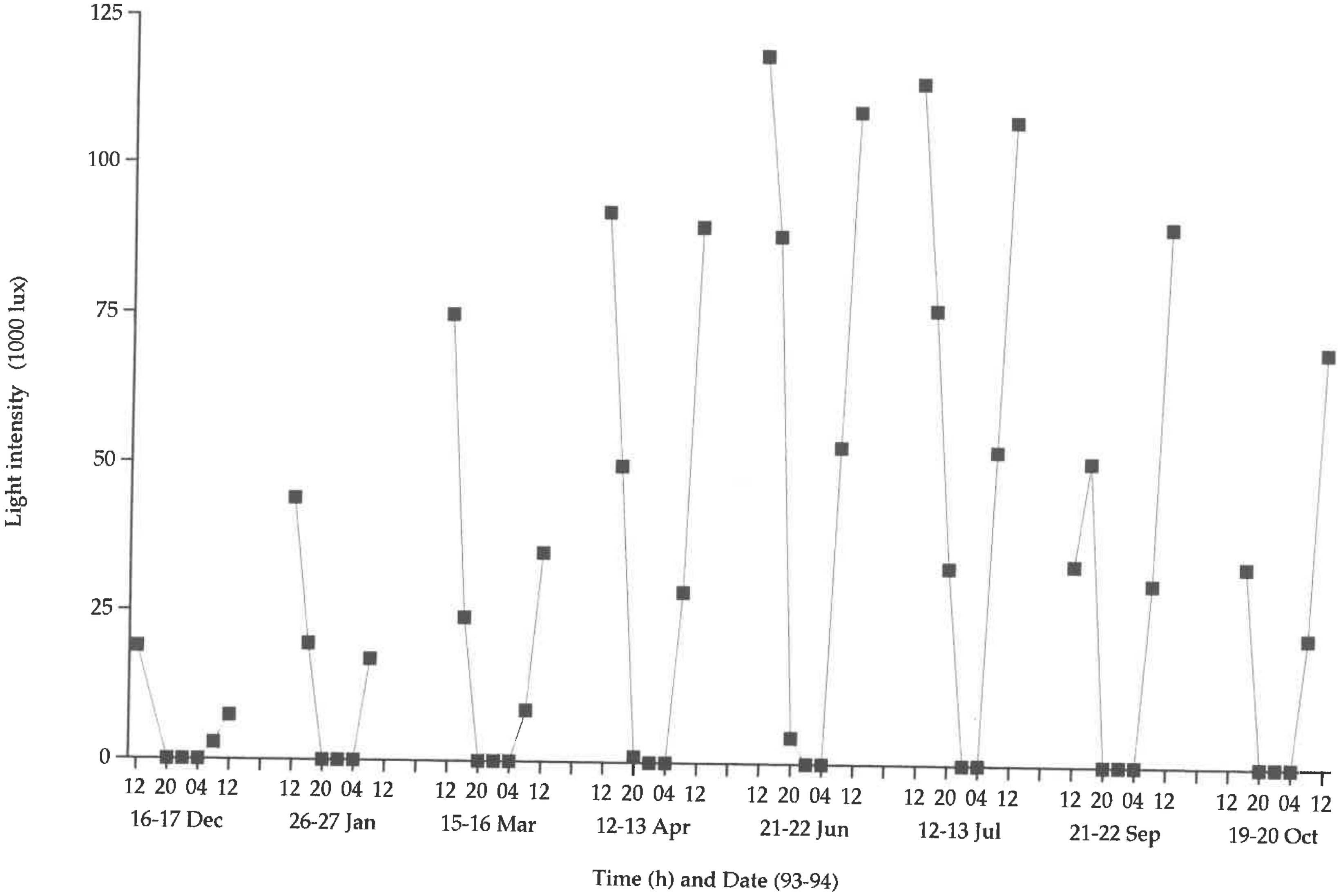
24 hour variation in Alkalinity of influent (■) and effluent (●) of the ATS/UV system.



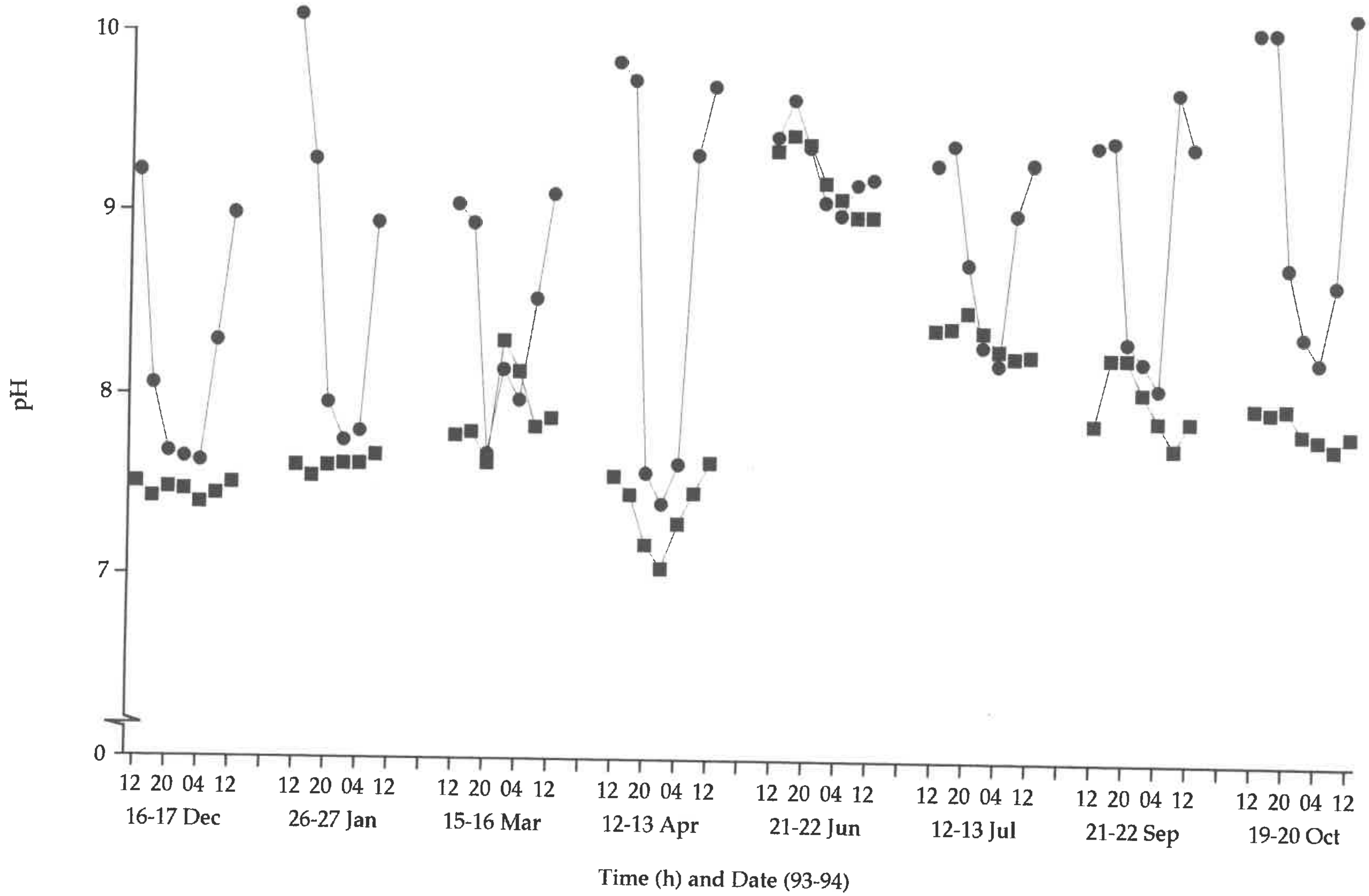
24 hour variation in Conductivity of influent (■) and effluent (●) of the ATS/UV system.



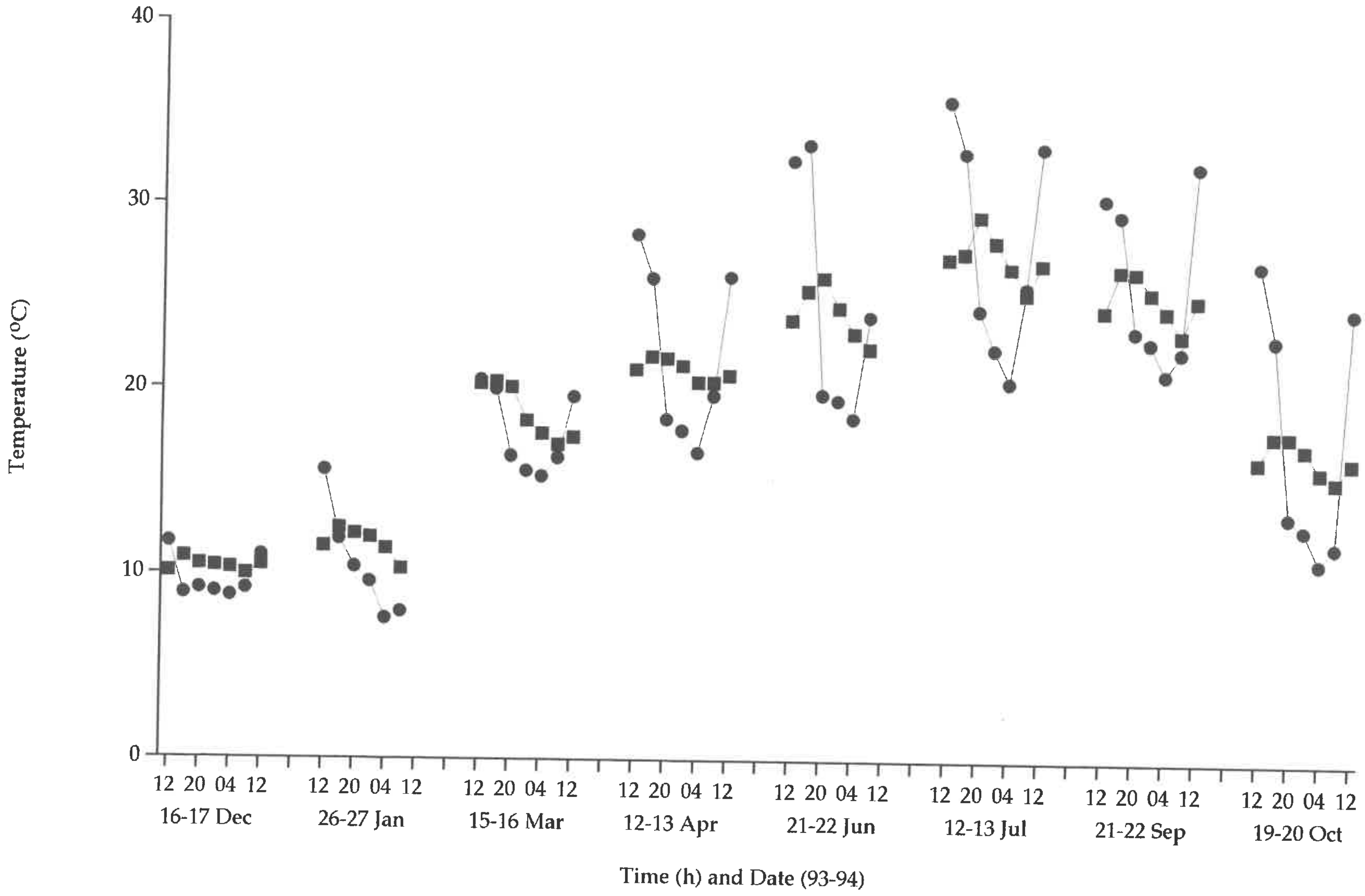
24 hour variation in Dissolved oxygen of influent (■) and effluent (●) of the ATS/UV system.



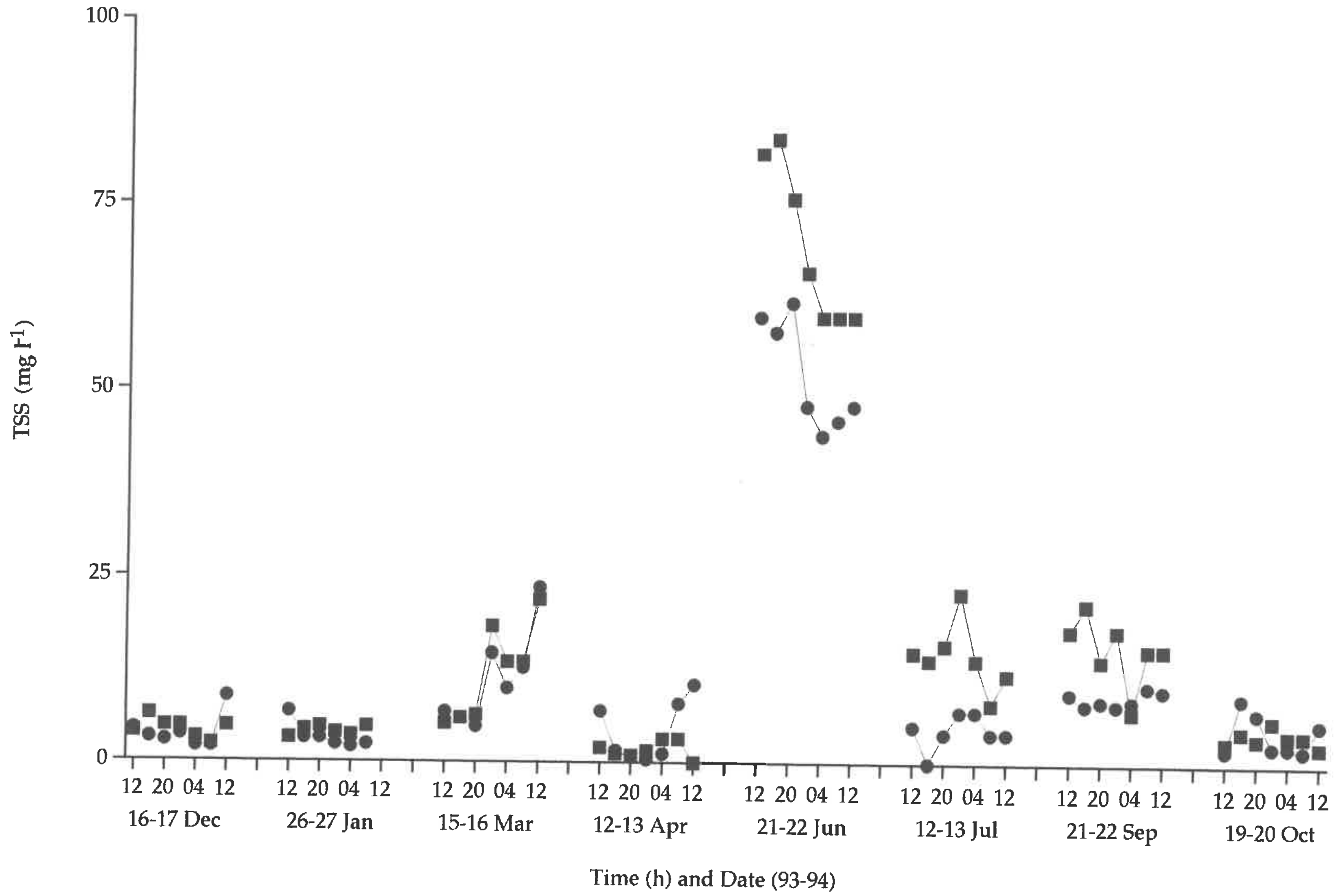
24 hour variation in Light intensity measured at time of sampling (11.00 am) .



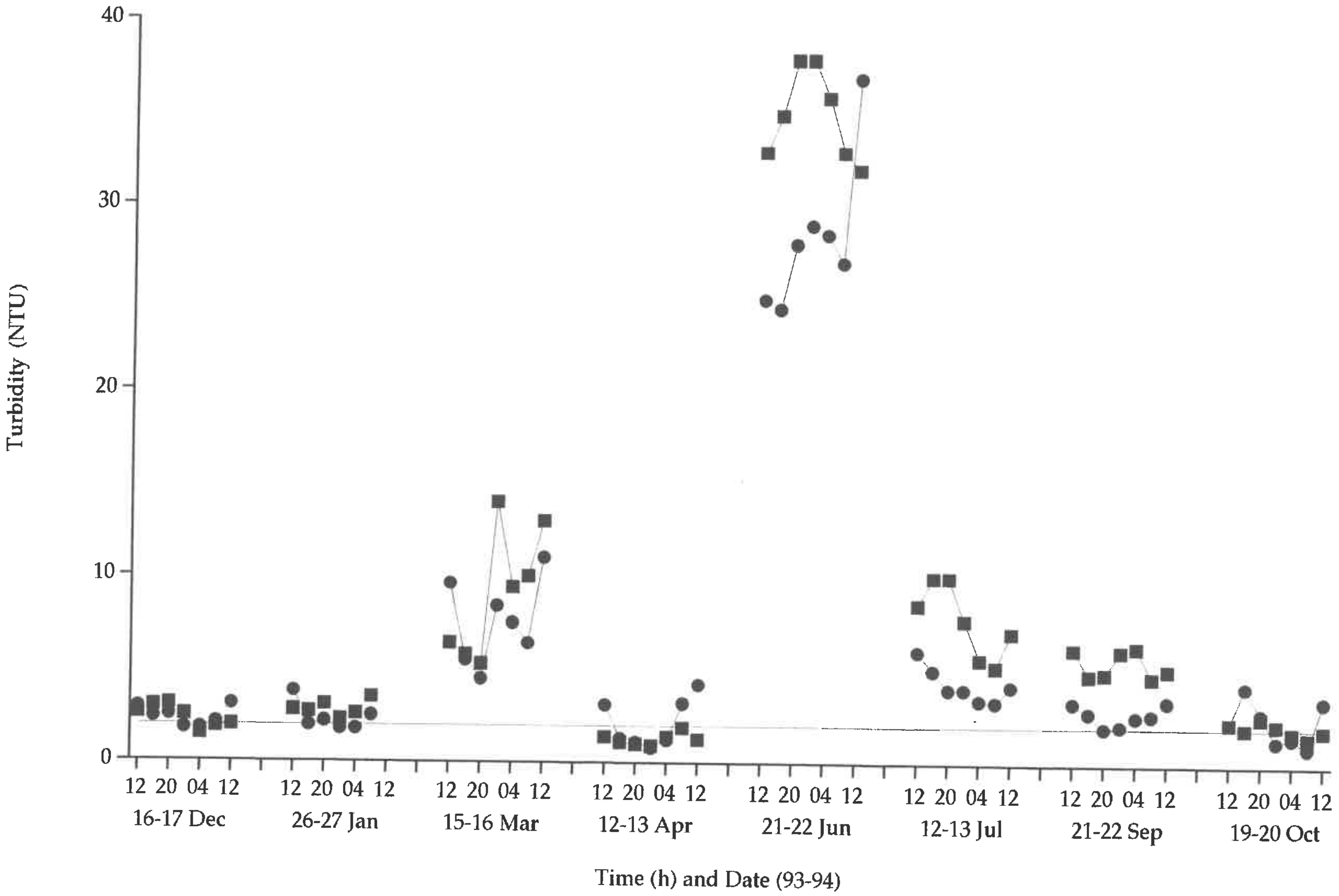
24 hour variation in pH of influent (■) and effluent (●) of the ATS/UV system.



24 hour variation in Temperature of influent (■) and effluent (●) of the ATS/UV system.



24 hour variation in Total suspended solids of influent (■) and effluent (●) of the ATS/UV system.



24 hour variation in Turbidity of influent (■) and effluent (●) of the ATS/UV system.