Title: THE EFFECTS OF DETERGENT LOADING ON ROTATING BIOLOGICAL CONTACTOR (RBC) WASTEWATER TREATMENT EFFICIENCY.

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ABSTRACT

There are presently over 182 RBC plants, treating domestic wastewater, in the Republic of Ireland, 136 of which have been installed since 1986. The use of this treatment plant technology, although not new, is becoming increasingly popular.

The aim of this research was to assess the effects that a household detergent has on rotating biological contactor treatment plant efficiency. Household detergents contribute phosphorus to the surrounding environment and can also remove beneficial biomass from the disc media. A simple modification was made to a conventional flat disc unit to increase the oxygen transfer of the process. The treatment efficiency of the modified RBC (with aeration cups attached) was assessed against a parallel conventional system, with and without detergent loading. The parameters monitored were chemical oxygen demand (COD), bio-chemical oxygen demand (BOD), nitrates, phosphates, dissolved oxygen, the motors power consumption, pH, and temperature. Some microscopic analysis of the biofilm was also to be carried out.

The treatment efficiency of both units was compared, based on COD/BOD removal. The degree of nitrification achievable by both units was also assessed with any fluctuations in pH noted. Monitoring of the phosphorus removal capabilities of both units was undertaken. Relationships between detergent concentrations and COD removal efficiencies were also analysed.

PRESENTATIONS

Paper Presentation

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Dedicated to my mother

Margaret Cunningham

1940 - 1997

An influence which is profoundly missed.

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Chapter 1

Introduction

1.1 INTRODUCTION

With the world population rapidly increasing man has been forced to investigate further ways of sustaining the environment in which we live. The progress of the developing world has in the past, had little regard for the surrounding environment. The onset of the industrial revolution with associated urbanisation of the 19th Century saw increased volumes of wastewater being generated and discharged into surrounding watercourses. This practice magnified the problem of water-borne diseases so some form of sewage treatment was deemed necessary. From this problem the birth of wastewater engineering stemmed. Bearing in mind that wastewater engineering stretches only slightly beyond one hundred years, wastewater treatment technology has made significant strides in promoting disease control and environmental protection. Fixed-film treatment has played an important role in this history dominating the technology of wastewater treatment for several decades.

The treatment of domestic wastewater usually involves the removal of primary solids, in a primary settlement tank, followed by biological treatment of dissolved and suspended organic matter before discharge from a secondary settlement tank. The discharge is well oxidised and should have little effect on the surrounding environment. The biological treatment options most commonly employed have been the trickling filter or activated sludge aeration, until the commercial development of other processes such as the rotating biological contactor (RBC).

The first commercially available RBC units were manufactured, in Germany, from expanded polystyrene discs 2 and 3 meters in diameter for use in wastewater treatment plants. The first commercial installation went into operation in 1960 and since then the RBC has been used for a wide range of applications. Apart from domestic wastewater treatment the RBC has been utilised successfully for the removal of volatile organic compounds from wastewater *(Hsueh et al., 1991, Parker et al. 1996)*. RBCs have also been successfully employed for the treatment of wool scouring effluent *(Oellermann et al., 1992)* and dye wastewater with COD and dye removal rates of 78% and 72% respectively *(Zaoyan et al., 1992)*.

The RBC units as specified today, particularly for treatment of domestic wastewater, can come as an integral unit or can be incorporated into a modular system *(Green et al., 1995)*. The integral unit has the primary and secondary settlement compartments contained in the same tank as the biological treatment section, containing the discs. The integral RBC treatment plant is particularly suitable for wastewater generated from communities with low population equivalents. The modular treatment unit, on the other hand, has the primary and secondary settlement tanks separate from the biological treatment zone. This type of configuration is usually used for the treatment of wastewater generated from larger population equivalents.

1.2 SMALL DOMESTIC TREATMENT UNITS

In Ireland the wastewater from over one third of the population is treated in small scale treatment works i.e. with a population equivalent (p.e.) of less than 500. These wastewater treatment units are mainly located in rural areas. According to the 1991 census, carried out in the Republic of Ireland, there are 345,200 households connected to septic tanks. There are approximately 400 small-scale wastewater treatment systems, such as the RBC and the biofilm aerated filter, treating quantities of wastewater ranging from the single domestic household up to 500 p.e. *(SSWTPS EPA, 1998).*

Reservations about the use of septic tanks for satisfactory treatment of wastewater are not a newly derived concern. It was suggested, in 1971, that although septic tanks were capable of operating hygienically and conveniently, without flies or smell, they did no always do so; they overflowed and seepage could occur through deteriorated fabric to the detriment of the surrounding environment. By itself the septic tank does not satisfy the Royal Commission Standard which recommended a suspended solids concentration of 30 mg/l suspended solids concentration *(Lord, 1971).*

In the USA there are more than 20 million septic tanks and, according to a report carried out on behalf of the USEPA by Cantor and Knox, an average of 40%, or 8 million of these tanks, do not function properly *(ENN News, 1998).* When these tanks fail untreated wastewater is discharged into the surrounding environment.

The two documents commonly used in the design of single house wastewater treatment systems, in Ireland, are SR.6: 1991 and BS 6297: 1983. In a survey on single house treatment systems *(SSWTPS EPA, 1998)* it was found that 98.9% of single house treatment systems are septic tanks, 0.5% are proprietary systems and 0.6% are cesspools or chemical/dry closets. Soakpits are used with 63% of the septic tanks; percolation areas are used after 36% of the septic tanks.

A conventional septic tank system consists of a septic tank and a percolation area. A soil percolation trench system, as specified in SR.6: 1991, is an effective method of percolating septic tank effluent through soil. To ensure this system works a suitable depth of unsaturated soil is required (0.9-1.2m) below the invert distribution pipes and seasonal variations in water table depths need to be assessed to avoid misleading results *(Bicki et al., 1984)*. Where percolation areas are unsuitable the use of peat or sand filters may also be employed.

Results from a survey *(SSWTPS EPA, 1998)* of 26 local authorities concluded that the main problems associated with single house treatment systems, including septic tank systems include:

- Ponding of percolation area;
- Inadequate sizing of percolation area;
- Lack of water-tightness in septic tank construction;
- Too infrequent desludging of septic tank;
- Discharging of all wastewaters and roof waters to a septic tank;
- Removal of beneficial biomass by detergents (in biofilm systems);
- Well and surface water pollution;
- Lack of inspection to ensure construction is in accordance with SR.6: 1991;
- Increased loading on septic tanks due to house extensions; and
- Failure to replace spent biofilm media in certain systems.

In a report conducted by Meath County Council *(Meath Co. Co., 1985)* the effect of population density and hence septic tank density was assessed. The septic tank effluent was mainly disposed of via a soakpit. Heavy gley soils in the area impeded percolation. Septic tank density also caused problems.

Further results from the recent study conducted for the EPA identified 406 individual wastewater treatment systems for population equivalents between 8 p.e. and 500 p.e. *(SSWTPS EPA, 1998).* Primary treatment only is provided in 112 out of the 406 systems; secondary treatment is provided in 276 of the 406 systems; the remaining 18 systems provide tertiary treatment. There is a wide variation in the sophistication of these systems. Package systems make up approximately half of the systems detailed *(SSWTPS EPA, 1998).* The earlier treatment systems constructed were of the septic tank and imhoff type so one can conclude that there is an upward trend in the use of package treatment systems.

In recent years many proprietary treatment systems have come on the market; these could offer a solution where there are no suitable soils for treating the septic tank effluent. Often, percolation rates are inadequate on site; in these situations proprietary systems have been mainly accepted *(SSWTPS EPA, 1998).*

As the environmental restraints grow tighter the use of the septic tank system will become more limited. Package treatment units such as the RBC may have a more important role to play in the future for applications varying from the single dwelling to small community treatment works.

In the U.K. the RBC is the main option for treatment of wastewater generated by small communities *(Greaves et al., 1990).* Severn Trent Water Ltd has specified Rotating Biological Contactors, either alone or in conjunction with a reed bed as the optimum wastewater treatment method for small communities *(Black and Finlay, 1993).* In Switzerland, future trends will be towards more small systems instead of long sewers and more frequent application of biofilm processes *(Boller and Deplazes, 1990).* Properly designed, the RBC system may be superior to other fixed-film systems due to lower organic loading per mass of biological solids, longer detention times and better control of short circuiting *(Metcalf and Eddy, 1991).*

1.3 DESCRIPTION OF RBC PROCESS

The RBC system consists of a primary settlement tank, a rotating biofilm media zone and a final settlement tank. Screens are sometimes employed to remove large objects in the influent. The Rotating Biological Contactor is basically a secondary treatment stage for wastewater. The media surfaces, comprising of circular discs, closely spaced, are mounted on a horizontal shaft within a tank and are slowly rotated so that 40-50% of the media surface is submerged in the wastewater. Organisms that occur naturally soon adhere to the media and multiply until a layer, 1 to 4mm thick, covers the surface.

During rotation (usually 1-2 rpm) the contactor carries a film of wastewater into the air, which trickles over the biomass and absorbs oxygen from air contact. Oxygen moves into the biofilm when it comes in contact with the air. Oxygen may move into or out of the biofilm when in contact with the wastewater, depending on the oxygen concentration in the wastewater. The speed of rotation of the RBC is usually limited to a peripheral velocity of 0.3m/sec. The shearing force exerted on the biomass during rotation ensures stripping of excess biomass from the media, which prevents clogging of the media surfaces and maintains an active micro-organism population. When the flow in the RBC unit is parallel to the shaft, the biofilm growth on the media is thicker in the initial stages where the organic concentration is higher. Carbonaceous oxidation will occur in these initial stages and if sufficient media is available (surplus to carbonaceous requirements) then nitrification will occur. The RBC biomass usually has a shaggy appearance due to the formation of macroscopic filaments. These filaments help to increase the aerobically active biomass surface exposed to the wastewater. The biofilm is protected from wind, rain and snow by a cover. The cover should be robust enough to protect the unit from malicious or accidental damage.

The sludge from the secondary settlement tank may be pumped to the primary settlement tank to avoid sludge flotation in the secondary settlement tank and also to cater for storage. The treated effluent is not recycled through the process as the high concentration of biomass on the media and in the mixed liquor permits a high degree of treatment in short time periods, typically 7 to 10 minutes per stage *(McCann, 1993)*.

1.3.1 The extent of RBC use in Ireland

There were at least 182 RBC wastewater treatment plants operating in the Republic of Ireland in 1998 *(Lyons, 1998)*. It is not clear as to how long all of these 182 plants have been in operation, but of the 182 identified, 136 plants have been installed since 1986. This data was generated from information gathered from Local Authorities, and the suppliers and manufacturers of RBC systems. There were 5 suppliers of RBC technology identified in Ireland, only two of these responded (BMS Ltd, Longford and John Molloy Eng. Ltd, Dublin) to the survey conducted. The two respondents are, however, the two most popular suppliers in Ireland, particularly to Local Authorities. 51 of the plants surveyed are under Local Authority control, the remaining RBC plants are used for various applications such as industry, hotels and private users, etc.

RBC USER	*Number*	*% of Total*
Local Authority	51	28
Private Dwellings	28	16
Industry/Manufacturing	24	13
Hotel	29	16
Pub/Restaurant	10	6
Golf Club	9	5
Nursing Home	4	2
Leisure Industry	7	4
Caravan Park	6	3
Other	12	7
Total	182	100

Table 1.1: The main uses of RBC technology in Ireland.

Of the 182 plants identified *(Lyons, 1998)*, information was obtained relating to the population equivalent (p.e.) of 124 of these plants. The results are summarised in Table 1.2. Where a RBC treatment plant is used, its application is most popular for the treatment of wastewater generated by population equivalents in the range of 51 to 100. The trend is the same for Local Authorities surveyed with the highest number, 11 out of the 51 plants, being used for the treatment of 51 to 100 population equivalent. There were no RBC plants identified under the jurisdiction of Corporations or City Borough Councils which indicates that the RBC is limited to rural areas.

Population Equivalent (p.e.)	*General Number*	*Local Authority Number*
N/A	58	8
1-10	6	1
11-50	18	5
51-100	38	11
101-150	19	9
151-200	7	3
201-300	18	4
301-400	1	0
401-500	3	2
501-600	11	7
>600	1	1
Total	182	51

Table 1.2: The P. E. catered for by RBC plants in Ireland *(Lyons, 1998)*.

1.3.2 RBC Manufacturers

The manufacturers involved in the construction and/or supply of RBC systems include:

Tuke & Bell Ltd., Staffordshire, England supplies the RoBec system. An integral unit is used normally for populations below 750 p.e. and a modular system for populations between 750 and 10,000 p.e.

Cambridge Specialist Services Ltd., West Midlands, U.K. supplies the Cambridge RBC. Single tank composite-package RBC plants cater for population equivalents below 400 persons. For the treatment of wastewater generated from population equivalents between

150 and 600 persons a Cambridge semi-package (secondary settlement tank separate from primary tank and bio-zone) RBC plant may be used. A modular system caters for population equivalents between 225 and 1000.

Biwater Treatment, U.K. supply a treatment system, the BISTAR, to treat wastewater from population equivalents between 300 and 2000 persons.

The two main manufacturers that supply to the Irish market are Butler Manufacturing Services (BMS) Ltd, Longford and Klargester Environmental Engineering Ltd., College Rd, Aston Clinton, Buckinghamshire, U.K. (agents John Molloy Eng. Ltd, Dundrum, Dublin 14).

Klargester manufactures compact RBC package units for processing sewage from residential, commercial and industrial premises with population equivalents up to 1000. Single modular systems, twin modular (separate primary tank) and fully modular systems are available.

BMS manufactures the Aerotor system, which is the combination of RBC technology and active aeration. The units are available in a range of standard module sizes from 2.7m to 7m in length.

1.3.3 Advantages of the RBC system

The RBC is a compact unit so it is easy to transport to site and install. They also have the ability to function under conditions of shock loading. They have low maintenance and operating costs, and take up small areas of land. The units have low noise emissions with no fly nuisance. There is little or no head loss through the system, which is a biologically and hydraulically stable one. There is the possibility of nitrification and denitrification if the units are properly designed. They operate well under varying climates.

1.3.4 Disadvantages with the RBC system

The main problems associated with the RBC relate to overloading. Package systems may have small sludge storage volume, which can lead to overloading of the biofilm. High concentration wastewater loading can lead to low dissolved oxygen levels (below 2 mg/l) which can lead to biofilm overgrowth and extra stress on the shaft and media. Grease may cause problems by coating the media. Little reduction in micro-organisms occurs unless addition treatment is incorporated. The motors and pumps require servicing by skilled personnel. Leakage between compartments of some RBCs has been reported *(Greaves et al., 1990)*. Removal of beneficial biomass by detergents may occur under certain conditions *(SSWTPS EPA, 1998)*. Shaft failure is a commonly reported problem with RBC systems (*Kiely, 1997*). Shaft breakage can occur particularly after power failure; due to uneven distribution of the biofilm on the RBC discs i.e. the upper half of the disc (exposed to the air) has dried out while the lower half has a large biofilm growth attached.

1.4 RESEARCH OBJECTIVES

The objective of this research was to assess the effects that a household detergent has on rotating biological contactor treatment plant efficiency and to attempt to alleviate any such problems by modifying the RBC design criteria. Household detergents contribute phosphorus to the surrounding environment and can also remove beneficial biomass from the disc media. Recent studies in the U.K. *(Fryer, 1996)* have suggested that a detergent concentration of higher than 10% of the wastewater volume can effect the treatment efficiency of the RBC system. A simple modification was made to a conventional flat disc unit to increase the oxygen transfer of the process. It was envisaged that the increase in oxygen transfer would stimulate the growth of suspended flocs or activated sludge biomass within the mixed liquor. The treatment efficiency of the modified RBC (with aeration cups attached) was to be assessed against a parallel conventional system, with and without detergent loading.

1.5 RESEARCH PROGRAMME

The first stage was to provide a detailed literature review of the historical development of the fixed film system and its subsequent progression to the rotating biological contactor treatment system. Previous research works relating to the RBC were also to be reviewed.

An assessment of the implications of newly published phosphorus regulations, relating to Ireland and the EU, was to be undertaken. The development of detergent use was to be traced from the stage where non-biodegradable surfactants were employed, up to the present situation where restrictions on wastewater discharge phosphorus content are affecting detergent compositions.

Initial testing would commence with an assessment of the most efficient design to optimise oxygen transfer efficiency. A unit comprising of three flat discs with varying numbers of aeration cups attached was to be assessed. The oxygen transfer efficiency of the modified RBC system would be evaluated by monitoring the dissolved oxygen increase with time when the model was operated within a fixed volume of tap water. The oxygen transfer coefficient K_La would be calculated, for each differing cup number, and related to varying disc rotational speeds.

Phase 1 of the research program would conclude with the design and construction of two-bench scale staged RBC models. One model incorporating the most efficient aeration cup arrangement ascertained from the initial testing; the other unit would be a conventional flat disc unit.

The second phase of the research would involve assessing the wastewater treatment performance of the two models, operating at a rotational speed of 2 revolutions per minute (peripheral velocity of 0.035m/s). This testing would be divided into 3 distinct stages:

Stage 1 would involve the treatment of wastewater at low and high hydraulic, and low to medium organic loading rates. The wastewater treated would not contain detergents. Retention times were to vary between 12 hours 41 minutes, 6 hours 22 minutes and 4 hours 14 minutes (Appendix 3).

Stage 2 would involve the treatment of wastewater with varying concentrations of detergents. The wastewater was to be set at a continuous hydraulic flow-rate of 180l/d with a corresponding retention time of 4 hours 14 minutes within the RBC trough.

Stage 3 would involve the treatment of wastewater at high hydraulic and high organic loading rates. The wastewater was to be at a continuous hydraulic flow-rate of 180l/d and a retention time of 4 hours 14 minutes in the RBC trough. Shock detergent loading was to be applied and treatment efficiencies assessed.

Treatment plant efficiency would be continuously monitored throughout the 3 stages. The parameters to be monitored were chemical oxygen demand (COD), bio-chemical oxygen demand (BOD), nitrates, phosphates, dissolved oxygen, the motors power consumption, pH, and temperature. Some microscopic analysis of the biofilm was also to be carried out.

The treatment efficiency of both units would be compared, based on COD/BOD removal. The degree of nitrification achievable by both units was also to be compared, with any fluctuations in pH noted. Monitoring of the phosphorus removal capabilities of both units was to be undertaken. Relationships between detergent concentrations and COD removal efficiencies were also to be analysed and compared to previous research findings.

A disc rotational speed of 2-rpm (peripheral velocity of 0.035m/s) while relatively low, for the scaled down units, was chosen primarily to assess if the unit with the aeration cups would have a distinct advantage over the flat disc unit. Similar peripheral velocities and disc rotational speeds have been adopted in comparable studies *(Surgeoner, 1997; McCann, 1993; Ellis and Banaga, 1976; and Uhan and Khararjian, 1984).*

Chapter 2

Development of the RBC system

2.1 EARLY DEVELOPMENTS IN SEWAGE PURIFICATION

In 1865 Dr. Alexander Mueller's demonstration that sewage could be purified by living organisms in a filtration column provided a major revelation *(Pearse, 1938)*. Dr. Mueller, a prominent City Chemist of Berlin, subsequently patented his biological purification process several years later *(Alleman, 1998)*. Since then there has been continuous development of the filtration process for the treatment of wastewater *(Schonborn, 1986)*.

Following upon the singular work by Mueller over a decade earlier, several researchers successively explored the microbial aspect of sewage purification. Schloesing and Müntz *(Schloesing et al., 1877)* first demonstrated soil nitrification in 1877. Five years later, Warrington confirmed that sterilised solutions lost their nitrifying ability until inoculated by fresh soil *(Warrington, 1891)*. And in 1890, Winogradsky succeeded in identifying Nitrosomonas bacteria *(Winogradsky, 1890)*. These pioneers were, however, still uncertain as to the pragmatic application of these bacterial mechanisms to effective treatment *(Alleman, 1998)*.

Up to this point, Europe had dominated the developments in wastewater treatment technology. Within the United States, though, comparable concern for pollution control resulted in the establishment of the Lawrence Experimental Station by the Massachusetts State Board of Health *(Metcalf et al., 1916, and Hazen, 1892)*. The Lawrence group began a series of filtration experiments in 1887; their first publication in 1890 provided an analysis of the microbial activity *(Hazen, 1892)*. Their findings demonstrated that micro-organisms carried within the filter media could degrade sewage in an aerobic environment facilitated by intermittent dosing *(Alleman, 1998)*.

Given the success of the Lawrence experiments, biological treatment systems rapidly expanded in terms of application and sophistication. Considerable controversy had arisen in the 1890's over patent rights obtained by Donald Cameron for septic tanks, *(Metcalf et al., 1916)* such that most municipalities were anxious to find suitable treatment alternatives *(Alleman, 1998)*.

Trickling filters were first introduced to the U. S. in 1901 at Madison, Wisconsin *(Metcalf et al., 1916)*. By 1910, several additions in mid-west and eastern cities brought the total to ten *(Kinnicut et al., 1919, Alleman, 1998)*.

2.2 HISTORICAL DEVELOPMENT OF THE RBC

With the advent of trickling filter applications, interest in intermittent-filtration began to fade. By the turn of the century a different form of filter was being considered for treatment proposes. In 1900 Weigand patented his rotating cylinder media system, which comprised a moving cylinder with wooden slats, for the treatment of wastewater *(Weigand, 1900)*. In 1901 Travis installed wooden strips which moved through sewage in "hydrolytic" tanks - their purpose was to catch non-settling solids by absorption, the solids would accumulate and slough off in time into a hopper below. In 1916 an experimental installation of rotating discs was set up and investigated by the City of Toronto Health Department. Poujoulat's patent in 1916 *(Poujoulat, 1916)* employed agglomerated slag or porous brick fashioned as a hollow cylinder and rotated about its horizontal axis. Flow distribution was provided using a perforated pipe placed over the cylinder (Banerji, 1980, Ellis et al., 1976 and Schonborn, 1986). Although neither option attracted much attention at the time, these designs could well be considered vintage predecessors to rotating biological contactor technology *(Alleman, 1998)*.

Buswell in 1928-1929 analysed the treatment efficiency of the "Biological Wheel", a process developed by the Paige and Jones Chemical Company. Wheels were made from sheets of plywood similar to paddle wheels, which were turned by the flow of sewage, so the blades were alternately exposed to air and wastewater *(Buswell, 1928 and Buswell, 1929)*. In 1929 J. Doman reported on the development of a contact filter using partially submerged rotating plates constructed from galvanised steel *(Doman, 1929)*. The schematic overview provided with this report bears a striking resemblance to modern RBC designs *(Alleman, 1998)*. In 1931 A. T. Maltby patented a process which was based on the Biological Wheel *(Allen, 1929, Banerji, 1980, Bunch, 1980, O'Neill, 1993)*.

In 1936 Mohlman defended the technologies developed by Buswell, Maltby, Doman and others referring to the fixed-film treatments as a worthy alternative to the rapidly advancing suspended-growth concept *(Mohlman, 1936)*.

Little more work was reported on these ideas until the 1950s. This was possibly due to the Depression of the 1930s, the Second World War, and the rise of the trickling filter in the 1950s *(Surgeoner, 1997)*.

Research and development on plastic media proceeded along two distinct lines during the early 1950's. In America, bundled plastic units were being proposed and tested as innovative packing for stationary filter applications *(Bryan, 1955)*. Investigators in Europe, though, began testing rotating plastic discs in much the same manner as Doman's rotating cast iron system *(Daillaire, 1979)*. Around 1955 Popel and Hartmann were carrying out research at Stuttgart University, West Germany. They conducted extensive testing on wooden and plastic discs, 1 meter in diameter *(Daillaire, 1979)*. Further improvement by Popel and Hartman *(Antonie, 1976)* led to the use of expanded polystyrene media, which then opened the door for commercial application.

By 1957, the J. Conrad Stengelin Company in Tuttlingen, West Germany had begun manufacturing expanded polystyrene discs 2 and 3 meters in diameter for use in wastewater treatment plants. The first commercial installation went into operation in 1960, and soon thereafter the process began to attract considerable interest throughout Europe *(Banerji, 1980, Bunch, 1980 and Smith et al., 1980).*

During the early 1960's, the research division of Allis Chalmers Corporation also investigated the use of rotating discs in various chemical-processing applications. Their disc was called a two-phase contactor (TPC), and was tested for applications of gas absorption and stripping, liquid-liquid extraction, liquid-liquid heat transfer, and other mass and energy transfer applications. Eventually, the device was considered for oxygen transfer. In the summer of 1965, three-foot diameter metal discs were evaluated at the Jones Island treatment plant in Milwaukee, Wisconsin. These units were initially employed for oxygen transfer in an extended aeration process, and then tested without sludge recycle and with an attached biomass (i.e. as a biological contactor). To confirm the favourable results of these initial tests and to learn more about the treatment process, laboratory tests were subsequently conducted using synthetic dairy waste and 3-foot diameter aluminium discs *(Alleman, 1998).*

After learning of the European activities, Allis-Chalmers reached a licensing agreement in 1968 with the German manufacturer for production and sales distribution in the U. S. The treatment process was marketed under the trade name Bio-Disc. The first commercial installation in the U. S. went into operation at a small cheese factory in 1969 *(Birks et al., 1971).*

In 1970, Allis-Chalmers sold its rotating biological contactor technology to Autotrol Corporation. At that time, RBC systems were still not competitive with the activated sludge process, primarily due to the high capital cost of the polystyrene discs. In 1971 the Autotrol Corporation demonstrated the first RBC treatment unit for secondary treatment of municipal wastewater in Pewaukee, Wisconsin. In contrast, by 1971 there were more than 700 full-scale units in West Germany. However, in 1972, Autotrol announced the development of new rotating contactor media constructed from corrugated sheets of polyethylene. Until then, *(Smith, 1980)* the RBC unit consisted of a series of parallel, flat 0.5 inch thick expanded polystyrene sheets, each separated by a 0.75 inch space. The new arrangement used 1/16-inch thick polyethylene sheets with a 1.2-inch space. RBCs came onto the UK market about 1970 with Simpson's "Bio-Disc", and was well established by the late 70s. There was a geometric growth rate of RBCs in use by 1980. By 1980 there were more than 1000 RBCs in use in the UK *(Ellis et al., 1976, O'Neill, 1995, Opatken, 1984).*

Operational problems such as shaft failure and media failures and high biomass concentrations, which led to low dissolved oxygen have been addressed. In 1979 the Aerosurf process was developed which used air driven units to increase the dissolved oxygen concentration. By 1995 there were more than 500 of these units world wide *(IWEM, 1988, O'Neill, 1995, Surgeoner, 1997).* The use of new shaft materials and the installation of alarm systems in the event of power failure, has led to the resurgence of the RBC system in the 1990s, with over 182 plants operating in the Republic of Ireland *(Lyons 1998).*

2.3 STUDIES ON EFFECTS OF DETERGENTS ON THE RBC

Marriott assessed the ability of laboratory scale RBC units to treat laundry effluent. Six units were loaded, with a synthetic wastewater, at an organic loading rate of 9.4g BOD/m^2.d. It was concluded, that in the short term laundry effluent was initially difficult to treat at concentrations in excess of 5% by volume. Microbial activity was inhibited at concentrations in excess of 10% by volume. However, after acclimatisation it was possible to treat even full strength laundry effluent in the RBCs. BOD removal decreased as the concentration of laundry effluent by % volume increased. It was suggested that this might have resulted from loading irregularities *(Marriott et al., 1995)*.

Another possible reason for the reduction in BOD removal efficiency may be attributed to an increase in the detergent concentration affecting the oxygen transfer within the RBC unit. Detergents have a profound influence on oxygen transfer, which is an important factor relating to the overall performance of aeration systems.

The rate of oxygen transfer, or KLa coefficient, is normally higher when aerating clean water rather than wastewater because the impurities within the wastewater have significant effects on KLa. Both fatty and surface-active materials such as detergents, when present in wastewater, reduce the rate of oxygen transfer. However, detergents and fatty acids when present as soaps (pH>6) are able to increase KLa by preventing bubble coalescence, thus maintaining a lower bubble size than normal. This increases the total interfacial area thus increasing the overall mass transfer of oxygen. These two opposing effects rarely cancel each other out and should be considered in the calculation of KLa. Other impurities in water can also alter KLa therefore the effects of all impurities must be calculated together by measuring the α-factor, which is the KLa of wastewater divided by the KLa of clean water *(IWPC, 1987)*.

In parallel with many other research and development organisations, the UK's Water Pollution Research Laboratory (WPRL) commenced a study of aerator performance *(Downing et al., 1960, Lister et al., 1973)*. Earlier work on the re-aeration of natural waters had shown the oxygen-transfer coefficients decreased with increasing concentration of detergent (alkyl benzene sulphonates - ABS) up to about 1 mg/l, and preliminary work indicated similar effects on aeration by diffused-air bubbles. WPRL conducted most of the initial work on diffused air systems, mainly in pilot-scale plants, with tap water containing 5 mg/l ABS – a concentration below that found in the mixed liquor of full-scale plants. This approach was justified for full-scale diffused-air plants by capturing and analysing the air issuing from the surface beneath floating hoods. The percentage of oxygen, which had been absorbed, was virtually the same as that calculated for the corresponding laboratory trials in tap water plus ABS.

In contrast, parallel measurements in full-scale plants which had been emptied and refilled with tap water to which detergent was then added, showed that the presence of detergents tended to increase oxygenation capacities somewhat relative to those in tap water alone. As time progressed, the results of this work and those obtained elsewhere began to fit into a coherent pattern, enabling aeration systems to be provided which could be expected to meet the predicted oxygen demands *(Cooper et al. 1998).*

The introduction of detergents into a flat disc RBC unit can reduce the oxygen transfer rate. Improved aeration efficiency within a RBC system through design modification could counteract any such effects. In 1993, McCann developed an aeration attachment to improve the conventional flat disc RBC system. Aeration cups were attached to a flat disc unit to increase the dissolved oxygen concentration and hence treatment efficiency of the unit. The cup arrangement yielded better treatment efficiency, than the flat disc unit, when operated at high organic loading rates and low disc rotational speeds.

The research work set out in this thesis has, as its basis, the work instigated by McCann, 1993 and Marriott et al., 1995.

Chapter 3

Phosphorus and detergents

3.1 IRISH REGULATIONS RELATING TO PHOSPHORUS DISCHARGE

In October 1998 national water quality standards, to tackle pollution in rivers and lakes, were published in Ireland. These regulations are implemented under the *Local Government (Water Pollution) Act, 1977 (Water quality standards for phosphorus) Regulations, 1998 – Statutory Instrument S.I. No. 258 of 1998.* These standards cover the phosphorus discharge allowed into Irish waters. Excessive inputs of phosphorus from sources such as sewage treatment plants are problematic in rivers and lakes and are addressed in the regulations. A benchmark water quality rating/status for the maintenance or improvement of quality standards will be assigned by the Environmental Protection Agency (EPA) based on monitoring that was carried out of certain rivers and lakes between 1995 and 1997. The benchmark quality rating/status for other unmonitored rivers or lakes, of concern, will be based on the EPA's first assessment after 1997. Compliance with the water quality standards will have to be achieved by the 31 December 2007 where a quality rating/status has been assigned based on the monitoring between 1995 to 1997. Otherwise a ten-year time frame applies from the first time the EPA assigns a rating based on monitoring carried out after 1997. In exceptional circumstances a six-year extension may be granted to the ten-year time frame where it may be difficult to comply with the standards. These exceptional circumstances cover situations where, even if wide-ranging measures are adopted under all relevant legislation, the standards may still not be met within a ten-year time frame. However, the Local Authority or EPA has to identify the additional measures required of those responsible for the emission and stipulate how such measures should be implemented within the sixteen-year period *(W. P. Circular, 1998).*

The decision as to the whether an extension should be granted is up to the Local Authority or the EPA depending on the source of the phosphorus. Where an Integrated Pollution Control (IPC) licensed discharge is not required a Local Authority may grant an extension on its own. However, when an IPC licensed discharge and other phosphorus sources are involved both the Local Authority and the EPA have to consult before an extension can be granted. The EPA can grant an extension on its own where an IPC licensed discharge is the only source of phosphorus.

The EPA has been given an important supervisory and reporting function in relation to the implementation of the regulations. Local Authorities are required to submit a report of measures to be taken under the terms of the regulations by 31 July 1999. A progress report on implementation of measures is required by the EPA one year later and further progress reports are required at least every two years there after. The EPA is required within 9 months of receipt of progress reports to prepare and publish reports on progress in relation to implementation of the regulations. These EPA reports should be all inclusive i.e. contain material from the Local Authorities along with material relating to IPC licensed discharges *(W. P. Circular, 1998).*

In order to secure compliance with the standards Local Authorities are adopting a catchment-based approach for the planning and implementation of measures to improve water quality. A £3.4m monitoring and management system has been introduced for the rivers Liffey, Boyne and Suir. This is in addition to other initiatives at Lough Derg, Ree and Leane. This catchment-based approach is outlined in a strategy document *"Managing Ireland's Rivers and Lakes – A Catchment-Based Strategy against Eutrophication, 1997".*

The implications of the phosphorus standards will affect all sectors that contribute to the overall phosphorus load reaching a river or lake. The responsibility for light to moderate pollution by various sectors was first identified by the EPA in a Report on Water Quality, 1991-1994. The principle sectors identified were agriculture, sewage and industry. Successful action against eutrophication will particularly depend on reducing phosphorus losses from agriculture. Local Authorities, as a key management tool, are developing Nutrient Management Plans (NMP's) for the farmer. Following a review of recommended phosphorus fertiliser application rates and crop production requirements; Teagasc announced revised lower rates for grasslands in December 1996. Teagasc and the Department of Agriculture, Food and Forestry will promote adoption of the new recommendations and ensure they are incorporated into NMP's under Rural Environmental Protection Schemes and such other measures.

Any industrial discharges governed by Local Authorities are now required to have their license reviewed in respect of discharge to a water body affected by the Regulations. Local Authorities are required to examine methods by which the phosphorus load may be reduced as part of the overall strategy to comply with the regulations within the timeframe *(W. P. Circular, 1998)*.

One of the sectors identified in the EPA Report on Water Quality, 1991-1994 as contributors of phosphorus is sewage. Priorities in this area are well established due to the requirements of the EU Urban Wastewater Directive (91/271/EEC). The EU Urban Wastewater Directive provides a comprehensive framework for action to deal with the pollution threat from sewage to rivers and lakes in Ireland. The EPA Act, 1992 (Urban Waste Water Treatment) Regulations, 1994, which give effect to the Directive, require the provision of collection systems and secondary treatment facilities for all inland discharges with a population equivalent (p.e.) of 2,000 or more. A deadline of the end 2000 applies to all towns in excess of 15,000 p.e. and the end of 2005 for lesser discharges. The 1994 regulations designate 4 lakes and sections of 6 rivers as sensitive areas on the basis that they are eutrophic or likely to become eutrophic if protective action is not taken. Phosphorus reduction facilities are required at towns with a p.e. greater than 10,000 discharging to these sensitive areas. The sensitive areas and towns concerned are:

Lakes: Ree-Longford; Leane-Killarney; Oughter-Cavan; Derg-Athlone, Nenagh and Tullamore.

Rivers: Boyne-Navan; Castlebar-Castlebar; Nenagh-Nenagh; Camlin-Longford; Liffey-Osberstown; Tullamore-Tullamore.

Phosphorus reduction facilities will be provided in respect of facilities below the 10,000 p.e. where these contribute to the eutrophication of the sensitive areas concerned or to the eutrophication of other rivers or lakes.

In the Department of the Environment report *"Managing Ireland's Rivers and Lakes – A Catchment-Based Strategy against Eutrophication, 1997"* controls on domestic effluent treatment systems are discussed. The predominant way of treating/disposing of domestic effluent in unserviced areas has been by way of the septic tank and soakpit/percolation area. However, in more recent years a number of alternative package treatment systems have been introduced. These domestic treatment systems are subject to the pollution control provisions of the Water Pollution Acts, 1977 and 1990. However, discharge from septic tanks or other disposal facilities which do not exceed 5 cubic metres in volume in a

24 hour period and which are made to an aquifer by means of a soakpit/percolation area or other method are exempt from licensing provisions. There is evidence that in some areas septic tanks are causing localised contamination of groundwater by faecal bacteria and nitrates and that they may also be impacting adversely on lakes. A report carried out by the Lough Conn Task Force, Co Mayo, estimates that septic tanks may contribute more to phosphorus loading in the lake (Figure 3.1) than effluent from the Crossmolina sewage treatment works, shown in Figure 3.2 *(Lough Conn Progress Report, 1997).*

The standard recommendations for new domestic tank systems (S.R.6: 1991) set out stringent site test requirements and minimum distances between percolation areas and groundwater sources so as to avoid pollution. In addition the Department of the Environment has given guidance to Local Authorities and the public about the location, performance standards and proper management of septic tanks and highlighted the potential risk to water supplies.

It is proposed to review controls in relation to domestic effluent treatment systems and pollution prevention with particular reference to:

- Ensuring a comprehensive and consistent approach by planning authorities in the setting of conditions and their enforcement when dealing with planning applications involving domestic treatment systems.

- Strengthening pollution prevention arrangements. This will entail the reassessment of the present licensing exemption for small discharges under the Water Pollution Acts as well as consideration of procedures for the monitoring of performance of systems and their maintenance so as to insure that planning conditions intended to prevent water pollution are observed.

- Promoting public awareness about the need for careful site selection and proper operational and maintenance practices.

- Review of S.R.6: 1991 to specifically address the use of alternative treatment systems *(Managing Ireland's Rivers and Lakes, 1997).*

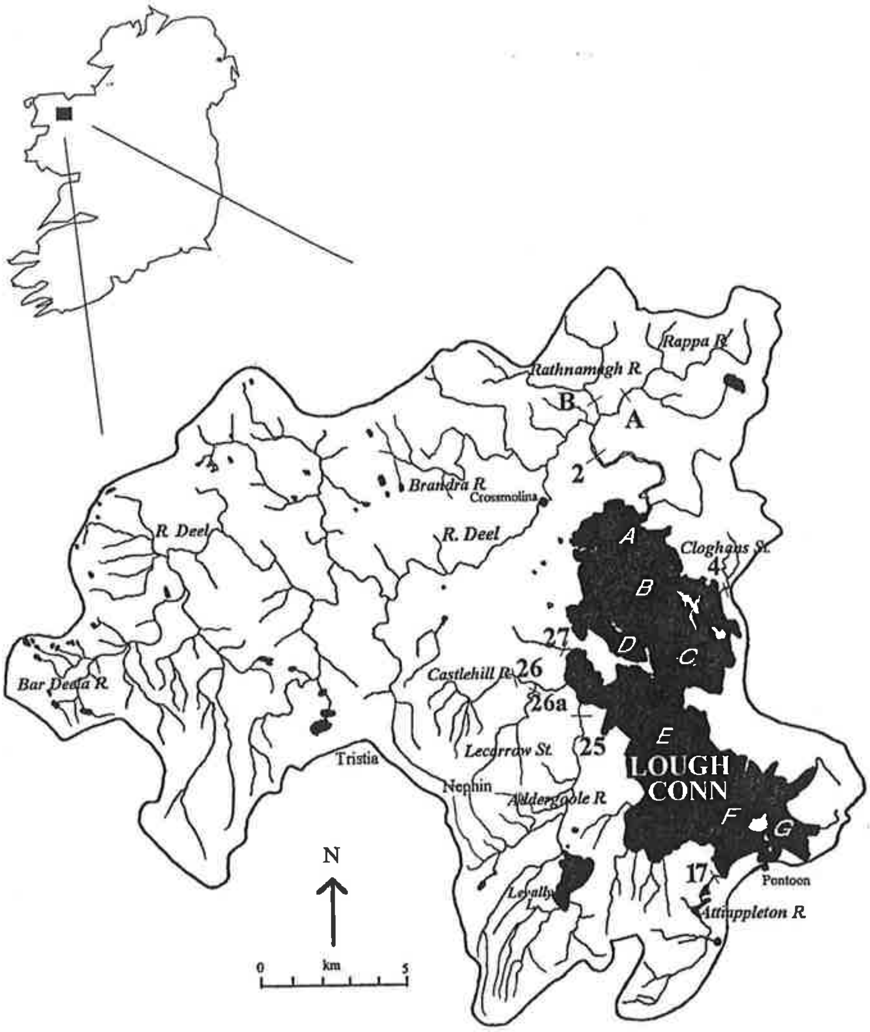


Figure 3.1 Location Map of Lough Conn *(Lough Conn Progress Report, 1997).*

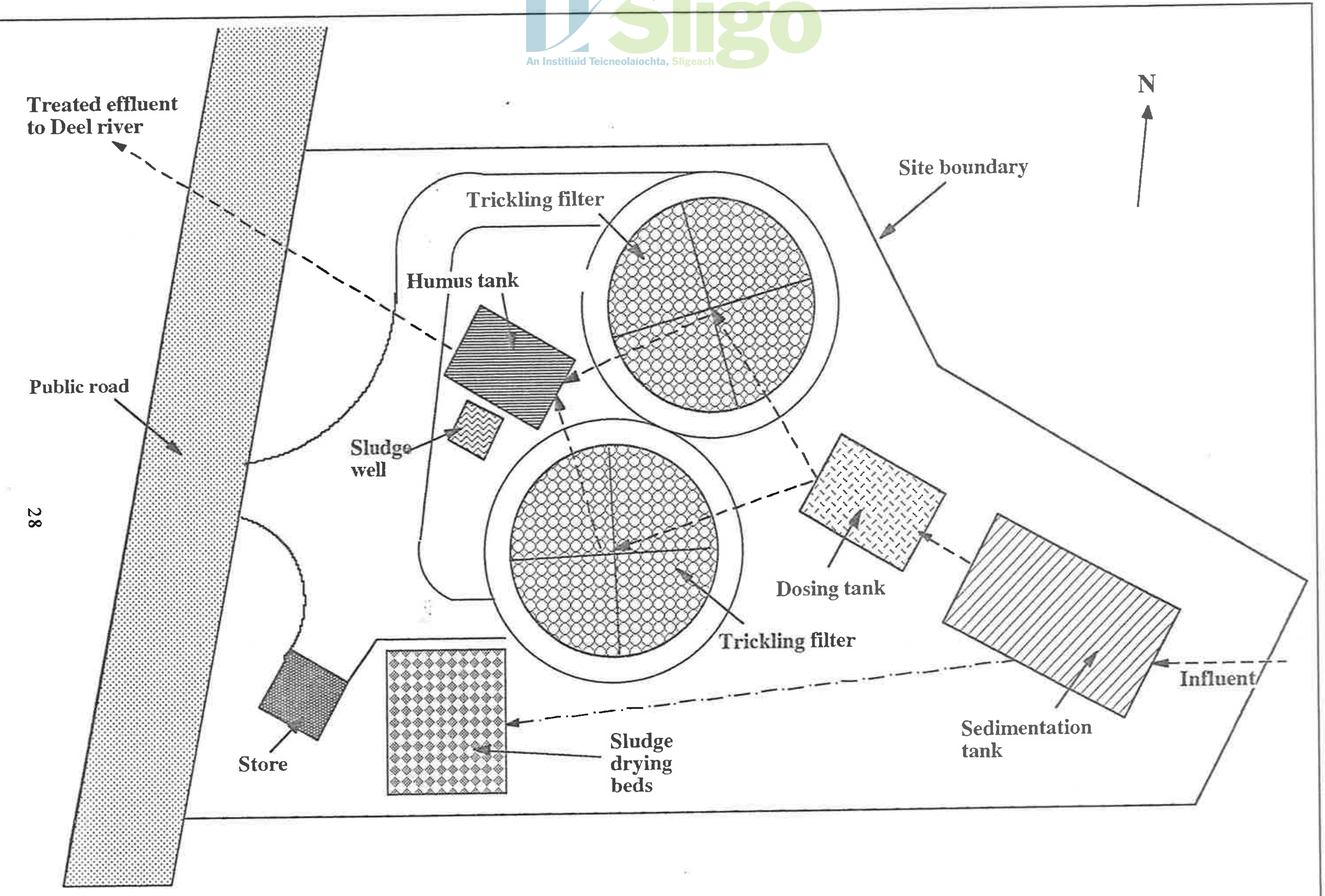


Figure 3.2 Layout Plan of Existing Treatment Works at Crossmolina Co. Mayo

3.2 FACTORS THAT CONTROL EUTROPHICATION

Eutrophication describes a condition of a water body where excessive algal growth can occur which may eventually deteriorate the body of water. There are many factors that control the rate of production of algae, including the availability of sunlight to power the photosynthetic process, and the concentration of nutrients required for growth. While the amount of sunlight available can be a limiting factor in algal growth, it is something that we are unable to control as a way to slow eutrophication. The more obvious approach is to try to reduce the supply of nutrients. Justus Liebig, in 1840, first formulated the idea that "growth of a plant is dependent on the amount of foodstuff that is presented to it in minimum quantity". Liebig's law of the minimum if applied in the context of eutrophication states that algal growth will be limited by the nutrient that is least available relative to its needs; therefore, the quickest way to control eutrophication would be to identify the limiting nutrient and reduce its concentration *(Masters, 1998)*.

Eutrophication begins when excessive plant nutrients such as phosphorus and nitrogen are input, from watershed runoff or sewage, into a water body. Plant biomass is produced, in the nutrient rich body of water, by photosynthesis. When the plant biomass dies, it settles and decays at the bottom of a water body. Nutrient carbon dioxide, phosphorus, nitrogen and potassium are recycled which can be harmful if excessive dissolved oxygen is consumed. The problem is further compounded if bottom rooted plants begin to grow, particularly in shallow water where marshes can form.

Human activity can greatly speed up the eutrophication process. The chemical elements necessary for plant growth are in surplus supply to support plant life in a water body. Hydrogen and oxygen come from the water itself. Carbon is provided via the atmosphere or decaying vegetation. Sulphate, magnesium and calcium are normally present in abundance from mineral strata in contact with water. The nutrients most likely to be growth limiting are nitrogen, phosphorus and potassium. Generally the limiting nutrient is phosphorus and is the common cause of eutrophication in waters *(Manahan, 1990).*

However, referring back to Liebig's Law it can also be inferred that reductions in a non-limiting nutrient will not provide effective control unless its concentration can be reduced until it becomes the limiting nutrient. Eliminating phosphates in detergents will have little effect in nitrogen-limited surface waters, but the same reductions could be very effective where phosphorus is the limiting nutrient.

As lakes eutrophy, the dominant species of algae are often blue-green Cyanophyta, which can, unusually, obtain nitrogen directly from the atmosphere. In addition, nitrogen enters water as "fallout" from combustion sources such as fossil fuel fired powered plants. With the atmosphere as a rather unlimited nitrogen supply for blue-green Cyanophyta, most freshwater systems are phosphorus limited *(Masters, 1998).*

To illustrate the relative amounts of nitrogen and phosphorus required for algal growth, consider the following representation of algal photosynthesis *(Stumm and Morgan, 1981):*

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \rightarrow C_{106}H_{263}O_{110}N_{16}P + 138O_2$$

Using stoichiometric analysis with the atomic weights of nitrogen (14) and phosphorus (31), the ratio of the mass of nitrogen to phosphorus, in this algae, is:

$$\frac{N}{P} = \frac{16 \times 14}{1 \times 31} = 7.2$$

As a first approximation, then, it takes about seven times more nitrogen than phosphorus to produce a given mass of algae. As a rough guideline, when the concentration (mg/l) of nitrogen in water is more than 10 times the concentration of phosphorus, the body of water will probably be phosphorus limited. When it is less than 10:1 it will probably be nitrogen limited *(Thomann and Mueller, 1987)*. Most marine waters have an N/P ratio less than 5 and are nitrogen limited *(Masters, 1998)*.

Sawyer (1947) suggests that phosphorus concentrations in excess of 0.015 mg/l and nitrogen concentrations above 0.3 mg/l are sufficient to cause blooms of algae. These are in line with more recent estimates that suggest that 0.010 mg/l of phosphorus are "acceptable" while 0.020 mg/l are "excessive" *(Voellenweider, 1975)*.

Household detergents are a common source of phosphate in wastewater, and eutrophication control has concentrated on eliminating phosphates from detergents, removing phosphate at the sewage treatment plant, and preventing the phosphate laden sewage effluent from entering bodies of water.

Phosphorus occurs in solution, in particles of detritus or in micro-organisms bodies as:

- Orthophosphate (HPO_4^{3-}, HPO_4^{2-}, H_2PO^{4-}, H_3PO^{4-})
- Polyphosphate (P_2O_7)
- Organically bound P

~ 70 percent of wastewater phosphorus

The sources of phosphorus include:

- Detergents, domestic and commercial
- Land fertilisers.
- Potable water treatment additives.
- Human excreta in sewage.

- Food residues in sewage.

It is desirable to reduce the "total phosphorus" in municipal wastewater to below 2mg/l to avoid eutrophication *(Kiely, 1997)*.

Domestic wastewater is relatively rich in phosphorus compounds. Prior to the development of synthetic detergents, the content of inorganic phosphorus usually ranged from 2 – 3mg/l and organic forms varied from 0.5 – 1.0mg/l. Most of the inorganic phosphorus was contributed by human wastes as a result of the human breakdown of proteins and elimination of the liberated phosphates in the urine *(Sawyer et al., 1994)*.

3.3 DETERGENTS

Detergents were developed just after World War 2 to replace soaps, which tended to form a scum of insoluble precipitates (the ring around the bathtub) in hard water. Detergents were non-biodegradable when first introduced, which led to mountains of foam on rivers, lakes and sewage treatment plants. The foaming problem was caused by the choice of surfactant. A surfactant is the ingredient in detergents that lowers the surface tension of water and allows dirt particles to be lifted from the soiled material, during washing. Biodegradable detergents were developed in 1965 by changing the surfactant but a new problem arose. Large phosphorus concentrations in detergents led to a further increase in phosphorus loading to treatment works and ultimately to watercourses, and stimulated algal growth. Enormous algal blooms resulted. Phosphorus is used in detergents to soften the water.

The phosphorus in detergents is usually in the form of sodium tripolyphosphate (STP), $Na_5P_3O_{10}$. When wash water containing this ingredient is discarded, the following reaction occurs and slowly releases the orthophosphate ion, PO_4^{3-}:

$$\underset{\text{Tripolyphosphate}}{P_3O_{10}^{5-}} \quad + \quad 2\,H_2O \;\rightarrow\; \underset{\text{Orthophosphate}}{3\,PO_4^{3-}} \quad + \quad 4H^+$$

Orthophosphate is the phosphorus form directly usable by plants, so it immediately begins to act as a fertiliser once released. Environmental concern over phosphorus effects has led to reductions in its use in detergents. In some countries, STP has been replaced by sodium nitrilotriacetate (NTA), but concerns for its safety are still unresolved and it is not used in the United States *(Masters, 1998)*.

Detergents, soaps and detergent builders are potential sources of organic pollutants contained in municipal sewage *(Manahan, 1990)*.

Soaps are the salts of higher fatty acids, stearic acid, $C_{17}H_{35}COOH$, which reacts with sodium hydroxide to form the salt, $C_{17}H_{35}COO^-Na^+$, known as sodium stearate. The cleaning action of soap results largely from its emulsifying power. This idea is understood by considering the dual nature of the soap anion. An examination of its structure shows that the stearate ion consists of an ionic carboxyl "head" and a long hydrocarbon "tail".

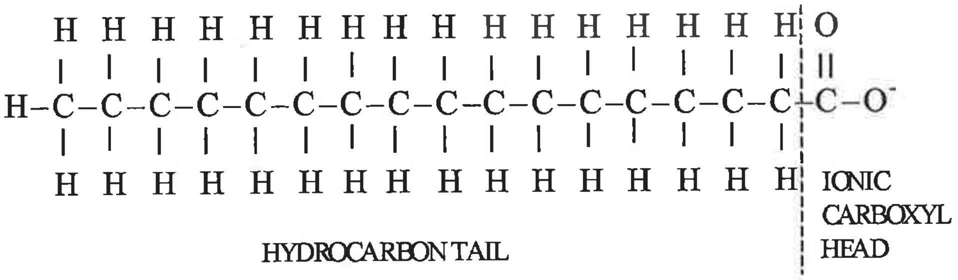


Figure 3.3: illustrates the stearate ion structure *(Manahan, 1990).*

In the presence of oils, fats and other water insoluble organic materials, the tail of the anion tends to dissolve in the organic matter, whereas the "head" remains in aqueous solution. The soap emulsifies or suspends organic material in water. Soap lowers the surface tension of the water *(Manahan, 1990).*

"The primary disadvantage of soap as a cleaning agent may be due to its reaction with divalent cations to form insoluble salts of fatty acids.

$$2C_{17}H_{35}COO^-Na^+ + Ca^{2+} \rightarrow Ca(C_{17}H_{35}CO_2)_2\,(s) + 2Na^+$$

The insoluble products such as salts of magnesium or calcium are not effective as cleaning agents and form unsightly deposits on clothing and washing machines. If sufficient soap is added all the divalent cations may be removed by their reaction with soap and the water containing excess soap will have good cleaning qualities. This approach is adopted when soap is used in the bathtub, where insoluble calcium and magnesium can be tolerated. However in applications such as clothes washing the water must be softened by the removal of calcium and magnesium or their complexions by substances such as polyphosphates" *(Manahan, 1997).*

Although calcium and magnesium salts formation has resulted in the elimination of soap as an agent for cleaning clothes, it has good environmental advantages. When soap gets into sewage it precipitates as calcium or magnesium salts. So environmental effects which soap might have are eliminated.

Synthetic detergents have good cleaning properties and do not form insoluble salts with "hardness ions" such as calcium and magnesium. These synthetic detergents have the additional advantage of being the salts of relatively strong acids which do not precipitate out of acidic waters as insoluble acids *(Manahan, 1997).*

Synthetic detergents usually have a surface-active agent or surfactant added to them to lower the surface tension of the water. When marketed 20 – 30% of the detergent are surfactants, the remaining 70 – 80% of materials are called building or bulking agents e.g. sodium sulphate, sodium tripolyphosphate, sodium pyrophosphate, and other materials which enhance the detergent properties of the active ingredients *(Sawyer et al., 1978).*

Until the 1960's the most common surfactant used was an alkyl benzene sulphonate, ABS which may be classed as an anionic surfactant. This surfactant is non-biodegradable and can be responsible for excess foaming at effluent out-fall points.

"The most objectionable use of non-biodegradable detergents was the foamy head that appeared in glasses of drinking water in areas where sewage was recycled through the domestic water supply. Other problems encountered were the formation of spectacular beds of foam at sewage treatment plants, where the entire activated sludge plant would be smothered in a blanket of foam" *(Manahan, 1997).*

Excessive foaming and other difficulties, resulting from the introduction of detergents into household washing and industrial cleaners, were particularly severe in the UK, and the development of remedial measures was carried out in the UK *(Symposium, 1961 and Eden et al., 1968).* The solution proved to be the replacement, in proprietary products, of the non-biodegradable "hard" components (mainly alkyl benzene sulphonates (ABS)) with "soft" detergents *(Cooper, 1998).*

Among other undesirable effects of ABS detergents upon wastewater treatment works were lowered surface tension of water, deflocculation of colloids, flotation of solids, emulsification of grease and oil, and destruction of useful bacteria. Consequently, ABS has been replaced by biodegradable LAS surfactant *(Manahan, 1997).*

LAS, α - benzene sulphonate, is a straight chain anionic detergent which is biodegradable with reduced foaming and are preferred over conventional anionic detergents.

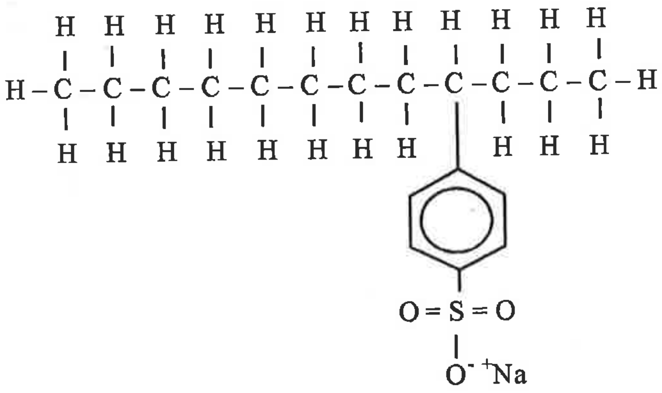


Figure 3.4: illustrates the LAS, α - benzene sulphonate structure *(Manahan, 1997).*

The benzene ring can be attached at any point along the alkyl chain except at the ends. LAS is not branched and does not contain the tertiary carbon which is so detrimental to biodegradability. Since ABS has been replaced by LAS problems arising from surface active agents in the detergents (such as toxicity to fish) have decreased along with the levels of surface-active agents found in water. Most of the later environmental problems associated with detergents have arisen from builders rather than surface-active agents *(Manahan, 1997).*

Most heavy-duty synthetic detergent formulations designed for the household market contain large amounts of polyphosphates as "builders". Many of them contain from 12 to 13 percent phosphorus or over 50 percent of polyphosphates. It is estimated from sales of polyphosphates to the detergent industry, that domestic wastewater contains two to three times as much inorganic phosphorus at the present time as it did before synthetic detergents became widely used. However, some local ordinances limit the use of phosphate based detergents *(Sawyer et al, 1994).*

Sewage treatment plants do not usually remove much phosphorus, so the simplest way to control releases is to reduce the amount of phosphorus reaching the facility in the first place, and the best way to do that is to limit the use of phosphorus in detergents.

The removal of phosphates from detergents has become a primary goal for environmental improvement. Polyphosphate substitutes are difficult to find. Precipitating builders such as sodium carbonate precipitate calcium as the carbonate. These insoluble products may deposit on clothing and make it stiff. Other detergent formulations are so basic that they pose a toxicological hazard *(Manahan, 1997).*

It is difficult to find detergent builders with performance qualities equal to those containing polyphosphates. Some may question whether the elimination of phosphates from detergents would materially reduce eutrophication. In efficient, properly operated sewage treatment works, phosphate removal is possible using a precipitating agent such as ferric sulphate. It is possible that phosphate removal by precipitation provides an addition fringe benefit through the co-precipitation of other undesirable impurities in water. The advantages of phosphate use in detergents may justify the expense of phosphate removal from wastewater *(Manahan, 1990)*.

3.3.1 Detergents and phosphate restrictions in Ireland

Domestic powder and liquid fabric washing products are by far the biggest single source of phosphates from detergents. Usage of phosphate based detergents in agriculture or industry is believed to be low. The domestic sector is accordingly the main sector for improvement. Changes beneficial to the environment have occurred in the use of phosphate detergent products over recent years.

These changes include:

- The reduction in phosphate content from about 35% to about 28%,
- Voluntary labelling to show the main ingredients, and
- Introduction of new ranges of phosphate-free concentrated powders; an estimated 12,000 tonnes (40% of total) of such products are now phosphate-free compared with none in 1988.

Despite these advances, the contribution of phosphate detergents to eutrophication warrants further attention. This matter is viewed as serious in many European countries which, as a consequence, have banned or restricted detergents containing phosphates.

The Department of the Environment will shortly conclude discussions with the Irish Detergent and Allied Products Association on the introduction of a voluntary agreement for reducing the phosphate content of detergents. In the absence of agreement, consideration will be given to the use of new statutory powers given under the Waste Management Act, 1996 *(Managing Ireland's Rivers and Lakes, 1997).*

There has been a steady increase in the sales of low phosphate detergents in the country as a whole. The micro-powders containing zeolites are to be preferred to those containing 30% phosphate – this information is clearly marked on the packets. Displays of low phosphate and phosphate free detergents have been provided at information meetings and their use widely advocated *(Lough Conn Progress Report, 1997).*

In areas, such as Lough Conn, there is a need for more households to switch to low phosphate or phosphate free detergents. All the major washing machine powders now have a large pack phosphate version and a smaller zeolite version. Unfortunately, there does not appear to be an equivalent available for dishwashers. Phosphate free detergents are also becoming more easily available.

The phosphate problems at Lough Conn are addressed as follows:

- It is important that everyone living in the catchment – whether attached to a public sewer or a private septic tank – should use low phosphate or phosphate free detergents in order to reduce the phosphate load to the lake.

- An ongoing education campaign is still required to emphasise the importance of maintaining septic tanks and reducing the phosphorus input to septic tanks. Controls are required on the disposal of sludge removed from septic tanks. There is still a large degree of uncertainty about the phosphorus contribution from rural septic tanks.

- Residential areas are not allowed within 100m of the lake and groups of new houses are excluded from a 400m band around the lake.

- New effluent treatment systems are being recommended for certain sites *(Lough Conn Progress Report, 1997)*.

3.3.2 Impact of phosphate detergent bans in other countries

One of the most successful actions taken to reduce the phosphorus load to the Chesapeake Bay in the USA, to reduce eutrophication was to ban phosphorus based detergents in the principal states of the watershed *(Randall, 1998)*. However, reports conducted at the Imperial College, London concluded that, before bans, only 10% of the phosphorus in municipal wastewaters is from detergents and that imposing a ban would not make a significant contribution toward the control of eutrophication *(Randall, 1998)*.

The problem is that the UK experience is different from the US one. A phosphorus detergent ban in Maryland resulted in an average influent phosphorus decrease of 32% to the wastewater treatment plants (WWTPs) serving the suburbs of Washington, D.C. *(Jones and Hubbard, 1986)*. There was also a decrease of 37% in the effluent discharges for all of the WWTPs in Maryland *(Maryland Water Management Administration, 1987)*. The latter was a comparison of the 1985 and 1986 data from the Maryland WWTPs, i.e., for the pre and post years of the ban. Some of the plants were practising chemical phosphorus removal before the ban, and their effluent reductions were small. There was an average effluent reduction of 43% for the WWTPs not practising phosphorus removal before the ban. Washington suburb plants that were practising chemical phosphorus removal before the ban had a 53 to 57% reduction in chemical usage after the ban. A phosphorus-based detergent ban in Washington, D.C. resulted in an influent phosphorus reduction of 26%, and a chemical reduction of 30% *(Jones and Hubbard, 1986)*. This was before a ban in Virginia, and the Virginia suburbs contribute a significant fraction of the wastewater to the Blue Plains WWTP. The Virginia phosphorus detergent ban, which went into effect January 1, 1988, resulted in a 31 % decrease in the influent total phosphorus (TP) concentration for a flow-weighted average of 37 plants receiving primarily municipal waste *(Virginia Water Control Board, 1988)*. The effluent TP decrease for 26 plants not practising phosphorus removal was 52 %, decreasing from 5.25 mg/l to 2.54 mg/l. The nine large WWTPs operated by the Hampton Roads Sanitation District (HRSD) averaged a 31 % reduction in the influent TP concentrations, and a 50 % decrease in effluent concentrations, from 5.31 to 2.64 mg/l, for the eight WWTPs not practising phosphorus removal. The HRSD York River WWTP was practising biological phosphorus removal both before and after the ban. The pre-ban effluent TP concentration averaged 2.3 mg/l, which was above the effluent requirements, and the post-ban effluent averaged 0.95 mg/l, which was well below the effluent requirement of 2.0 mg/l *(Randall, 1998)*.

3.4 MECHANISMS FOR PHOSPHORUS REMOVAL

The organisms involved in the biological processes of wastewater treatment all require phosphorus for reproduction and synthesis of new cell tissue. Domestic wastewater contains phosphorus far in excess of the amount needed to stabilise the limited quantity of organic matter present. This is demonstrated by the presence of appreciable amounts in effluents from biological wastewater treatment plants *(Sawyer et al, 1994).*

Only about 30 percent of the phosphorus in municipal wastewater is removed during conventional primary and biological treatment. Since phosphorus is very often the limiting nutrient, its removal from the waste stream is especially important when eutrophication is a problem *(Masters, 1998).*

Under some sewage plant-operating conditions, much greater than normal phosphorus removal has been observed. In such plants, characterised by high dissolved oxygen and high pH levels in the aeration tank, removal of 60-90% of the phosphorus has been attained, yielding two to three times the normal level of phosphorus in the sludge. In a conventionally operated aeration tank of an activated sludge plant, the CO_2 level is relatively high because the aeration rate is insufficient to sweep out sufficient dissolved carbon dioxide to bring its concentration down to low levels. Thus, the pH is generally low enough that phosphate is maintained primarily in the form of the $H_2PO_4^-$ ion. However, at a higher rate of aeration in relatively hard water, the CO_2 is swept out, the pH rises, and reactions such as the following occur:

$$5Ca^{2+} + 3HPO_4^{2-} + H_2O \rightarrow Ca_5OH(PO_4)_3\,(s) + 4H^+.$$

The precipitated hydroxyapatite or other form of calcium phosphate is incorporated in the sludge floc *(Manahan, 1993).*

Precipitant(s)	*Products*
$Ca(OH)_2$	$Ca_5OH(PO_4)_3$ (Hydroxyapatite)
$Ca(OH)_2 + NaF$	$Ca_5F(PO_4)_3$ (Fluorapatite)
$Al_2(SO_4)_3$	$AlPO_4$
$FeCl_3$	$FePO_4$
$MgSO_4$	$MgNH_4PO_4$

Table 3.1 illustrates Chemical precipitants for phosphate and their products *(Manahan, 1993).*

There are two principle methods employed for the removal of phosphorus:

1. Chemical removal, which is a one step process.
2. Biological removal, which is a one step process in alternating aerobic and anaerobic environments.

3.4.1 Chemical precipitation

Phosphorus in wastewater exists in many forms, but all of it, eventually, ends up as orthophosphate ($H_2PO_4^-$, HPO_4^{2-}, and PO_4^{3-}). Removal of phosphates can be accomplished by adding a coagulant, usually alum [$AL_2(SO_4)_3$], ferric [$Fe(Cl)_3$, $Fe_2(SO_4)_3$] or lime [$Ca(OH)_2$]. The pertinent reaction involving alum is:

$$AL_2(SO_4)_3 + 2PO_4^{3-} \rightarrow 2\,AlPO_4\downarrow + 3SO_4^{2-}$$

Alum is sometimes added to the aeration tank when the activated sludge process is being used, thus minimising the need for additional equipment *(Masters, 1998)*.

Chemical precipitation processes are capable of at least 90-95% phosphorus removal at reasonable cost. Lime, $Ca(OH)_2$, is a commonly used chemical for phosphorus removal:

$$5Ca(OH)_2 + 3HPO_4^{2-} \rightarrow Ca_5OH(PO_4)_3\,(s) + 3H_2O + 6OH^-.$$

Lime has the advantages of low cost and ease of regeneration. The efficiency with which phosphorus is removed by lime is not as high as would be predicted by the low solubility of hydroxyapatite, $Ca_5OH(PO_4)_3$. Some of the possible reasons for this are slow precipitation of $Ca_5OH(PO_4)_3$; formation of non-settling colloids; precipitation of calcium as $CaCO_3$ in certain pH ranges and the fact that phosphates may be present as condensed phosphates (polyphosphates) which form soluble complexes with calcium ion *(Manahan, 1993)*.

When lime is used as the calcium source, precipitation normally follows biological treatment. With alum or iron as the precipitant, treatment may be effected in the activated sludge operation itself or even in the primary clarifier *(Bailey and Ollis, 1986)*.

3.4.2 Biological phosphorus removal

Biological phosphorus removal is based on the idea of forcing the micro-organisms to accumulate more phosphorus than is necessary for cell growth. Typically, wastewater biomass has bacteria cells composed of mainly carbon (~50 percent), oxygen (~20 percent), nitrogen (~15 percent), hydrogen (~10 percent) and phosphorus (3 percent). In other words, there appears to be a limit to the amount of phosphorus that can be taken up by the bacteria *(Kiely, 1997)*.

Regulated standards for total phosphorus are at 1mg/l *(Urban wastewater Directive, 1991)*. Conventional treatment processes are inadequate to meet the standard so chemical precipitation of phosphorus was common until the development of biological P removal systems *(Kiely, 1997)*.

Biological phosphorus removal was noted by researchers in the USA in the 1950s *(Greenburg et al., 1955 and Srinath et al., 1959)*, but its extent appeared to be somewhat haphazard. This excess phosphorus removal referred to as "luxury uptake" was shown to be inhibited by the addition of 2-4 dinitrophenol, proving the process was biological *(Levin et al., 1965)*. It was noted that (a) all the plants which removed phosphorus were plug-flow plants which were operated to nitrify, and (b) all these plants experienced a release of phosphorus near the inlet zone where no dissolved oxygen could be detected *(Milbury, 1971)*. However, the requirements which are necessary to control the process were revealed by the work of Barnard in South Africa where, in his Daspoort pilot plant aimed at denitrification, he noticed phosphorus reductions from 8 mg/l to 0.2 mg/l *(Barnard, 1974 and Barnard, 1998)*. Removals were not consistent and, as Barnard realised, were good only when the release of phosphorus in the second anoxic zone was high and the concentration of the nitrate in the effluent was low. He noted that nitrate interfered with removal and it was necessary to have a zone free of oxygen and nitrates for phosphorus release, followed by an aerated zone to allow the uptake of phosphorus *(Barnard 1974 and Barnard, 1998)*. From these observations whole ranges of biological nutrient removal (BNR) processes have developed. Other researchers in South Africa *(Pitman, 1992 and Lotter, 1991)* developed biological phosphorus removal processes further. During the 1980s, these processes became accepted and are now to be found in many countries such as the Severn-Trent Water's Stratford-upon Avon plant in the UK *(Cooper et al., 1998)*.

3.4.3 Description of the Pho-Strip process

The PhoStrip process removes the phosphorus not in sludge form but in a phosphorus-rich supernatant, which can be later removed by chemical precipitation. Some of the waste activated sludge from the secondary clarifier is sent through an anaerobic phosphorus stripper with a retention time of 8 to 10 hours. The phosphorus is released in the supernatant while the phosphorus-poor sludge is returned to the aeration tank. The supernatant is chemically "post" precipitated with lime to produce sludge and a supernatant, which is returned to the aeration basin *(Kiely, 1997)*.

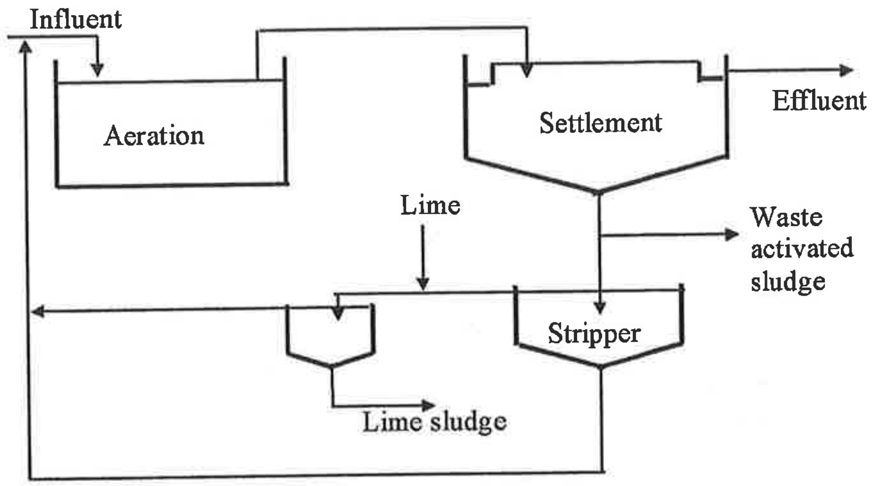


Figure 3.5: illustrates the Phostrip process *(Barnard, 1998)*.

In 1975, an important paper was published, proposing a theory for biological phosphorus removal in the Phostrip process *(Fuhs et al., 1975)*. It was proposed that a bacterial species *Acinetobacter* had the ability to store phosphorus within their cells as long chains of inorganic polyphosphate (Figure 3.6). They proposed that energy associated with the polyphosphate bonds could be used to take up short-chain fatty acids, especially acetic acid, in the absence of dissolved oxygen. By breaking the phosphate energy bonds, phosphorus is released to the liquid phase. The volatile fatty acids taken up in this way are stored as poly-β-hydroxybutyrate (PHB) until the organisms reach the aerobic zone of the process. Here they metabolise the poly-β-hydroxybutyrate and use the energy to take up the phosphorus released, plus all available phosphorus in the feed, and store it as energy rich polyphosphate chains. This in turn serves as the energy source for volatile fatty acid (VFA) uptake when the organisms return to the anaerobic zone. Removal of the organisms from the liquid phase in the secondary settlement tanks effectively removes the phosphorus from the sewage.

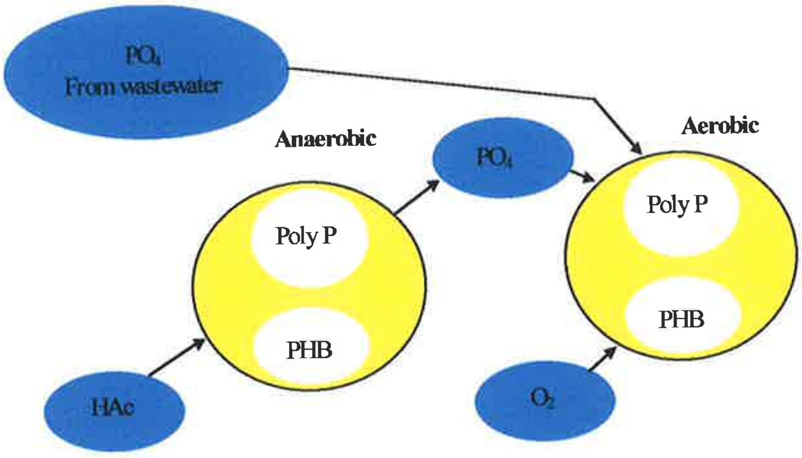


Figure 3.6: Biological phosphorus removal model proposed by Fuhs and Chen, 1975.

Other methods of stripping phosphorus from the organisms in the Phostrip process were investigated *(Fuhs et al., 1975)*. It was found, that bubbling CO_2 through, or adding a mineral acid to, activated sludge from a phosphorus removal plant resulted in the release of phosphorus. While this was relevant to the Phostrip process, the true meaning of this finding would only become apparent later *(Barnard, 1998)*. While monitoring the five-stage Bardenpho plant (Figure 3.7) at Randfontein, South Africa, it was noticed that there was a complete uptake of phosphorus at the end of the aeration basin with a release of phosphorus in the second anoxic zone *(Barnard, 1984)*. As a result of a high degree of simultaneous nitrification and denitrification in the aeration basin, there was no nitrate in the second anoxic zone. The findings that phosphorus could be released by blowing CO_2 through the sludge *(Fuhs et al., 1975)*, led to the conclusion that if the bio-P organisms are subjected to anaerobic conditions in the absence of VFAs, they will release phosphorus but there will be no uptake of phosphorus in the aerobic zone. This was referred to as "secondary release of phosphorus" *(Barnard, 1984)*. It was found that in most plants, which had difficulty in reducing the soluble phosphorus to very low concentrations, that such secondary release was taking place. It is possible that this may be the single most common reason for plants not being able to produce a soluble phosphorus concentration in the effluent as low as 0.1 mg/l *(Barnard, 1998)*.

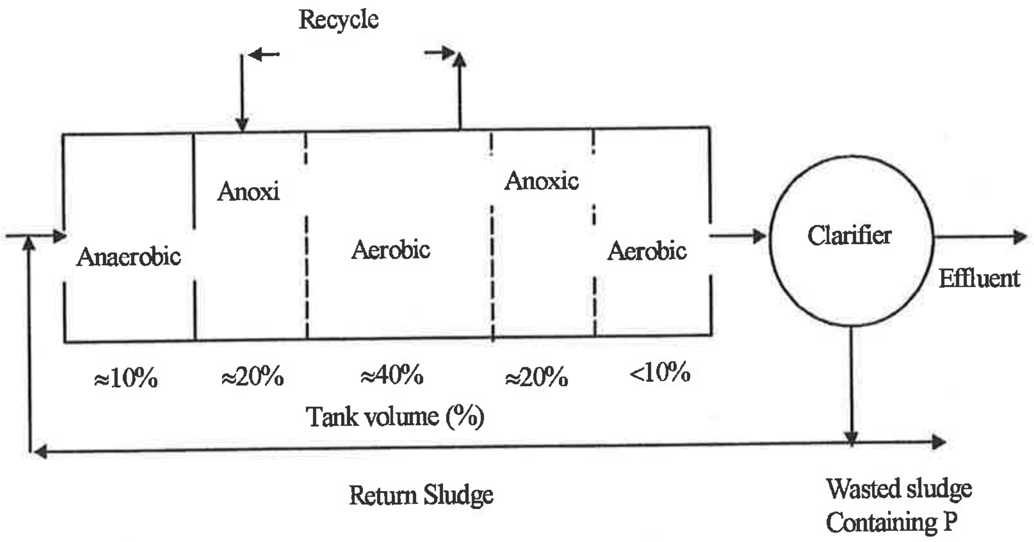


Figure 3.7: Modified Bardenpho process for nitrogen and phosphorus removal *(Kiely, 1997)*.

The use of culture dependent methods for identifying bacteria from activated sludge with enhanced biological phosphorus removal (EBPR) has strongly implicated *Acinetobacter* with the process. However, using fluorescent in-situ hybridisation (FISH) probing to analyse microbial populations, recent studies have shown evidence opposing this belief. Several bacteria are capable of bio-P removal. Of two sludge samples with extremely high P removal capabilities, FISH probing indicated that *Acinetobacter* made up only a small portion of the cells in both samples *(Raper and Swinton, 1997)*.

3.5 PHOSPHORUS REMOVAL IN A PILOT RBC PLANT

In a seven-week experimental program carried out on behalf of the Canadian Mortgage and Housing Corporation in 1980 the viability of phosphorus removal in a RBC system, by adding metal salts, was assessed. Using a four-stage, 2m-diameter commercial RBC unit, with $734m^2$ media area, raw degritted wastewater was fed at a constant hydraulic loading of 4.5×10^{-2} $m^3/m^2.d$. The average BOD_5 loading during the seven-week period was approximately 5kg total $BOD_5/1000$ $m^2.d$. During the first two weeks system performance was monitored with no chemical being added (control period). An alum solution was added continuously to the first stage of the four-stage RBC during the following two-week period. Ferric chloride solution was added for the last three-week period. An excess of metal ion was used in each case to ensure that insufficient chemical addition could not be blamed for poor phosphorus removals *(Murphy et al., 1980)*.

It was concluded that alum and ferric chloride could be added directly to a RBC with no net effect on treatment efficiencies and effluent quality, provided that proper attention is given to the design and operation of the final clarifier.

- Both the aluminium and ferric ions did not adversely affect the concentrations of BOD_5 (~20 mg/l) and NH_4-N (~1.4 mg/l) in the treated effluent.

- Effluent pH values became slightly lower during chemical addition because hydrolysis released hydrogen ions. However, the observed pH was in the range of 6 to 7, the optimum range for phosphorus precipitation when using iron or aluminium.

- Suspended solids determinations were made on treated RBC samples after 30 minutes of quiescent settling in an imhoff cone in addition to samples taken from the clarifier effluent. There was a significant increase in the suspended solids concentration in the settled effluent. Consistently lower suspended solids concentrations were observed in the final clarifier operated at a hydraulic loading of 0.6 m/h and a hydraulic detention time of two and a half hours.

3.5.1 Phosphorus removal

The phosphorus removal results are summarised in Table 3.2. One third to a half of the phosphorus in the raw wastewater was filterable; the remainder was associated with the suspended solids. Data from the control period shows that much of the particulate phosphorus was removed during normal treatment, but there was little change in filterable phosphorus. With chemical addition virtually complete removal of filterable phosphorus was observed. However, the corresponding removal efficiencies for total phosphorus were only 75 to 80%. During alum and ferric chloride treatment the average concentrations of total phosphorus in the settled effluent samples were 1.3 and 1.4 mg/l respectively. As a further 50% reduction in suspended solids was obtained in the pilot clarifier compared to settled samples, a similar reduction in particulate phosphorus would be expected.

		Total P			*Filterable P*		
Treatment	No. of Observations	Influent mg/l PO_4-P	Effluent (Settled)* mg/l PO_4-P	% removal	Influent mg/l PO_4-P	Effluent (Settled)* mg/l PO_4-P	% removal
Control	6	4.7	2.4	49	2.3	1.9	17
Alum	7	6.0	1.4	77	2.1	0.2	90
Ferric	8	5.5	1.3	76	2.6	0.2	92

Table 3.2: illustrates summary of phosphorus removal *(Murphy et al., 1980).*

Note * 30 minute settling test

There was no difference in phosphorus removal efficiencies between the alum and ferric chloride treatments. Effluent concentrations for both total and filterable P were consistent, and varied within relatively small ranges *(Murphy et al., 1980)*.

The chemical addition increased sludge production within the system. This increase was greater than stoichiometric predictions *(Murphy et al., 1980)*. However, the observed effects were consistent with those of chemical addition to suspended growth biological systems *(Sutton et al., 1977)*.

3.6 PHOPHORUS REMOVAL - RBC FOLLOWED BY REED BEDS

The two forms of phosphorus removal, biological and chemical, discussed require the direct involvement of an aerobic treatment system. However, another treatment option, which may be considered for nutrient phosphorus removal, is a reed bed system. This system does not necessitate the involvement of aerobic treatment to achieve removal of the phosphorus nutrient.

The principle of an aerobic treatment plant (RBC) followed by a reed bed system has been adopted at Hollymount in Co. Mayo. The treatment works is designed to treat wastewater, generated from 150-population equivalent, which is mainly domestic in origin. Since the treated effluent is discharged in to an adjoining river (the river Robe) the treated effluent requirements are stringent at 10mg/l BOD, 10mg/l suspended solids, 2mg/l total phosphorus and 15mg/l nitrogen.

The RBC unit is a modular configuration designed to produce a final effluent quality of 20mg/l BOD, 30mg/l suspended solids and 20mg/l NH_4-N. The reed bed system provides tertiary treatment, where the treated effluent from the RBC is passed over an area of reeds 16m x 10m.

The reeds are planted on a granular material approximately 0.5m deep with a 1.5mm thick polyethylene membrane (liner) placed underneath. The first two thirds of the reed bed system comprises of normal gravel, the latter third nearest the discharge point comprises of expanded fireclay grog (EFG). It has been claimed that EFG can optimise the nutrient removal (particularly phosphate removal) ability of the reed bed. Approximately 30 tonnes of EPG material was used at Hollymount.

The Hollymount scheme is considered as a major pilot study in Ireland as to whether the reed bed system can be successfully employed for effluent polishing and nutrient removal. However, analysis of test results carried out, by Mayo County Council, in 1995 and 1997 indicate that the 2mg/l total phosphorus standard is not being complied with. The reed bed system is reducing the phosphorus content in the effluent from the RBC unit by approximately 58%. The results for the month of October 1997 gave a reduction in total phosphorus averages of 34.1 mg/l from the RBC unit down to 14.1 mg/l from the reed bed system. The influent total phosphorus concentration was on average 47.3 mg/l, this would indicate that the RBC unit was achieving 28% total phosphorus removal. This result compares well with the suggestion by *Masters, 1998* that only about 30 percent of the phosphorus in municipal wastewater is removed during conventional primary and biological treatment.

Further analysis of the 1995 and 1997 results show that the combination of the RBC and reed bed system ensures compliance with the BOD and suspended solids requirements. The influent BOD concentration was on average 1045 mg/l, from 10 test results taken between the 21st June and the 27th September 1995, with corresponding treated effluent average values of 10 mg/l from the RBC unit and 5 mg/l from the reed bed. On no occasion did the final BOD values exceed the 10 mg/l standard. Over the same period the suspended solids concentrations averaged at 429 mg/l for the influent, 12 mg/l from the RBC unit and 4 mg/l from the reed bed. Results for the month of October 1997 also gave results well below the standards of 10 mg/l BOD and suspended solids concentrations.

Chapter 4

Equipment, materials and methods

4.1 THE TEST UNITS

Following on from the research work carried out at the University of Hertfordshire it was decided to build a staged RBC system. The staged RBC system gives increased nitrification capabilities. When the RBC contains discs set in stages, very efficient nitrification occurs in the latter stages after degradation of the organic carbon is virtually completed *(Antonie, 1974, Weng and Molof, 1974 and Boller et al., 1990).*

Shaft failure is a commonly reported problem with RBC systems (*Kiely, 1997*). This problem was addressed by incorporating a protective material (copper) over the steel shaft.

Other special features that were included in the design were adjustable weirs, which could be moved along the length of the RBC trough. The adjustment of these weirs allowed for a variation to be made to the number of discs in each stage. The shaft assembly was also split into two sections; the first section was approximately the length of the first stage. This section comprised of a hollow box section of steel (25mm outside measurement) and was connected to the second shaft by a circular steel (20mm diameter) bar.

The practical advantage of using this design is that the entire shaft would not have to be replaced in the event of one section failing. This is particularly advantageous for a full size RBC plant, as failure of a shaft on-site may involve removal of the unit from the ground. By moving the 20mm steel bar back or over between shafts 1 and 2 it was made possible to remove either shaft without requiring free space at either end of the unit.

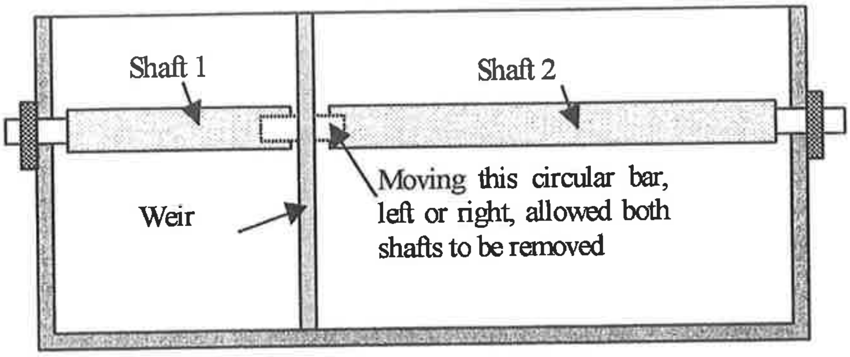


Figure 4.1: illustrates shaft assembly for the RBC unit.

The final design of the RBC Unit had the weirs sealed, with silicone, in place and all surfaces of the steel shaft were covered with copper tubing. The copper tubing also acted as a spacer between individual discs and stages.

4.1.1 Design aspects

Two pilot plants were constructed, one unit with aeration cups and the other an ordinary flat disc design. It is important, before constructing a pilot plant, that a scale down factor is justified so some correlation may be made to a full size plant.

4.1.2 Disc design of a full size RBC plant

1) Assume a design Population Equivalent (PE) = Six Persons.

2) Assume Organic Load = 55g BOD/Head/d (*E.U. Urban Wastewater Directive, 1991*).

3) Therefore the Total Organic Load = 6 x 55g ⇒ 330g BOD/d.

4) Thus the Disc area required is:

$$= \frac{330\text{g BOD/d}}{2.5\text{g BOD/m}^2\text{.d}}$$

(2.5g BOD/m/d manufacturers design organic loading rate required for nitrification.)

$\Rightarrow$ Area required = 132m^2.

5) Assuming a disc diameter of 2m:

$$\text{Area of disc} = \pi r^2 = 3.14(1)^2 \Rightarrow 3.14\text{m}^2$$

Giving a total area per Disc = 6.28m^2. (2 sides)

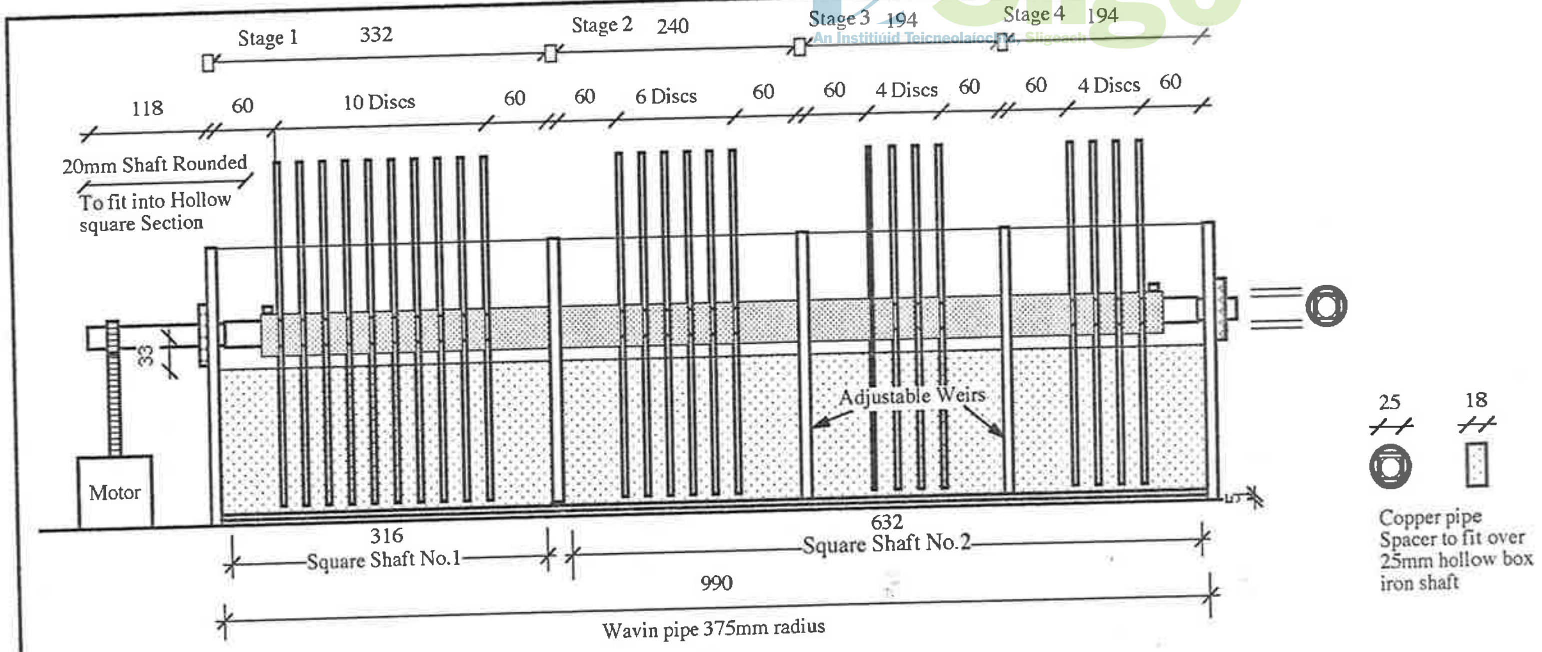
6) Number of Discs required:

$$\Rightarrow 132 \div 6.28 = 21 \text{ Discs.}$$

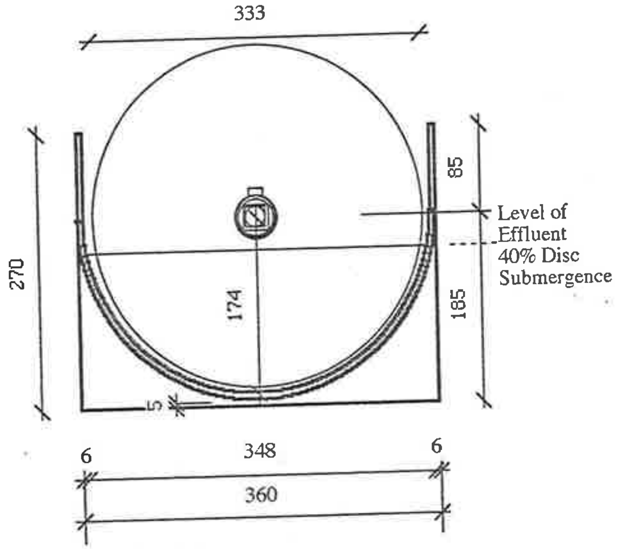
This is only a guide as to how conventional RBC disc design may be approached.

In the case of the pilot plant design 24 discs were used in each unit, the scale down factor of disc diameter was 1/6th i.e. from a 2m to 0.333m diameter disc.

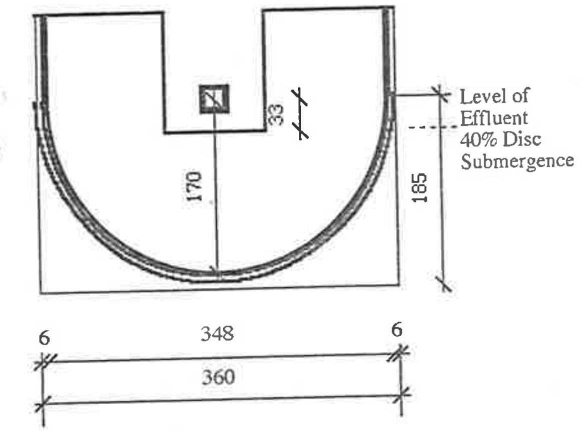
The difficulty with scale down of disc size in the RBC system is that the design organic loading is based on the provision of a specific area per gram of BOD to be removed. In effect a reduction in disc diameter of 1/6th will account for a reduction in area of 1/36th.



SECTIONAL ELEVATION OF ROTATING BIOLOGICAL CONTACTOR MODEL



SECTION THROUGH TROUGH



SECTION OF ADJUSTABLE WEIR

Notes:

ONE MODEL WITH CUPS
ONE MODEL WITHOUT CUPS
DISCS 5MM THICK
(POLYETHELENE)

ADJUSTABLE WEIRS AND
END SECTION MADE
FROM 10MM THICK
PERSPEX

Revision No. 4
Figure 4.2 (a)

Title:
R.B.C. Design

Designed By:
Patrick Cunningham B.Eng.

Client:
Sligo Institute of Technology
Ballinode, Sligo.

Scale 1:5
Date 19-3-99

Figure 4.2: illustrates the layout of the flat disc RBC system. The first stage consisted of 10 discs; the second stage had 6 discs and the third and fourth stages each had 4 discs. These high-density polyethylene discs were fixed at 40% submergence within the wastewater. The spacers, between each disc, were of copper tubing, which also acted as protection for the steel shaft. Rounded sections of steel were used at both ends of the unit to attach the shafts to bearings, which were in turn attached to 10mm thick perspex ends. Screws attached the perspex ends to a semicircular pipe section (355mm diameter) to form a containment trough for the wastewater. Weirs consisted of 10mm thick perspex sheets, which were sealed onto the 355mm-diameter pipe section. These weirs had a rectangular section cut out to allow the wastewater to flow from one stage to the next. The treated effluent flowed from stage four into an upward flow clarifier.

The difference between the flat disc unit and the modified RBC unit was that "aeration cups" were incorporated into the modified unit. A total of four aeration cups per disc were used. The cups were fabricated from a hollow spherical plastic ball divided in two. This hollow hemispherical ball was fitted into a groove cut through the perimeter of each disc. The positioning of the cups on the perimeter of the disc was of significance. When the rotating cup contacts the wastewater surface the optimum amount of oxygen must be imparted into the liquid. This was achieved by ensuring that the flat hemispherical cup surface contacted the wastewater perpendicular to its surface.

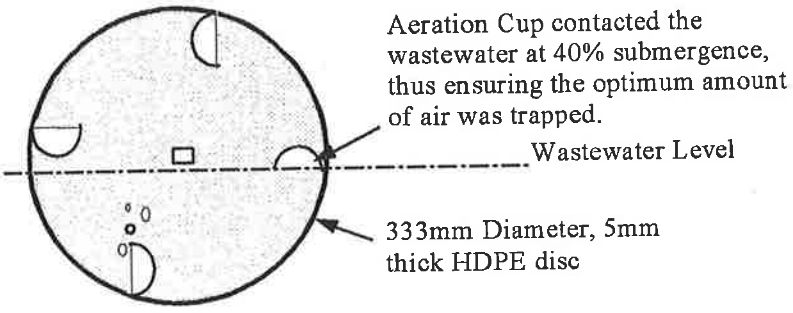


Figure 4.3: illustrates the aeration cup trapping oxygen.

This ensured that an entire hemisphere of air was imparted into the liquid phase. Other sources of oxygen transfer, by aeration cups, have also been identified *(McCann, 1993)*. The decision to use 4 aeration cups per disc is discussed in the initial test results section.

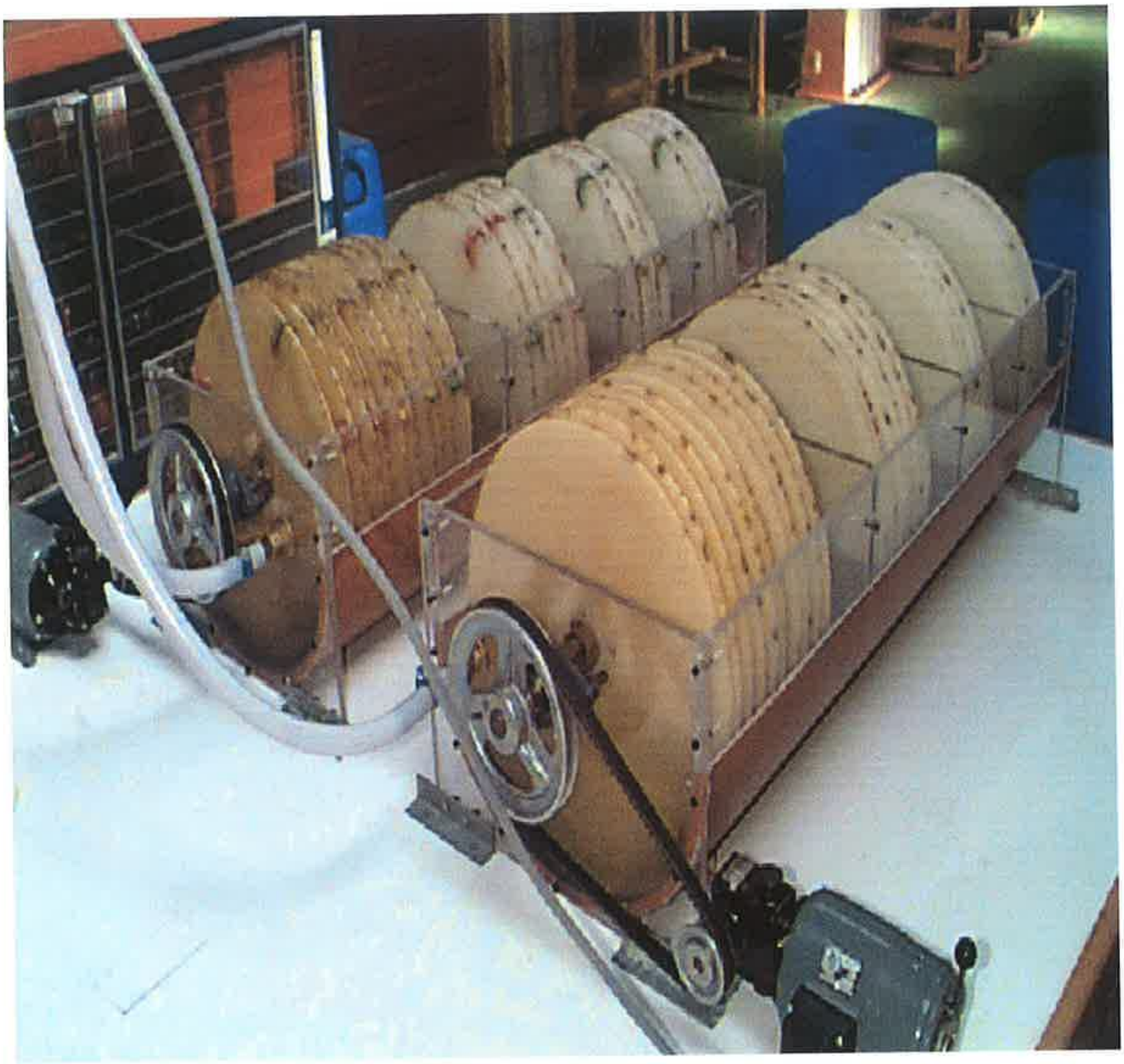


Plate 4.1: unit with aeration cups on left. Both units were driven by variable speed motors (Groschopp Motors, Micromotors Ltd, Galway) and pulley wheels.

4.2 SEEDING OF THE UNITS

To promote the development of a microbial population on the discs it was necessary to first seed both RBC units. The "seed" was returned activated sludge obtained from Strandhill Wastewater Treatment Plant. The treatment works treats mainly domestic wastewater. Soil was also collected, from the Institute grounds, mixed with water and allowed to settle. The settled supernatant was decanted and added to the RBCs to further ensure a diverse microbial population.

4.2.1 Synthetic wastewater

The major pollutant characteristics of raw domestic wastewater are dissolved and suspended solids which provide organic matter for microbial growth. In the absence of a suitable domestic or industrial wastewater feed the units were loaded with synthetic wastewater based on a recipe developed by the OECD, 1976, and still used for EU biodegradability testing *(Karsa et al., 1995).* The formulation for the synthetic sewage was modified by *Marriott, 1988* and is similar to that adopted by *Fryer, 1996.* The substance that was used to feed the micro-organisms was a mixture of nutrients, distilled water and other essential elements required for microbial growth.

The concentrated feed was made up as required. The demand on feed varied depending on whether a high strength influent was required or not. Stage 1 of the testing program involved the treatment of a synthetic domestic wastewater without the addition of any detergent. The stock synthetic feed was mainly made up of Lab-Lemco Broth^{TM} (contains mostly peptone which the main organic substance) as illustrated in table 4.1. The stock synthetic wastewater was prevented from decaying by adding 5M sulphuric acid. The acid reduced the pH of the stock feed from above 7 to below 5 and ensured complete dissolution of all constituents. As the testing progressed to Stage 2 the amount of Lab-Lemco Broth was decreased as detergent was added. However, the weight of Lab-Lemco Broth and detergent combined did not exceed 135g throughout Stage 2.

10 litre stock solution	*Stage1*	*Stage2*
	No detergent	10%detergent
Lab-Lemco Broth	135g	135g made up of 13.5g detergent + 121.5g Lab-Lemco Broth
NH_4Cl	81g	81g
K_2HPO_4	42g	42g
NaCl	10.5g	10.5g
$CaCl_2.2H_2O$	6g	6g
$MgSO_4.7H_2O$	3g	3g

Table 4.1: illustrates the constituents of the stock synthetic feed for Stage 1 testing. A 10% detergent concentration is indicated for Stage 2 (This concentration varied).

4.2.2 Start up procedure

After seeding of the RBC units different feeding and flow-rate regimes were established for each testing stage. The stock feed was fed at a constant flow-rate of 50ml/hr (1.2 l/d) from a sealed plastic tank to a mixing tank via a peristaltic pump. The stock feed was diluted down to the desired influent concentration by tap water from a header tank. The mixture of stock feed and dilution water was kept homogenised in the mixing tank by occasionally stirring with a Janke and Kunkel, IKA-WERK RW 20 DZM, stirrer. The influent from the mixing tank was controlled by gas valves and was maintained at 60, 120 and 180 l/d for Stage 1 and at 180 l/d for testing thereafter. The flow-rate was checked twice daily by use of a gap gauge. The wastewater flowed through each of the four-stage

RBC units into the upward flow clarifiers. These clarifiers were designed so as to provide a minimum of two hours quiescent settlement to the wastewater i.e. at the highest flow-rate of 180 l/d. Influent samples for analysis were taken from the pipe leading from the mixing tank to the RBC unit (X on diagram) and effluent samples were taken from the clarifier outlet pipe (Y on diagram).

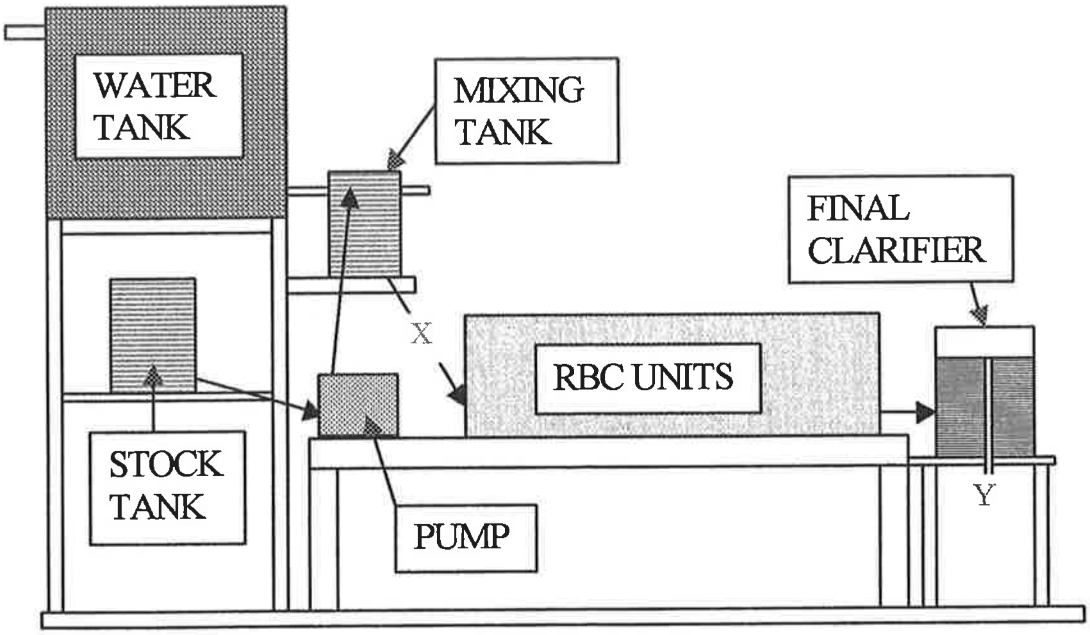


Figure 4.4: illustrating the flow through arrangement for both units.

4.3 CHEMICAL AND PHYSICAL ANALYSIS

4.3.1 Chemical Oxygen Demand (COD)

COD determination is a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical. If a waste sample contains only readily available organic bacterial food and no toxic matter, the results can be used to approximate the ultimate carbonaceous biochemical oxygen demand (BOD) values *(APHA-AWWA-WPCF, 1975)*.

The estimation of sample COD was obtained by using tubes containing digestion solution. This digestion solution was either purchased pre-prepared in tubes from HACH or prepared in the laboratory. The closed reflux, titrimetric method was used with COD vials prepared in the laboratory in accordance with the *Standard Methods, 1995.* These vials were used for analysis of COD results at Stage 1 only. Each 16 x 100mm-culture tube contained 1.5ml of potassium dichromate ($K_2CR_2O_7$) solution and 3.5ml of sulphuric acid reagent (COD acid). Mercuric sulphate was added to the $K_2CR_2O_7$ solution in the initial preparation to counteract the effects of chlorides in the samples.

The COD of the sample was determined by adding 2.5ml of the sample to the digestion solution, in the tube and sealing tightly. Each tube was inverted twice and placed in the COD reactor (Velp Scientifica ECO-16 digestion block heater) for 2 hours at 150^{0}C. After cooling to room temperature the contents of each tube were titrated against 0.1M ferrous ammonium sulphate using ferroin indicator.

The Molarity of the titrant was checked by, adding distilled water (blank) to a prepared COD tube followed by titration, and using the following formula:

$$\text{Molarity of FAS solution} = \frac{\text{Volume } 0.0167\text{M } K_2CR_2O_7 \text{ solution titrated, mL}}{\text{Volume FAS used in titration, mL}} \times 0.10$$

The COD was calculated using the formula:

$$\text{COD as mg } O_2/\text{L} = \frac{(A - B) \times M \times 8000}{\text{mL Sample}} \qquad \textit{(Standard Methods, 1995).}$$

Where:

A = mL FAS used for blank

B = mL FAS used for sample, and

M = molarity of FAS.

For testing subsequent to Stage 1 the pre-prepared COD vials were purchased from HACH (Celtic Engineering, Dublin agents for Chaussee de Namur 1, B-5150 Floriffoux, Belgium). These vials catered for high range (0-1500 mg/L) and low range (0-150 mg/L) COD values. The COD tests were carried out in accordance with the supplier's HACH manual *(HACH Water analysis handbook, 1997).* A 2ml sample was pipetted into the vial, which was sealed and shaken, before being placed on the digestion-heating block, at 150^0C for 2 hours. Samples were then allowed to cool to room temperature. A HACH DR2000 spectrophotometer was used to analyse each sample, following the manufacturer's instructions at all times. A wavelength of 420nm was used for the low range vials, while a 620nm wavelength was used for high range vials.

4.3.2 Biochemical Oxygen Demand (BOD)

The BOD test is used to determine the relative oxygen requirements of wastewater, effluent and polluted water. It is a measure of the amount of oxygen used by micro-organisms in the degradation of organic matter.

BOD testing was carried out in accordance with the *Standard Methods, 1995*. The 5-day BOD test was adopted (Method 5210 B). Duplicate diluted samples were filled, to overflowing, in 300mL bottles and made airtight. One of each duplicate sample was placed in an incubator for 5 days at 20^0C, the other had its dissolved oxygen (DO) content determined as soon as possible after taking the sample (the time did not exceed 2 hours). The DO of each sample was obtained by using the azide modification of the iodometric method (Section 4500-O.C, *Standard Methods, 1995*). The BOD analysis was not carried out as frequently as the COD analysis. The main reason for doing BOD analysis was to try to establish a correlation between BOD and COD. Calculation of BOD (dilution water was not seeded):

$$BOD_5\text{, mg/L} = \frac{D_1 - D_2}{P}$$ *(Standard Methods, 1995).*

Where: D_1 = DO of diluted sample immediately after preparation, mg/L,

D2 = DO of diluted sample after 5 d incubation at 20^0C, mg/L,

P = Decimal volumetric fraction of sample used.

4.3.3 Nitrates (NO_3 -N)

Tests for nitrates were carried out using the HACH DR2000 spectrophotometer and Nitra-Ver 5 Nitrate reagent powder pillows. A powder pillow was added to a 25ml sample with an initial mixing period of 1-minute being used. The samples were then left to stand for 5 minutes after which they were analysed in the spectrophotometer at a wavelength of 400nm. The degree of mixing in the 1-minute period can be subjective and if over mixing is used higher reading will be given. This method was standardised against a standard method to ensure more accurate results were obtained. The standard method adopted, involved using the nitrate electrode method (Section 4500-NO_3 –D).

4.3.4 Phosphorus

Phosphorus analyses embody two procedural steps: (a) conversion of the phosphorus form of interest to dissolved orthophosphate, and (b) colorimetric determination of dissolved orthophosphate.

Phosphates that respond to colorimetric tests without preliminary hydrolysis or oxidative digestion of the sample are termed "reactive phosphorus". While reactive phosphorus is largely a measure of orthophosphates, a small fraction of any condensed phosphate present usually is hydrolysed unavoidably in the procedure.

Acid hydrolysis at boiling water temperature converts dissolved and particulate condensed phosphates to dissolved orthophosphate. The hydrolysis unavoidably releases some phosphates from organic compounds. The term "acid-hydrolysable phosphorus" is preferred over "condensed phosphate" for this fraction.

The phosphate fractions that are converted to orthophosphate, only by oxidation destruction of the organic matter present, are considered "organic" or "organically bound" phosphorus. Like reactive phosphorus and acid-hydrolysable phosphorus, organic phosphorus occurs in the dissolved and suspended fractions.

The total phosphorus as well as the dissolved and suspended phosphorus fractions each may be divided analytically into the three chemical types that have been described: reactive, acid-hydrolysable, and organic phosphorus.

Both reactive and total phosphorus methods were employed for analysis of wastewater samples from the RBC units.

4.3.4.(a) Reactive Phosphorus (PO_4^{3-})

Tests for reactive phosphorus were carried out using the amino acid method from the HACH handbook adapted from the *Standard Methods (HACH Water analysis handbook, 1997).* To each 25ml sample in a graduated cylinder 1-mL of molybdate reagent and 1-mL of amino acid reagent was mixed. After a 10-minute reaction period the samples were analysed in a HACH DR2000 spectrophotometer at a wavelength of 530nm.

4.3.4.(b) Total phosphorus

Tests for total phosphorus were performed using the acid persulphate digestion method from the HACH handbook adapted from the *Standard Methods (HACH Water analysis handbook, 1997).* To each 25-mL sample, in a 50-mL Erlenmeyer flask, one potassium persulphate powder pillow and 2-mL of 5.25 N sulphuric acid was added. The samples were then boiled gently for 30-minutes and allowed to cool to room temperature, after which 2-mL of 5.0 N sodium hydroxide was added. The sample was returned to a 25-mL volume, where a reactive phosphorus test was then performed i.e. the amino acid test.

4.3.5 Dissolved Oxygen (DO)

The DO levels at each stage within the RBC units were determined on a daily basis using an industrial DO probe and meter (Jenway, 9090-supplied by AGB scientific, Dublin). The DO probe was stored and calibrated according to the manufacturer specifications.

4.3.6 pH

Daily pH readings were recorded at each stage within the RBC units, using a hand held probe (WPA CD70 pH meter). The probe was standardised at least once a week.

4.3.7 Temperature

The temperature of the wastewater was recorded daily using a glass-mercury thermometer.

4.3.8 Suspended solids

Suspended solids are the residual left on filter paper after sample filtration. The test was carried out in accordance with section 2540 D of the *Standard Methods, 1995*. Measured samples were passed through a pre-wetted filter. Filters were dried at 103°C for a minimum of 1-hour until dry weight differences were negligible. This method was only adopted for a short period of time at Stage 1, as low suspended solids concentrations were measured in the test samples throughout the study. The suspended solids fraction was calculated using the formula:

$$\text{mg total suspended solids / l} = \frac{(A-B) \times 1000}{\text{sample volume, ml}} \quad \text{(Standard Methods, 1995)}$$

Where: A = Weight of filter + dried residual, mg, and

B = Weight of filter, mg

4.3.9 Microscopic analysis

An optical microscope with a camera attached was used to observe the predominant micro-organisms present in the biofilm. The direct sampling procedure was adopted, for both RBC models, due to ease of assess to any area of disc.

4.3.10 Power consumption

The power requirements of each of the motors were recorded using a multimeter.

Chapter 5

Results and observations

5.1 DETERMINATION OF NUMBER OF CUPS/DISC

The decision to use four cups per disc was based on methods adopted by *McCann, 1993*. In order to assess the most efficient aeration cup arrangement, the Dissolved Oxygen (DO) was removed from a water sample, contained in a prefabricated trough with a three disc RBC unit installed, and the time was then recorded to reach 90% DO saturation concentration. The oxygen was removed (or brought below 1mg/l Conc.) from the water by adding sodium sulphite. Cobaltous chloride was also added to act as a catalyst. DO concentrations were measured by inserting a DO probe (Syland 2000) into the prefabricated disc unit and trough holding six litres of water. Under the various test conditions, 95g/m^3 Sodium Sulphite and 9.5g/m^3 cobaltous chloride were added to the water sample *(Standard Methods, 1976)*. Using the six-litre trough 0.54g of Sodium Sulphite and 0.054g of cobaltous chloride were added per test.

Three different design aspects were tested using three discs with four, five and six aeration cups (cup diameter of 36mm) attached for the respective tests.

The first test had four cups attached to each of the three 333mm diameter discs. Five operational speeds were used in the first test, 3.3, 5, 7.5, 10 and 12 revolutions per minute (RPM). The second test had five aeration cups attached to each of the three 333mm diameter discs. Four operational speeds were used in this test 5, 7.5, 10 and 12 RPM. The third and final test had six aeration cups attached to each of the three 333mm diameter discs. Four operational speeds were used in this test 5, 7.5, 10 and 12 RPM. The temperature and times taken to reach 90% DO saturation were recorded for all three tests the results of which are shown in Appendix 1.

5.2 DETERMINATION OF OXYGEN TRANSFER COEFFICIENT K_La

The oxygen transfer coefficient K_La can be determined by using the following equation:

$$K_La = \frac{\text{Ln}\,(Cs - C_1) - \text{Ln}\,(Cs - C_2)}{t_2 - t_1}$$

(Standard Methods, 1976)

Where:

K_La = oxygen transfer coefficient, l/hour.

Cs = Saturation concentration of gas in solution (at a certain temperature), mg/l.

C_1 = DO Concentration after addition of chemicals (below 1mg/l), at time t_1.

C_2 = 90% of Cs (temperature dependent) mg/l, at time t_2.

t_1 = Time at start of experiment i.e. when DO levels start to rise, min.

t_2 = Time at end of experiment (when 90% DO saturation is reached), min.

The K_La values obtained from the experiment carried out with the four, five and six aeration cups attached are presented in table 5.1.

	4 Cups / Disc	*5 Cups / Disc*	*6 Cups / Disc*
RPM	K_La (litres/hour)	K_La (litres/hour)	K_La (litres/hour)
12	7.05	7.66	9.2
10	4.6	6.0	6.7
7.5	3.73	5.3	5.3
5.0	2.88	2.82	3.68
3.3	1.79		

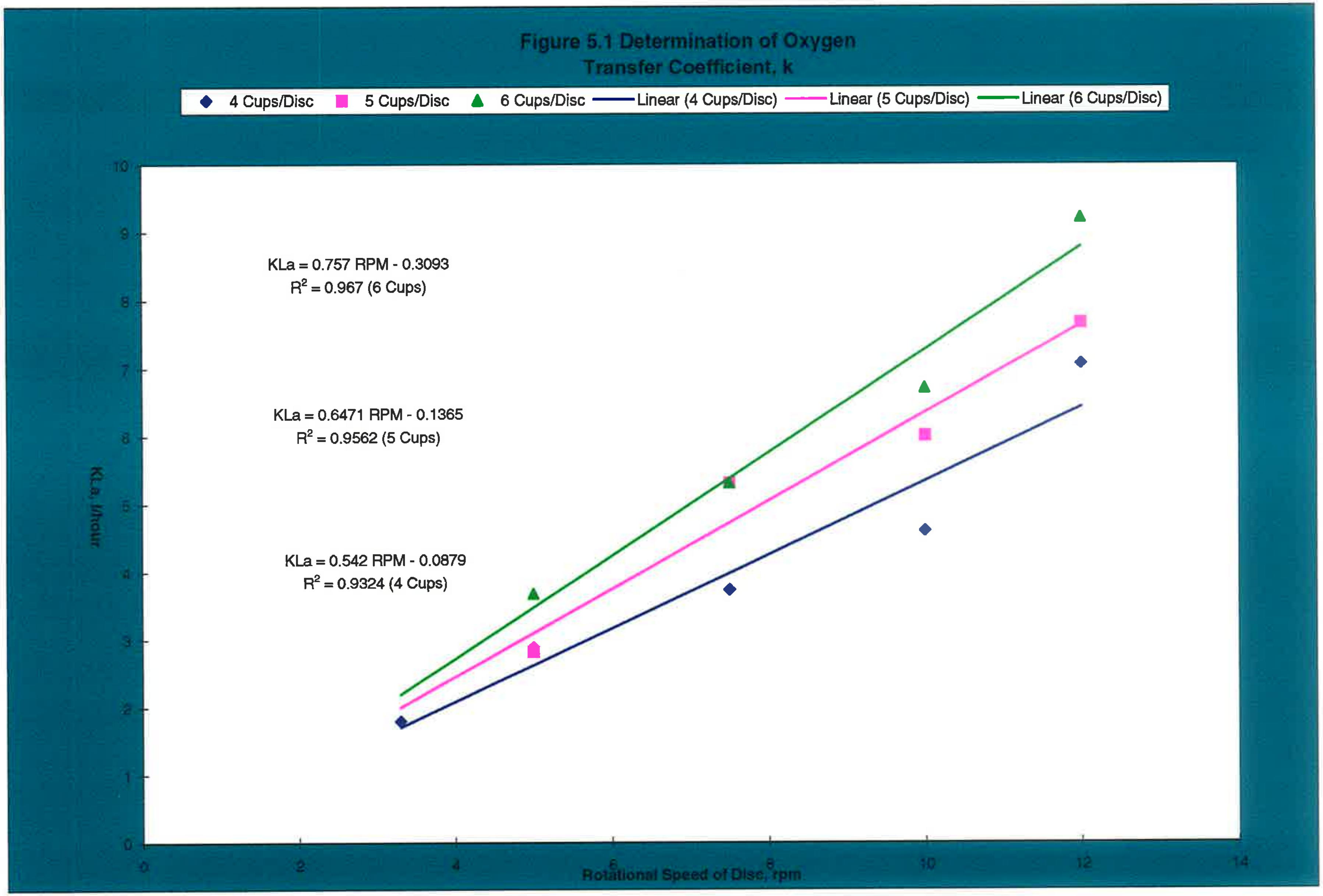


Figure 5.1 Determination of Oxygen Transfer Coefficient, k

5.2.1 Regression analysis of K_La plotted against disc speed

By plotting a graph of disc rotational speed against K_La and carrying out a linear regression analysis, the slope of the best-fit line gives a value for the slope, k. This slope "k" is a measure of the oxygen transfer efficiency of each cup arrangement at varying disc speeds. The k values, along with the relationship between K_La and disc speed for each test case is shown in figure 5.1,

Where:

$$K_{La} = k.\ RPM + \text{Constant.}$$

and RPM= disc speed in revolutions per minute.

The most efficient cup arrangement could be determined as the one with the highest k to volume of air ratio.

The volume of air for each test condition can be calculated as follows:

$$\text{The volume of hemisphere} = {}^2/_3\ \pi r^3\ \text{(Cup section entraining air)}$$

Where: r = 18mm.

$$\text{Volume of hemisphere (Cup)} = {}^2/_3\ \pi(0.018)^3$$

$$\Rightarrow 0.0122\ \text{litres of air per Cup}$$

The aeration cup was fitted into a groove in each disc, so it was necessary to subtract the cup volume space taken up by each 5mm thick disc.

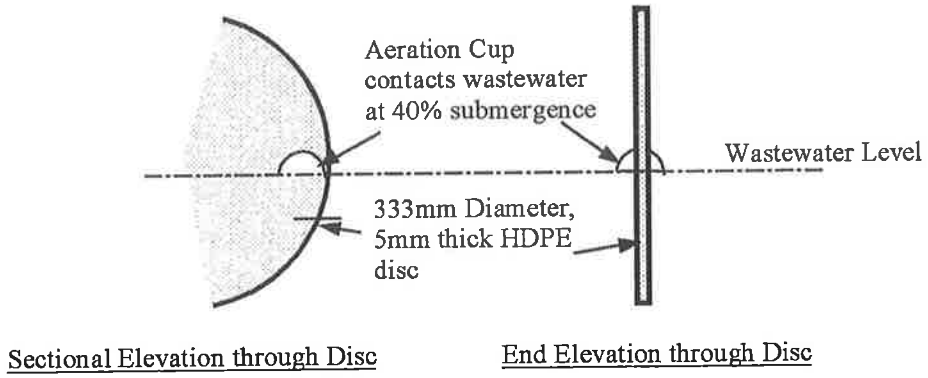


Figure 5.2 illustrates the aeration cup attached to a Disc.

The amount of cup volume lost to each disc:

Area of disc space in aeration cup = $^1/_2\ \pi r^2$ (where r = 18mm)

Volume of disc space in aeration cup = $^1/_2\ \pi r^2$ x 5mm thick disc.

$\Rightarrow$ Volume = $^1/_2\ \pi(0.018)^2 \times 5$

$\Rightarrow$ Volume = 0.0025 litres/aeration cup.

The volume of air imparted into the liquid volume by each cup is given by:

V_a/Cup = 0.0122 – 0.0025 = 0.00966 litres of air/cup.

The volume of air for each cup arrangement used in the aeration experiment is shown in table 5.2 below.

	V_a / Disc (litres)	V_a / 3 Discs (used in experiment)
4 Cups	0.0386	0.116
5 Cups	0.0483	0.145
6 Cups	0.058	0.174

Table 5.2: shows the volume of air imparted into the water for initial aeration tests.

It is now possible to establish a relationship between the Volume of air (V_a) and the oxygen transfer coefficient, k. This relationship can be described as the oxygen transfer constant per total cup volume, K_b. The results for the K_b constant plus all the graphical results, figure 5.1, obtained from the initial aeration tests are presented in table 5.3.

Cup Diameter	Cup No.	V_a, l	k	Constant	R-Square	K_b
36mm	4	0.116	0.543	-0.0879	0.9324	4.68
	5	0.145	0.647	-0.1365	0.9562	4.46
	6	0.174	0.757	-0.3093	0.967	4.35

Table 5.3: showing among other details the K_b constant (k/V_a ratio).

The cup arrangement with the highest k/V_a ratio or K_b constant is the most efficient i.e. with the 4 aeration cups /disc. The K_b constant or oxygen transfer constant per total cup volume = 4.68 for the 4 cups / disc, as opposed to 4.46 for the 5 cups / disc and 4.35 for the 6 cups / disc arrangements.

The oxygen transfer coefficient K_La, for 4 cups / disc:

$$K_La = k.\ RPM + Constant.$$

$$\Rightarrow K_La = 0.542\ RPM - 0.0879.$$

The oxygen transfer coefficient K_La, for 5 cups / disc:

$$K_La = k.\ RPM + Constant.$$

$$\Rightarrow K_La = 0.6471\ RPM - 0.1365.$$

The oxygen transfer coefficient K_La, for 6 cups / disc:

$$K_La = k.\ RPM + Constant.$$

$$\Rightarrow K_La = 0.757\ RPM - 0.3093.$$

It was decided to use the 4 aeration cups /disc arrangement as the highest k/V_a ratio or K_b constant is obtained, which implies that it is the most efficient oxygen transfer system.

5.2.2 Physical factor affecting oxygen transfer coefficient, K_{La}

Fick's first law of diffusion was developed to obtain a relationship between the rate of change of DO concentration, $^{dc}/_{dt}$ and O_2 deficit, Cs – C in aeration systems *(Benefield and Randall, 1980)*. This is expressed as:

$$K_La = \frac{D_L \, . \, A}{Y_F \, . \, V}$$

K_L = liquid phase mass transfer coefficient.

a = specific surface, (A/V).

D_L = diffusivity constant, m^2/hr.

A = cross sectional area of constant (interfacial area), m^2.

V = volume of liquid phase, m^3.

Y_F = thickness of liquid film, m.

Any factor affecting these parameters affects the overall oxygen transfer coefficient K_La.

Benefield and Randall, 1980 suggest such factors as:

1) Oxygen saturation.

2) Temperature.

3) Wastewater characteristics.

4) Degree of turbulence.

For the initial aeration tests carried out the affects of each factor were assessed.

1) Oxygen saturation: this factor can be eliminated since the liquid under consideration was tap water and the depth below aeration was insignificant.

2) Temperature: this factor can also be ignored as the actual test temperature was used in the calculation of Cs, which yields a K_La value independent of temperature.

3) Wastewater characteristics: surface-active agents in wastewater can increase the resistance to oxygen transfer and reduce the K_La value. As tap water was the liquid aerated this effect can be ignored.

4) Degree of turbulence: surface active agents were not present in the tap water so the rate of diffusion will not decrease from the theoretical, so the factor relating the K_La value of wastewater to tap water becomes unity.

Analysis of the K_La diffusion formula indicates that increased agitation will reduce the liquid film thickness, which will increase the K_La value. Also an increase in the A/V ratio or specific surface of the entrained air bubbles during aeration will further increase the K_La value.

There are three ways to create interfacial area between a liquid and gas (*Winkler, 1981*).

1) Liquid dispersal in gaseous form by spraying or in droplet form.

2) Gas can be dispersed to the liquid in the form of bubbles.

3) A solid packing material's surface can be wetted with the liquid and the gas drawn over this surface.

All three methods are employed when aeration cups are used. The conventional flat disc unit is more limited relying almost solely on the third method for dissolution of oxygen.

5.3 METHODS OF OXYGEN TRANSFER

5.3.1 Flat disc conventional model

There are three main sources of oxygen transfer to a liquid when operating a conventional flat disc unit *(McCann, 1993)*.

1. Shearing between the disc/water interface produces localised entrainment of air by means of oxygen being drawn into the water during rotation.

2. The rotation of the disc through the water creates a current resulting in surface undulations of low amplitude, which disturbs the liquid film at the surface and induces the process of oxygenation of the liquid.

3. Water adheres to the disc surface during rotation out of the liquid phase and becomes oxygenated when in contact with the air until its subsequent return to the liquid phase below.

These sources of oxygen transfer to the liquid have an increased influence with increased rotational speed.

5.3.2 Modified RBC model with aeration cups attached

There are six main sources of oxygen transfer to a liquid when operating the modified disc unit *(McCann, 1993)*.

1. Shearing between the disc/water interface produces localised entrainment of air, as with a conventional model.

2. Surface undulations, causing air entrapment, are produced by disc rotation through the liquid. These undulations increase the surface area, in contact with the air, of the

liquid film and induce oxygen into the liquid. Higher amplitude waves are also produced when aeration cups are attached. These waves disturb the surface enough to cause a direct entrainment of oxygen into the liquid.

3. The cups pushing into the liquid and displacing the liquid during the subsequent rotation through the trough cause aeration due to turbulence. As the cups rotate the displaced liquid moves rapidly to the surface and turbulence occurs at the surface. When the cups rotate out of the liquid they trap a volume of liquid equivalent to the air volume and lift it into the air phase. This displaced liquid in turn causes turbulence at the liquid surface as the void left by the cupped volume of liquid is filled by liquid pushed up from below.

4. Bubble aeration is induced into the liquid by the revolving cups trapping air and gradually releasing it into the liquid. Oxygen is transferred from the rising bubbles into the liquid, the amount of which is related to the velocity of rise and bubble diameter.

5. As the cups rotate out of the liquid they trap a volume of liquid and as the disc rotates further the liquid pours gradually from the cups, either directly onto the liquid surface or down the adjacent discs. The liquid tends to wash over the disc surface before returning to the trough. Both pouring and washing effects entrain air into the system.

6. The rotation also induces the adherence of water from the trough liquid onto the disc surface during the air phase, similar to a conventional flat disc system. The liquid comes in contact with oxygen during the air phase of rotation, resulting in oxygen transfer to the liquid.

5.4 STAGE 1 TEST RESULTS

In Stage 1- the main parameters that were varied were the hydraulic loading rate and hence the organic loading rate, the stock feed pumping was also varied. The three hydraulic flow-rates applied to each unit were 60, 120 and 180 l/d. The period of operation for each flow-rate is highlighted in Table 5.4, together with the corresponding hydraulic retention times.

Hydraulic flow-rate	*Period of operation*	*Hydraulic retention time*
60 litres/day	23 May to 15 June	12 hrs 41 minutes
120 litres/day	15 June to 27 July	6 hrs 20 minutes
180 litres/day	27 July to 6 October	4 hrs 14 minutes

Table 5.4: illustrates the parameters varied for Stage 1.

5.4.1 Influent chemical oxygen demand concentrations

Figure 5.2 shows the average influent COD concentration to both units, with standard deviations, for each hydraulic flow-rate. The final effluent values are also plotted on figure 5.2.

- At a hydraulic flow-rate of 60 l/d to each unit the average influent COD concentration was 543 mg/l with a standard deviation of 56 mg/l. The standard deviation is relatively high which is attributable to start up problems such as pipe blockages etc.

- At a hydraulic flow-rate of 120 l/d to each unit the average influent COD concentration was 275 mg/l with a standard deviation of 18 mg/l, from the 15 June until the 3 July. From the 3 July until 27 July the influent COD concentration was 143 mg/l with a standard deviation of 28 mg/l.

- At a hydraulic flow-rate of 180 l/d to each unit the average influent COD concentration, from the 27 July until the 17 August, was 102 mg/l with a standard deviation of 36 mg/l. A 5% detergent concentration was added to the influent feed from the 18 August to 2 September. However this practice ceased as further testing was deemed necessary at a higher organic loading rate, without detergent addition. The results for the period of time when the detergent was added are disregarded. On the 3 September the feeding regime was reverted back to a case where no detergent was added. The average influent COD concentration, from the 3 September until the 2 October, was 138 mg/l with a standard deviation of 36 mg/l.

5.4.2 Steady state operation

For the purpose of assessment of the final COD effluent values the results at steady state of operation are of the greatest importance. Many approaches have been adopted to ascertain when steady state has been achieved e.g. when the plot of [(COD at day$_n$ – COD at day$_{n+1}$)/COD at day$_n$)] against time changes from a rising trend to a horizontal trend line above the zero value *(Surgeoner, 1998)*. Another approach is when consecutive results are within ±3% over consecutive days *(McCann, 1993)*. In this case steady state is deemed to occur when the standard deviation of results is not greater than 10 mg/l.

Figure 5.3 shows the treated effluent COD values for both RBC units. From general observation of the results, taken either individually or using the 2 point moving average system, the unit with the aeration cups attached gives a higher quality final effluent.

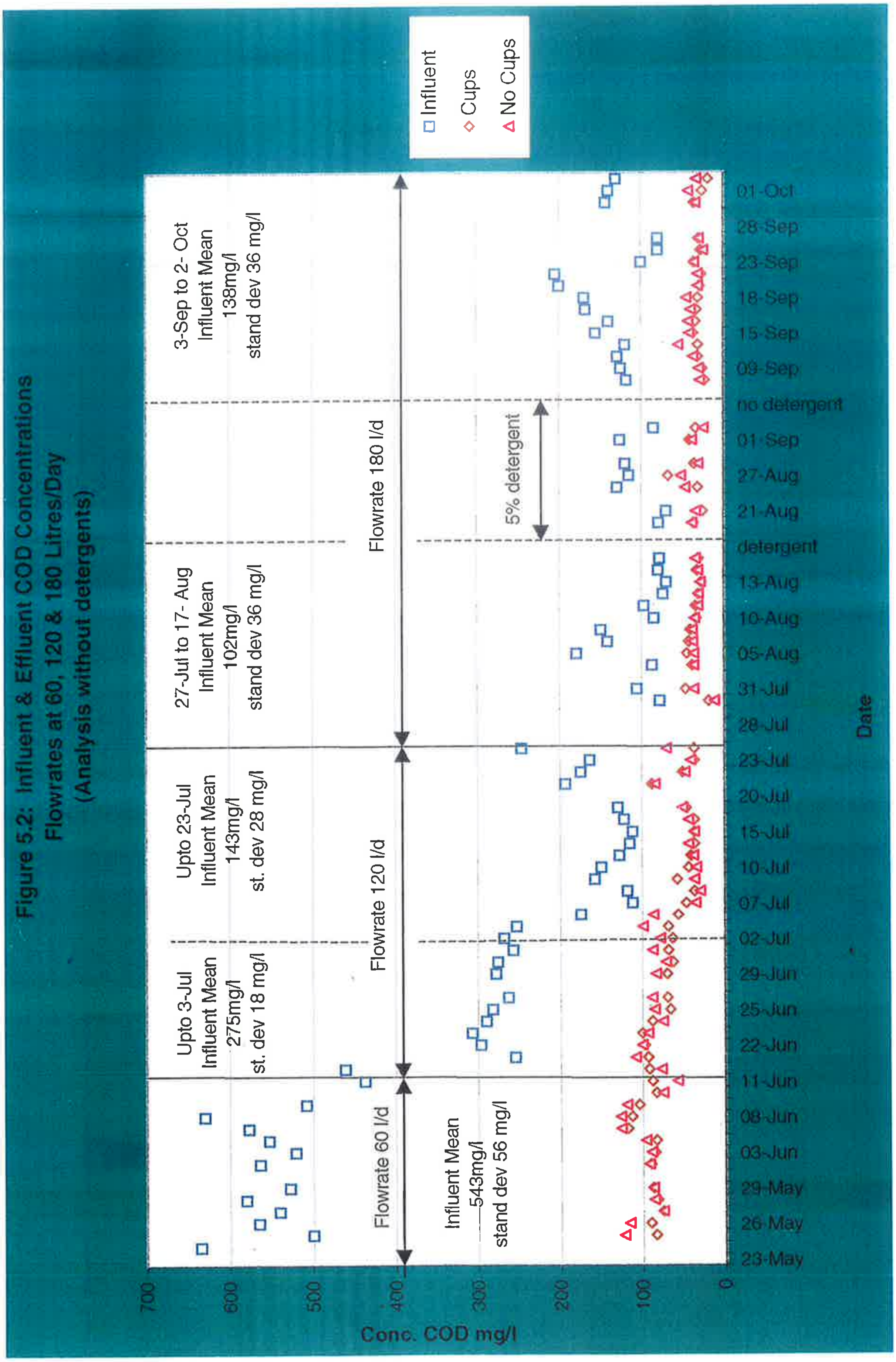


Figure 5.2: Influent & Effluent COD Concentrations Flowrates at 60, 120 & 180 Litres/Day (Analysis without detergents)

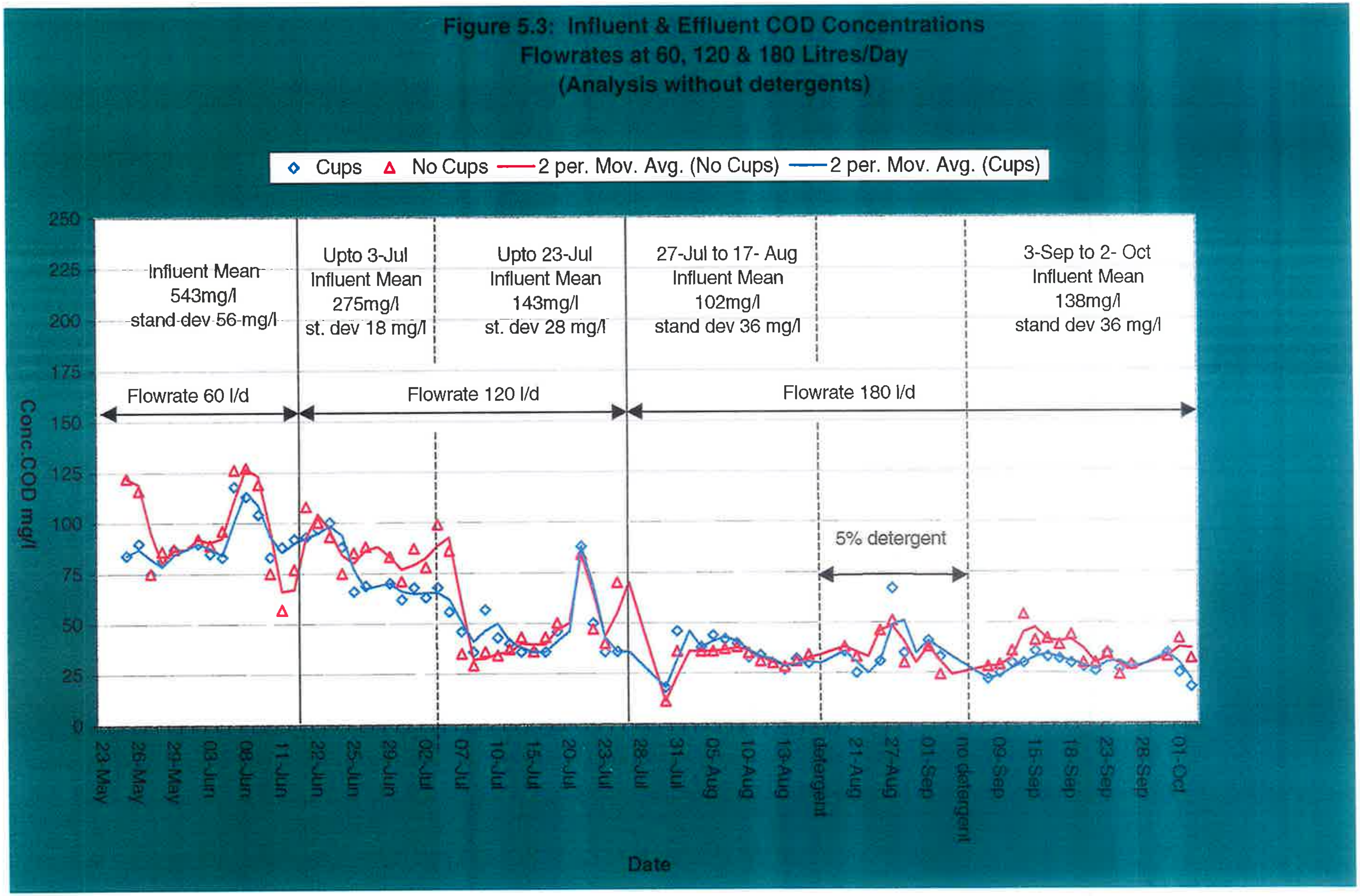


Figure 5.3: Influent & Effluent COD Concentrations
Flowrates at 60, 120 & 180 Litres/Day
(Analysis without detergents)

- At a hydraulic flow-rate of 60 l/d to each unit steady state occurred between the 27 May and the 4 June. The average results are summarised in Table 5.5 below (refer to Appendix 2 for results over this period).

Steady state at 60 l/d	*COD Mean(St. deviation)*	*gCOD/m^2.d*
Influent	548 (22) mg/l	7.86
Effluent COD (Cups)	84 (5) mg/l	1.21
Effluent COD (No Cups)	88 (7) mg/l	1.26

Table 5.5: illustrates average steady state results at a hydraulic flow-rate of 60 l/d.

- At a hydraulic flow-rate of 120 l/d to each unit steady state first occurred between the 25 June and the 3 July. The average results are summarised in table 5.6 below (refer to Appendix 2 for results over this period).

Steady state at 120 l/d	*COD Mean(St. deviation)*	*gCOD/m^2.d*
Influent	268 (11) mg/l	7.7
Effluent COD (Cups)	67 (3) mg/l	1.92
Effluent COD (No Cups)	84 (9) mg/l	2.41

Table 5.6: illustrates the first steady state results at a hydraulic flow-rate of 120 l/d.

- At a hydraulic flow-rate of 120 l/d to each unit steady state occurred for the second time between the 13 July and the 17 July. The average results are summarised in Table 5.7 below (refer to Appendix 2 for results over this period).

Steady state at 120 l/d	*COD Mean (St. deviation)*	*$gCOD/m^2.d$*
Influent	121 (8) mg/l	3.49
Effluent COD (Cups)	39 (4) mg/l	1.12
Effluent COD (No Cups)	42 (6) mg/l	1.21

Table 5.7: illustrates the second steady state results at a hydraulic flow-rate of 120 l/d.

- At a hydraulic flow-rate of 180 l/d to each unit steady state first occurred, at the lower organic loading rate, between the 10 August and the 17 August. The average results are summarised in table 5.8 below (refer to Appendix 2 for results over this period).

Steady state at 180 l/d	*COD Mean (St. deviation)*	*$gCOD/m^2.d$*
Influent	81 (10) mg/l	3.47
Effluent COD (Cups)	31 (3) mg/l	1.33
Effluent COD (No Cups)	32 (3) mg/l	1.38

Table 5.8: illustrates the first steady state results at a hydraulic flow-rate of 180 l/d.

- At a hydraulic flow-rate of 180 l/d to each unit steady state occurred for the second time, at the higher organic loading rate, between 15 September and 22 September. The average results are summarised in Table 5.9 together with a COD: BOD ratio. The BOD testing was carried out on the 30 September and 2 October (refer to Appendix 2 for results over this period).

Steady state at 180 l/d	COD Mean (St. deviation)	COD:BOD Ratio	$gCOD/m^2.d$
Influent	174 (28) mg/l	1.7	7.5
Effluent COD (Cups)	31 (4) mg/l	5.52	1.33
Effluent COD (No Cups)	37 (7) mg/l	5.29	1.64

Table 5.9: illustrates the second steady state results at a hydraulic flow-rate of 180 l/d.

5.4.3 Suspended solids

Table 5.10 shows the values for suspended solids taken over a short period of time. The suspended solids concentration in the influent was as expected low. The suspended solids concentration in the treated effluent are as high as 56 mg/l in the no cup unit and 54 mg/l in the cup unit, which may be attributable to high retention times in the RBC units. The results for the 11th and 12th June were taken when the retention time was 12 hours 41 minutes. The other results were for a retention time of 6 hours 20 minutes.

Date	influent	Cup	no cup
11-Jun	62	12	14
12-Jun	19	54	30
23-Jun	31	43	47
24-Jun	25	48	56
25-Jun	19	52	46
26-Jun	16	40	14
15-Jul	39	22	44

Table 5.10: The suspended solid concentrations of samples taken during Stage 1

5.4.4 Nitrates

The biological oxidation of wastewater involves the oxidation of carbonaceous material, followed by nitrogen oxidation. Increased nitrogen control utilises aerobic bacteria to convert ammonia (NH_4^+) to nitrate (NO_3^-), which is nitrification. The nitrification process occurs in two stages, ammonia is converted to nitrites (NO_2^-) and this is then converted to nitrate (NO_3^-). *Nitrosomonas* and *Nitrobacter* were once thought to be responsible for this process but the work of *Raper and Swinton, 1997* has led to the identification of other organisms which may also have an equally important role. Nitrate will only be produced if the carbonaceous content of the wastewater is low enough to allow the formation of the nitrifying bacteria. The nitrifying organisms themselves prefer higher levels of dissolved oxygen in the wastewater *(Surgeoner, 1997).*

Figure 5.4 shows the varying levels of nitrification achievable by both RBC units (refer to Appendix 2 for daily results).

- The average influent nitrate concentration, at a flow-rate of 60 l/d, was 0.9 mg/l. The treated effluent nitrate values were as high as 38 mg/l in the cup unit and 33mg/l in the flat disc unit. A relatively high influent COD concentration existed at this flow-rate. The high degree of nitrification was achievable due to a long retention time.

- The average influent nitrate concentration, at the hydraulic flow-rate of 120 l/d, was 0.5 mg/l. The treated effluent nitrate values ranged between a high of 38 mg/l and a low of 19 mg/l in the cup unit; and 28 mg/l to 18 mg/l in the flat disc unit. As the influent COD concentration decreased the nitrate levels also tended to decrease in the cupped unit, possibly due to media slough off. The flat disc unit tended to maintain a less varied degree of nitrification throughout.

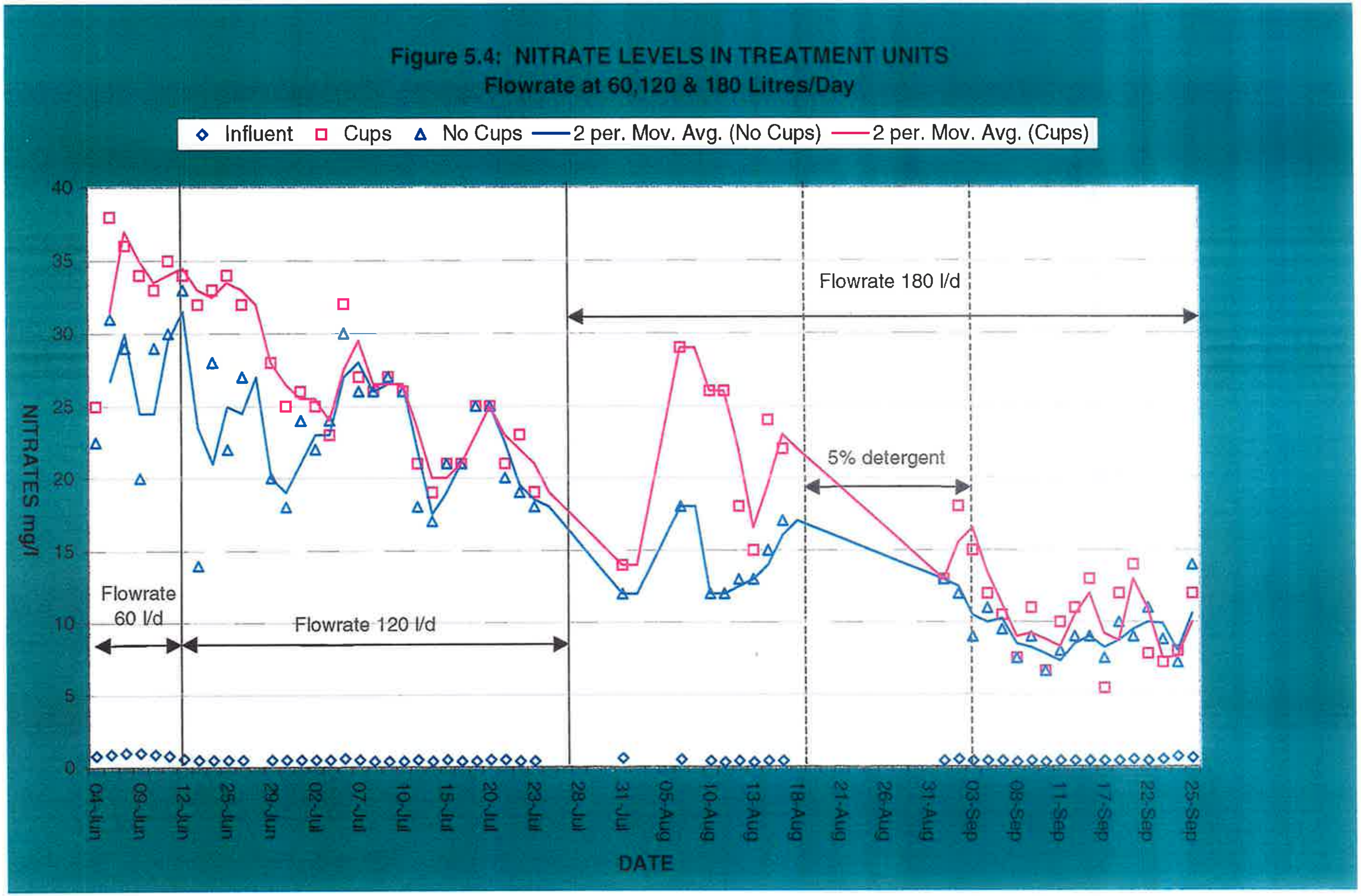


Figure 5.4: NITRATE LEVELS IN TREATMENT UNITS
Flowrate at 60,120 & 180 Litres/Day

- The average influent nitrate concentration, at the hydraulic flow-rate of 180 l/d, was 0.4 mg/l. The treated effluent nitrate values ranged between a high of 29 mg/l and a low of 5 mg/l in the cup unit; and 18 mg/l to 7 mg/l in the flat disc unit. The higher nitrate values were achieved at the lower influent COD concentration (organic loading 3.47 gCOD/m^2.d). As the influent COD concentration increased (organic loading 7.46 gCOD/m^2.d) the nitrate levels decreased.

From general observation of the results, taken either individually or using the 2 point moving average system, the unit with the aeration cups attached gave a higher degree of nitrification.

5.4.5 pH

Figure 5.5 shows the daily pH readings taken for the model RBC trough with the aeration cups attached. The general trend was that the pH in stage one of the models was close to 7, but then began to drop as each stage progressed. This is particularly noticeable at the hydraulic flow-rates of 60 where there was a distinct variation in pH values from stages 1 through to 4. The pH in stage 1 of the RBC varied from 7 down to 6 while the pH in stage 4 varied from 7 down to as low as 4. At 120 l/d the pH values dropped as low as 5 in stages 3 and 4, this is also where the higher degree of nitrification took place. The drop in pH may be attributable to the release of the hydrogen ion in the nitrification process. The same effect is highlighted, in Figure 5.6, for the pH readings taken from the ordinary flat disc unit. At a flow rate of 180 l/d the pH reading in both units levelled off to just above 7 in all stages of the RBC. This was at a time when the least amount of nitrification occurred. At start-up the pH readings, at all stages, in both units were above 7, this might be due to the fact that the nitrifying bacteria were not yet established.

Figure 5.5: pH Levels In Unit with Cups
Flowrate at 60, 120 & 180 Litres/Day

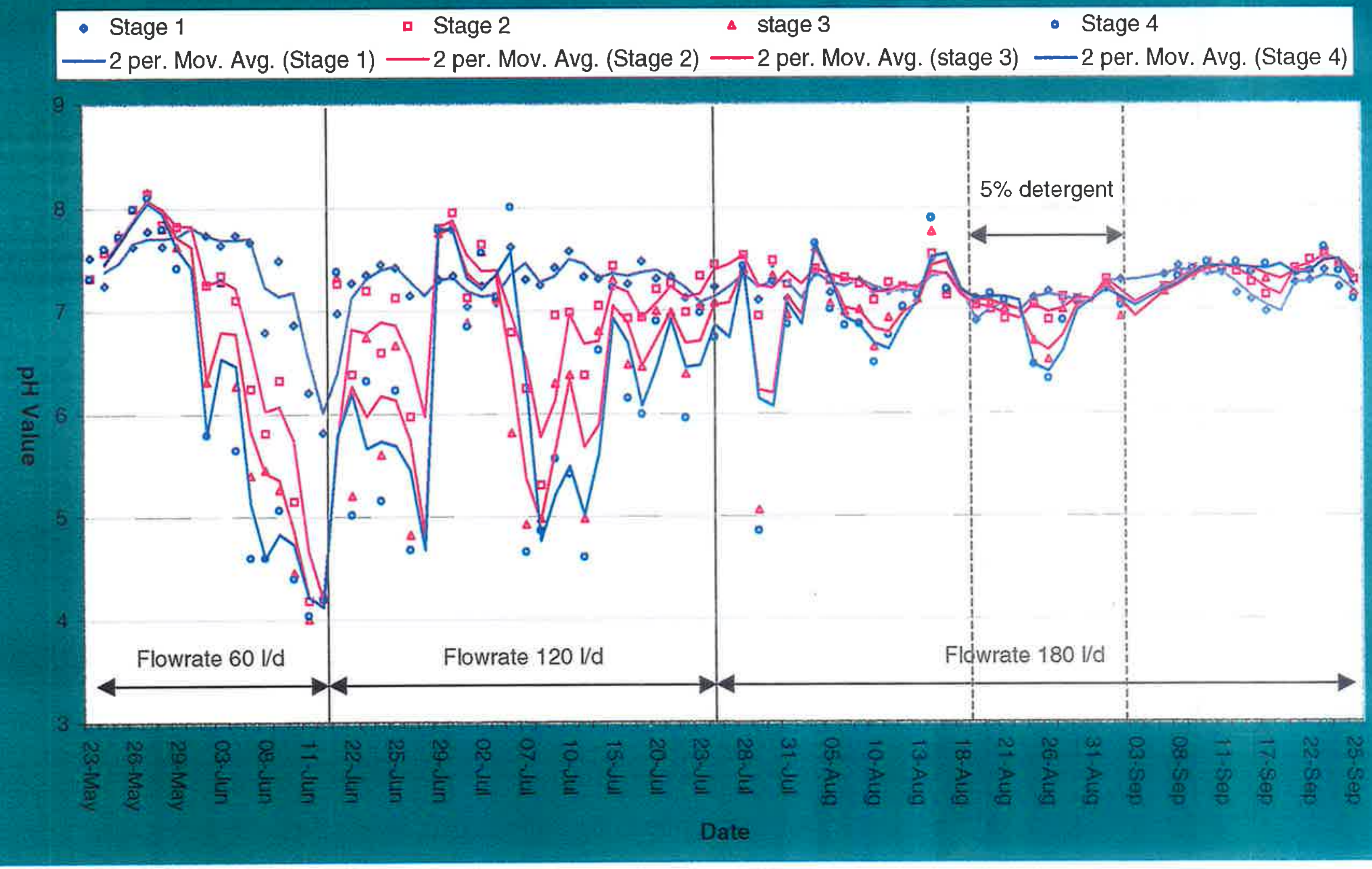
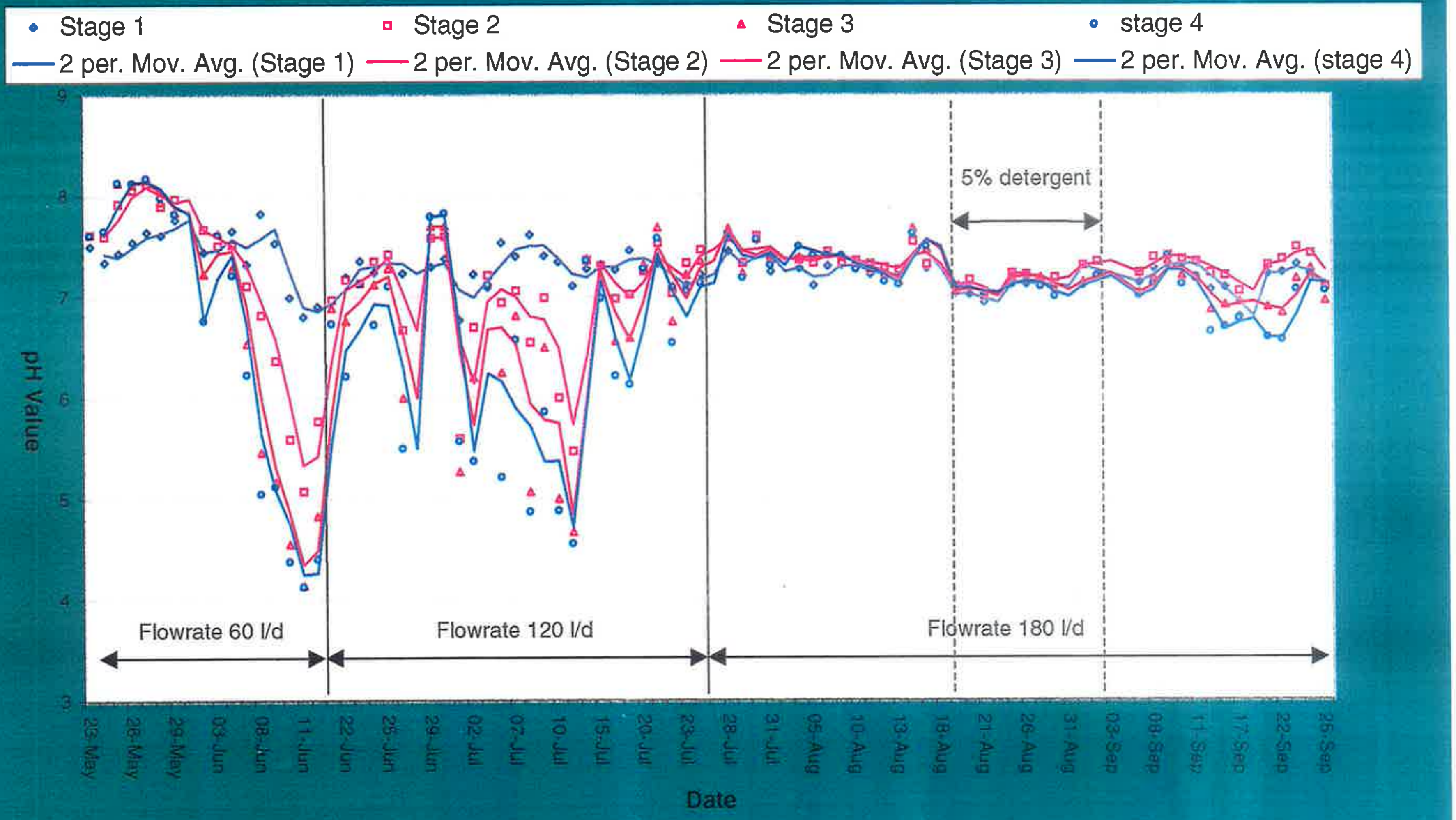


**Figure 5.6: pH Levels In Unit Without Cups
Flowrate at 60, 120 & 180 Litres/Day**



5.4.6 Dissolved Oxygen

The dissolved oxygen concentrations for the RBC unit with the aeration cups attached are shown in Figure 5.7. There is a clear trend in the way the DO concentrations are distributed through each stage i.e. stage one has the lowest DO concentration; stage four the highest for the flow-rates of 60 and 120 l/d. However, near the end of testing at a flow-rate of 180 l/d, the DO concentration in stage one is higher than stage 2. This is due to sloughing off of media from stage one and stage two and subsequent stages becoming more active. The DO concentrations for the flat disc unit, Figure 5.8, show a similar trend. Comparison of Figures 5.7 and 5.8 while following the 2 point moving averages shows the unit with the aeration cups attached has a higher DO concentration throughout. This factor also contributes to the higher degree of nitrification in the cupped unit when compared to the flat disc unit. At a hydraulic flow-rate of 60 l/d the DO concentration in the first stage of the unit with the aeration cups attached fell below 2 mg/l on one occasion. However the DO concentration fell below the desired 2-mg/l level in the first stage of the flat disc unit on a number of occasions at the 60 l/d flow-rate. This may be attributable to an excessive build-up of biomass on the discs in this stage. This problem was not as apparent in the discs with the aeration cups attached due to the pouring action of the cups.

Figure 5.7: DO Conc. In R.B.C. Unit with Cups Flowrate at 60, 120 & 180 Litres/Day

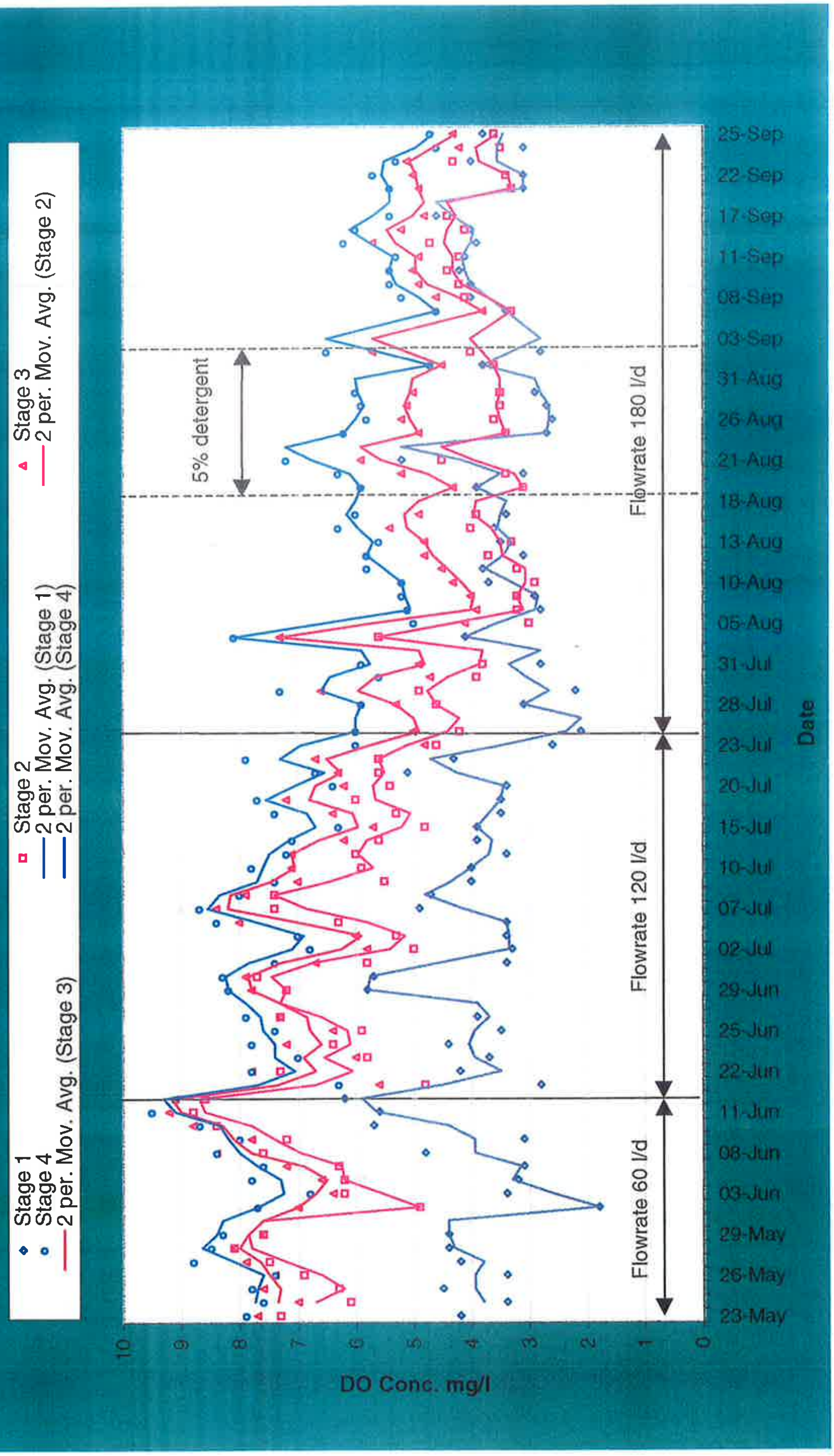
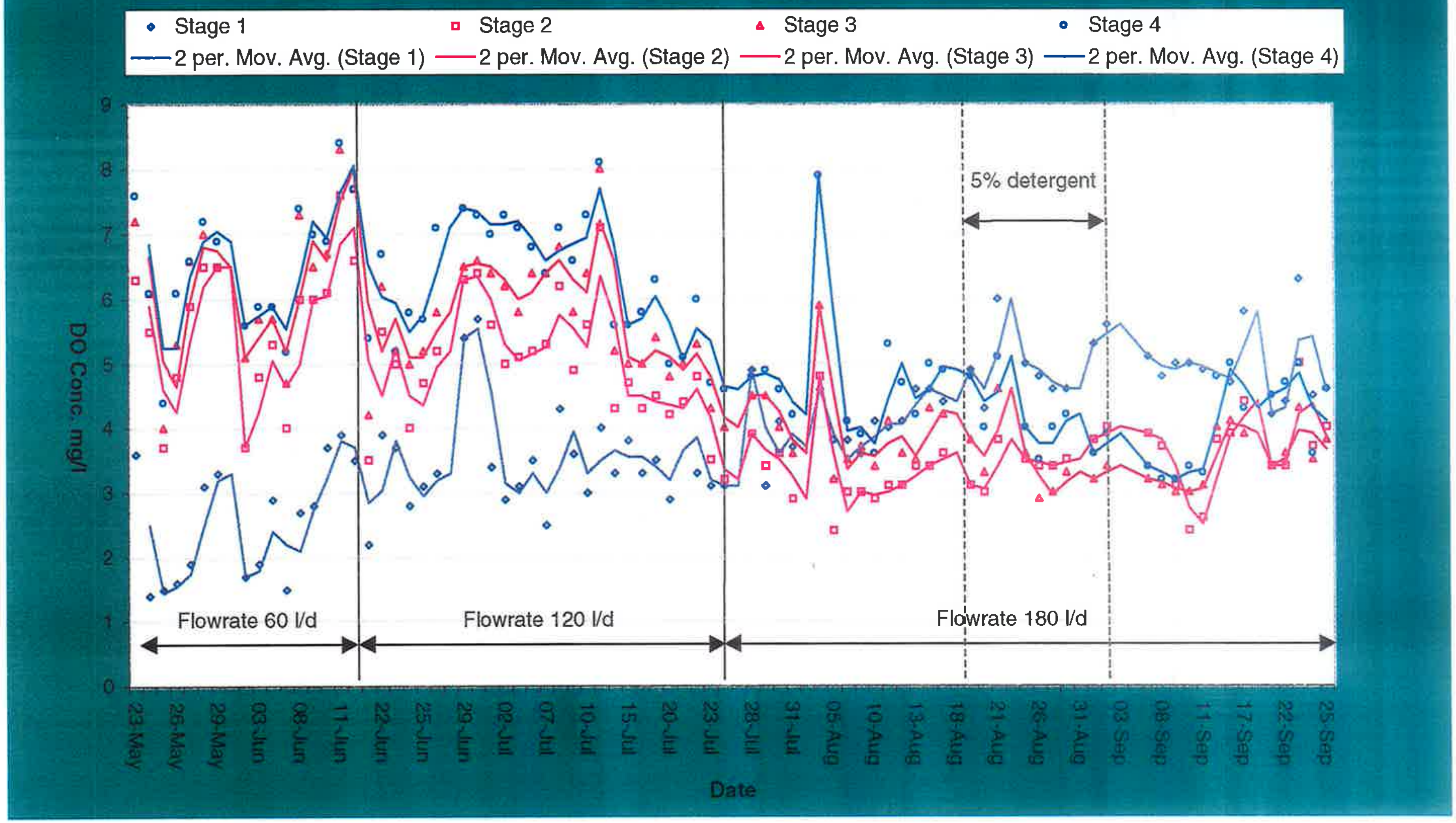


Figure 5.8: DO Conc. In R.B.C. Unit without Cups
Flowrate at 60, 120 & 180 Litres/Day



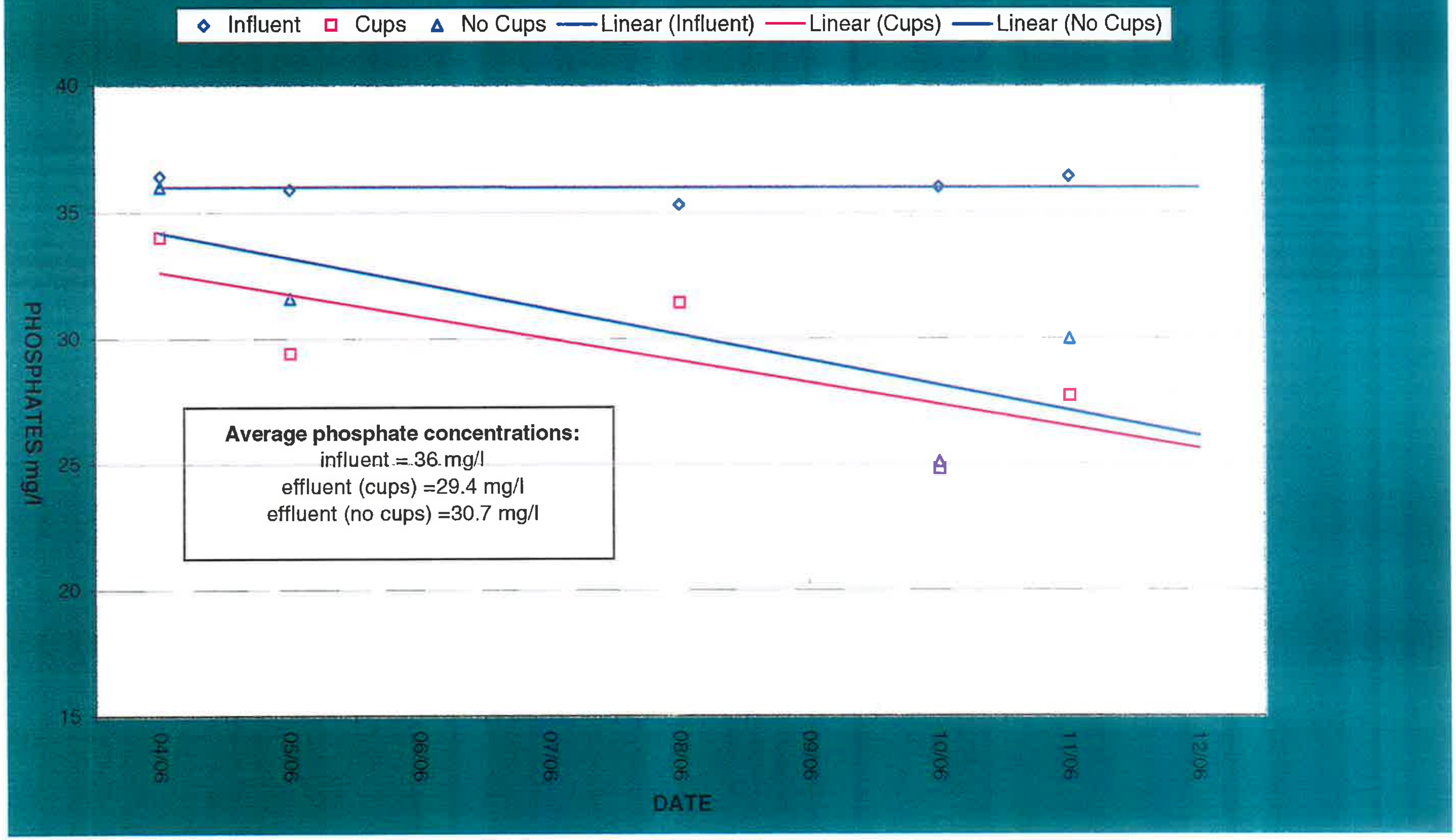
5.4.7 Phosphates

- The phosphate results for both units operating at a hydraulic flow-rate of 60 l/d are shown in Figure 5.9. The average influent phosphate concentration was 36 mg/l with the average treated effluent values for the cup and no cup units at 29.4 and 30.7 mg/l respectively. This would account for a removal efficiency of 18.4% in the cupped unit and a removal efficiency of 14.8% in the flat disc unit.

- The phosphate results for both units operating at a hydraulic flow-rate of 180 l/d are shown in Figure 5.10. The average influent phosphate concentration was 8.4 mg/l with the average treated effluent values for the cup and no cup units at 6.37 mg/l and 6.32 mg/l respectively. This would account for a removal efficiency of 24.3% in the cupped unit and a removal efficiency of 25.9% in the flat disc unit.

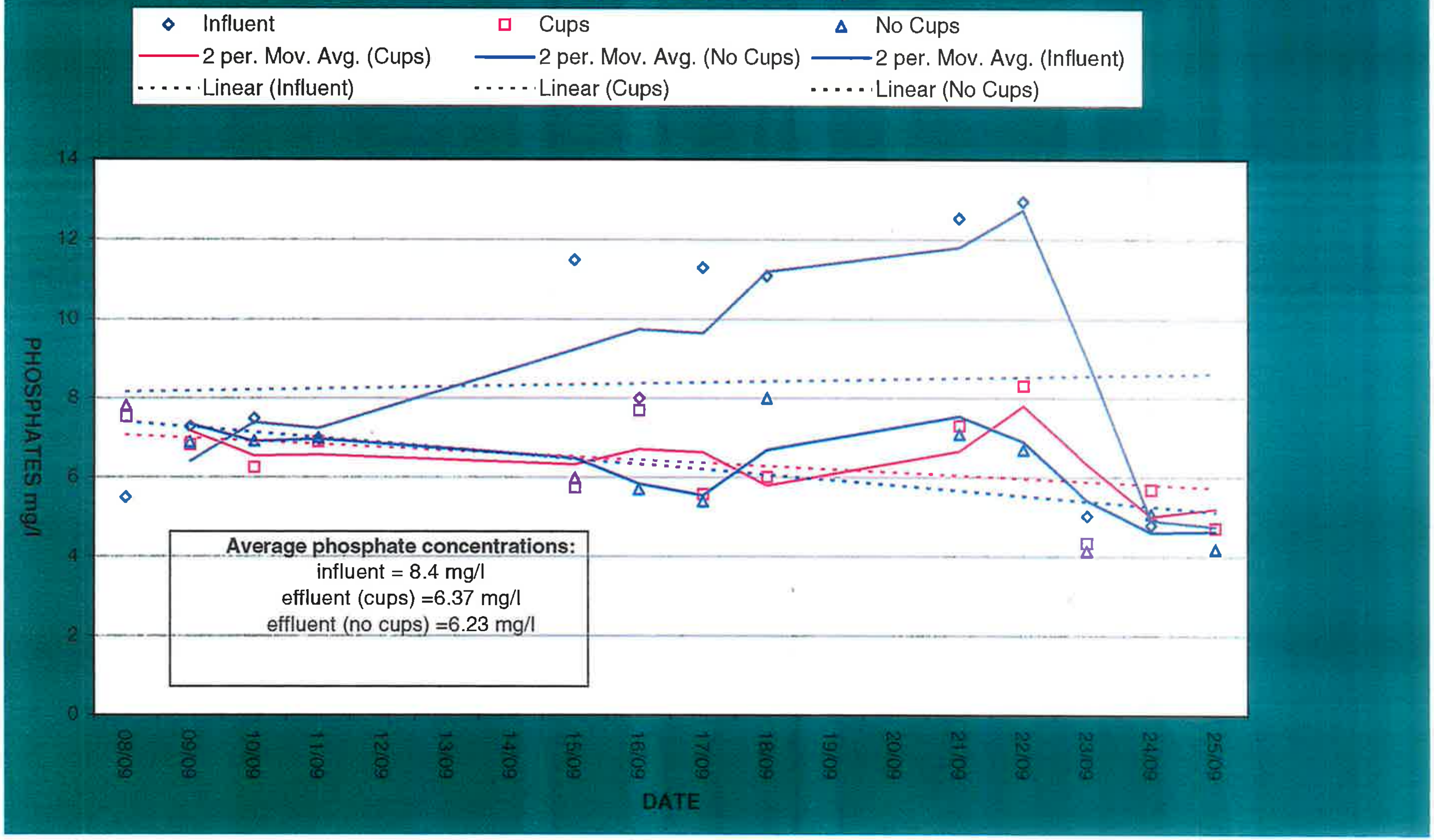
There was little difference found between the reactive and total phosphate reading (the daily phosphate results can be found in Appendix 2).

Figure 5.9: PHOSPHATE LEVELS IN TREATMENT UNITS
Flowrate at 60 Litres/Day



Average phosphate concentrations:
influent = 36 mg/l
effluent (cups) =29.4 mg/l
effluent (no cups) =30.7 mg/l

Figure 5.10: PHOSPHATE LEVELS IN TREATMENT UNITS
Flowrate at 180 Litres/Day



Average phosphate concentrations:
influent = 8.4 mg/l
effluent (cups) =6.37 mg/l
effluent (no cups) =6.23 mg/l

5.5 STAGE 2 TEST RESULTS

In Stage 2 the hydraulic loading rate was maintained constantly at 180 l/d, there was however five different detergent concentrations added to the stock feed. The five detergent concentrations applied to each unit were 10, 12.5, 20, 15 and 5% of the stock feed. The period of operation with each detergent addition is highlighted in Table 5.11.

Hydraulic flow-rate	*Period of operation*	*Detergent Concentration*
180 litres/day	6 October to 27 October	10% detergent
180 litres/day	27 October to 22 January	12.5% detergent
180 litres/day	22 January to 1 March	20% detergent
180 litres/day	1 March to 18 March	15% detergent
180 litres/day	18 March to 20 April	5% detergent

Table 5.11: illustrates the variations in detergent concentrations during Stage 2.

5.5.1 Influent chemical oxygen demand values

Figure 5.11 shows a plot of the daily influent COD concentrations together with the final effluent values for both units during Stage 2 testing.

Figure 5.12 shows the average influent COD concentration to both units, with standard deviations, for each detergent loading case. The final effluent COD values are also plotted on Figure 5.12. Both units appeared to be operating relatively similarly, however the unit with the aeration cups attached achieved a slightly higher quality final effluent.

- At a detergent concentration of 10% to each unit the average influent COD concentration was 154 mg/l with a standard deviation of 43 mg/l.

- At a detergent concentration of 12.5% to each unit the average influent COD concentration was 174 mg/l with a standard deviation of 53 mg/l.

- At a detergent concentration of 20% to each unit the average influent COD concentration was 252 mg/l with a standard deviation of 53 mg/l. The lower COD concentration at 20% detergent than at 15% detergent may be due to a more viscous feed, which was more difficult to pump consistently.

- At a detergent concentration of 15% to each unit the average influent COD concentration was 386 mg/l with a standard deviation of 13 mg/l.

- At a detergent concentration of 5% to each unit the average influent COD concentration was 246 mg/l with a standard deviation of 39 mg/l. The high COD concentration may be attributable to a less viscous, more consistently pumped feed.

5.5.2 COD:BOD relationship

Detergent Concentration	*Influent COD:BOD ratio*	*Cup Unit (effluent) COD:BOD ratio*	*No Cup Unit (effluent) COD:BOD ratio*
10% detergent	2.18	4.92	7.49
12.5% detergent	1.94	3.79	6.77
20% detergent	2.03	2.5	1.92
15% detergent	1.74	1.98	1.71
5% detergent	1.83	2.61	1.90

Table 5.12: illustrates an approximate COD: BOD relationship for each detergent loading.

Figure 5.11: Influent & Effluent COD Concentrations
Flowrate at 180 Litres/Day
(detergent added)

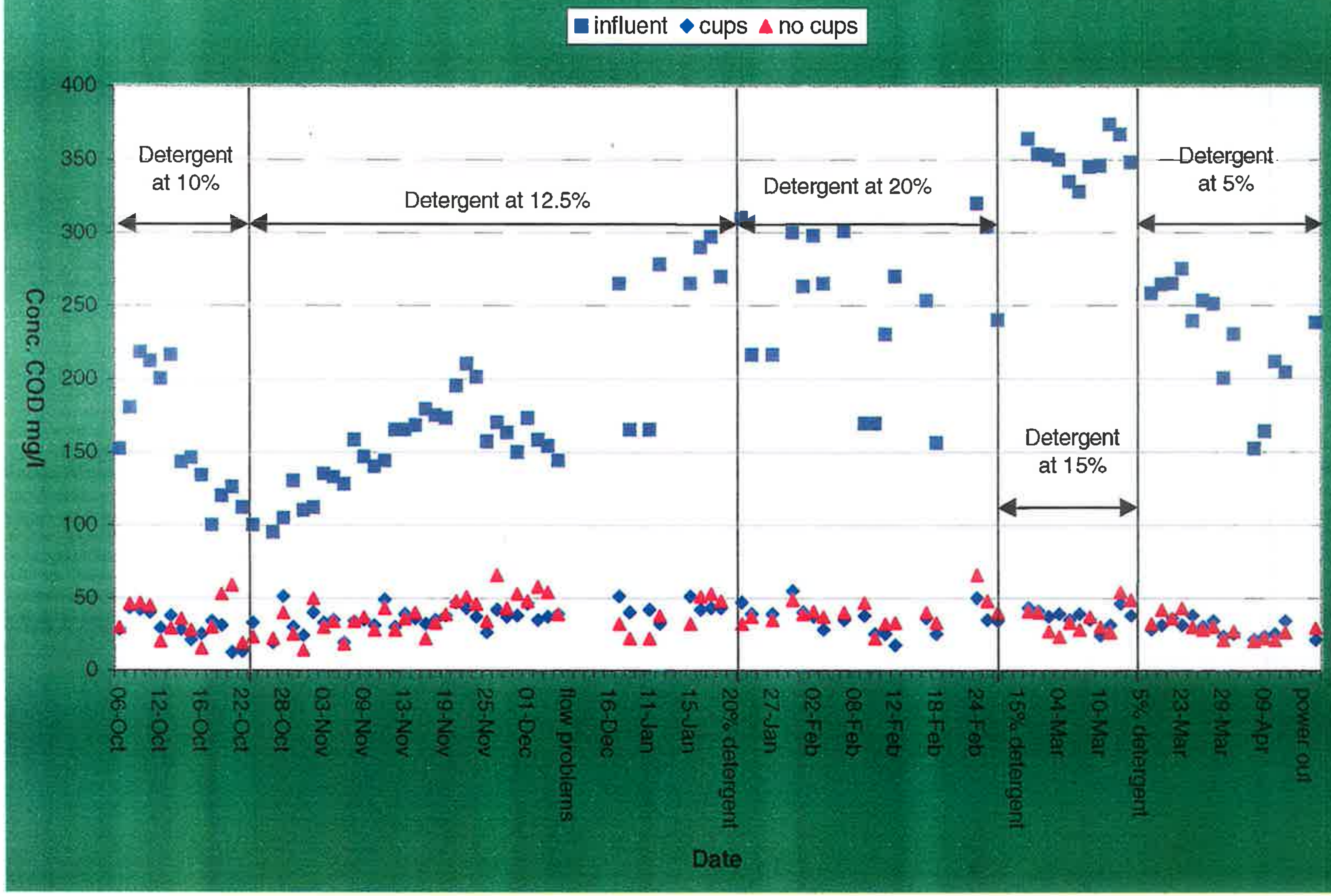
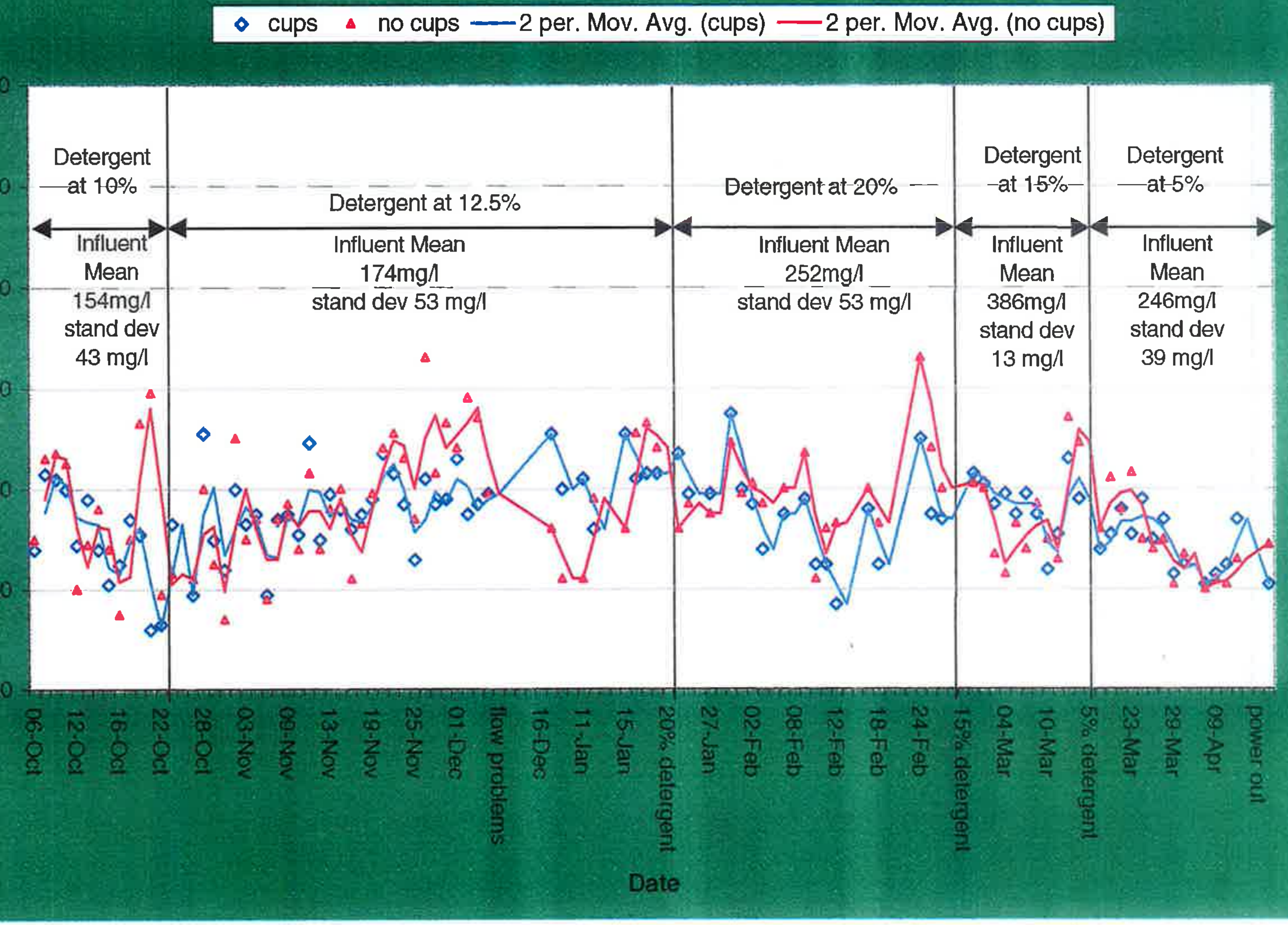


Figure 5.12: Influent & Effluent COD Concentrations
Flowrate at 180 Litres/Day
(detergent added)



- At a detergent concentration of 10% to each unit steady state conditions were taken to occur over the entire test period. The average results are summarised in Table 5.13 below (refer to Appendix 2 for full results over this period).

10% Detergent Concentration	*COD Mean (St. deviation)*	*gCOD/m².d*
Influent	154 (43) mg/l	6.63
Effluent COD (Cups)	30 (10) mg/l	1.29
Effluent COD (No Cups)	34 (14) mg/l	1.46

Table 5.13: illustrates average steady state results at a detergent concentration of 10%.

- At a detergent concentration of 12.5% to each unit steady state conditions were taken to occur over the entire test period. The average results are summarised in Table 5.14 below (refer to Appendix 2 for full results over this period).

12.5% Detergent Concentration	*COD Mean (St. deviation)*	*gCOD/m².d*
Influent	174 (53) mg/l	7.49
Effluent COD (Cups)	37 (8) mg/l	1.59
Effluent COD (No Cups)	38 (12) mg/l	1.64

Table 5.14: illustrates the steady state results at a detergent concentration of 12.5%.

- At a detergent concentration of 20% to each unit steady state conditions were taken to occur over the entire test period. The average results are summarised in Table 5.15 below (refer to Appendix 2 for full results over this period).

20% Detergent Concentration	*COD Mean(St. deviation)*	*$gCOD/m^2.d$*
Influent	252 (53) mg/l	10.85
Effluent COD (Cups)	36 (10) mg/l	1.55
Effluent COD (No Cups)	39 (10) mg/l	1.68

Table 5.15: illustrates the steady state results at a detergent concentration of 20%.

- At a detergent concentration of 15% to each unit steady state conditions were taken to occur over the entire test period. The average results are summarised in Table 5.16 below (refer to Appendix 2 for full results over this period).

15% Detergent Concentration	*COD Mean(St. deviation)*	*$gCOD/m^2.d$*
Influent	386 (13) mg/l	16.62
Effluent COD (Cups)	37 (6) mg/l	1.59
Effluent COD (No Cups)	35 (10) mg/l	1.51

Table 5.16: illustrates the steady state results at a detergent concentration of 15%.

- At a detergent concentration of 5% to each unit steady state conditions were taken to occur over the entire test period. The average results are summarised in table 5.17 below (refer to Appendix 2 for full results over this period).

5% Detergent Concentration	*COD Mean(St. deviation)*	*$gCOD/m^2.d$*
Influent	246 (39) mg/l	10.59
Effluent COD (Cups)	31 (5) mg/l	1.33
Effluent COD (No Cups)	31 (8) mg/l	1.33

Table 5.17: illustrates the steady state results at a detergent concentration of 5%.

5.5.3 Nitrates

Figure 5.13 shows the varying levels of nitrification achievable by both RBC units (refer to Appendix 2 for daily results).

- The average influent nitrate concentration, throughout the entire second stage of testing, was approximately 1 mg/l. The treated effluent nitrate values were on average 13 mg/l in the cup unit and 7mg/l in the flat disc unit. These are relatively low nitrate values. The reason for this may be that the introduction of the 10% detergent concentration initially inhibited the nitrifying bacteria. The effluent COD values were initially high also due to the introduction of the detergent.

- At a detergent concentration of 12.5% there appeared to be a steady increase in the degree of nitrification being achieved by both units. The unit with the cups again has a slightly higher degree than the flat disc unit. The final nitrate values in the treated effluent peaked at 26 mg/l in the cupped unit and 25 mg/l in the flat disc unit.

- At the 20% detergent concentration there appeared to be a downward trend in the degree of nitrification being achieved by both units. The nitrate values in the treated effluent fell from highs of 26 mg/l to a low of 10 mg/l in both units.

- At the 15% detergent concentration this downward trend in the degree of nitrification continued in both units. The nitrate values in the treated effluent stabilised at approximately 16 mg/l in both units.

- With the detergent concentration at 5% there is an increase in the degree of nitrification achieved by both units. The nitrate values, in the treated effluent, were on average above 20 mg/l in both units.

5.5.4 pH

Figure 5.14 shows the daily pH reading taken within the RBC trough with the aeration cups attached. The trend is the same as in Stage 1 testing i.e. that the pH in stage one of the RBC models was close to 7, but then began to drop as each disc stage progressed. This trend is particularly noticeable at the detergent loading of 12.5%; where the higher degree of nitrification also took place. Again the drop in pH could be attributed to the release of the hydrogen ion in the nitrification process. The same effect is highlighted, in Figure 5.15, for the pH readings taken from the ordinary flat disc unit. At the detergent loading of 10% and later on at 15% the pH readings in all the four stages of the RBC unit were at 7 or higher, this is at a time when the least amount of nitrification occurred. In the other three cases i.e. at the detergent loading of 12.5, 20 and 5% there was a slight decrease in pH as each stage progressed from inlet to outlet (stages one to four) of the RBC model.

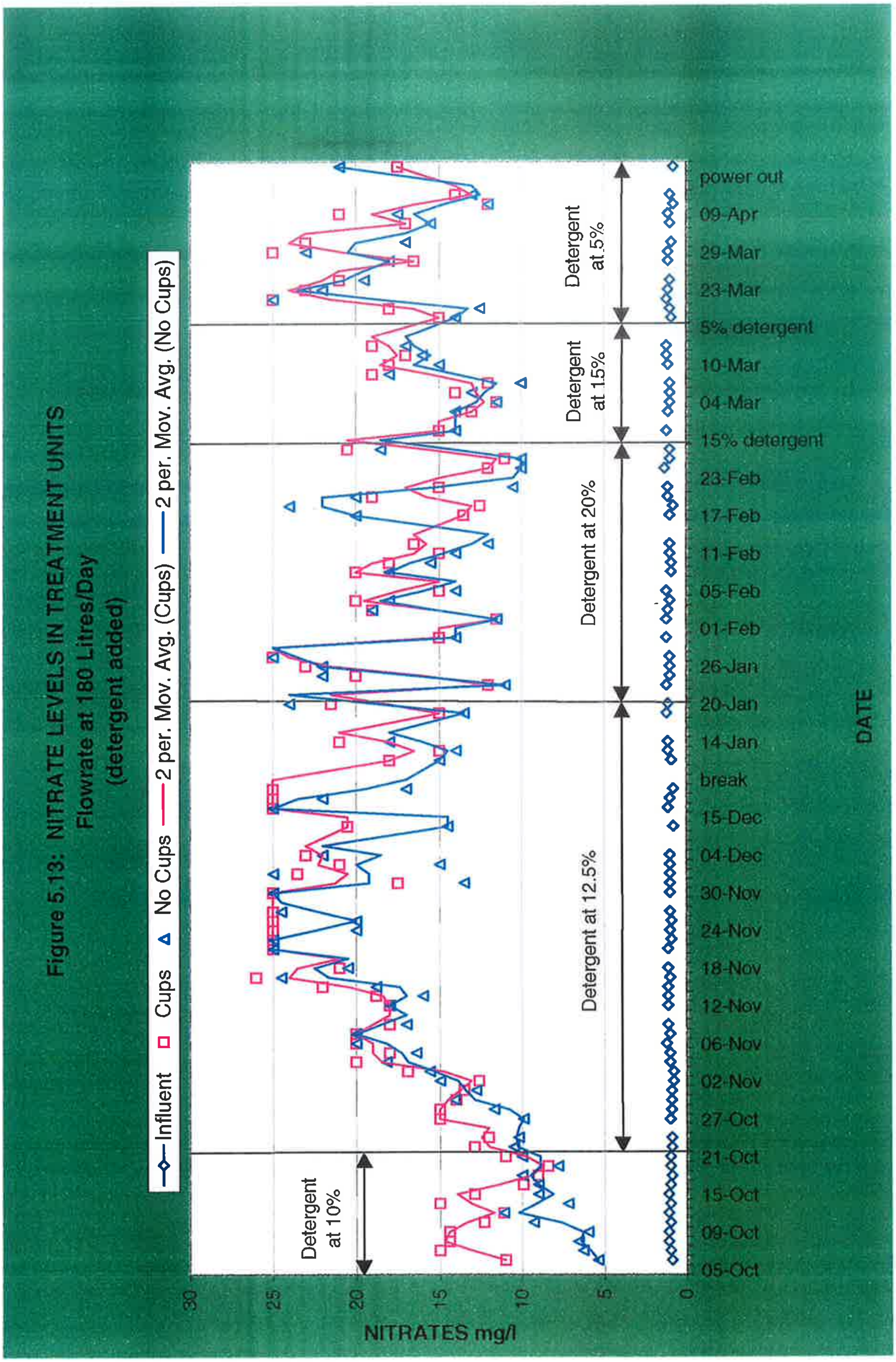


Figure 5.13: NITRATE LEVELS IN TREATMENT UNITS
Flowrate at 180 Litres/Day
(detergent added)

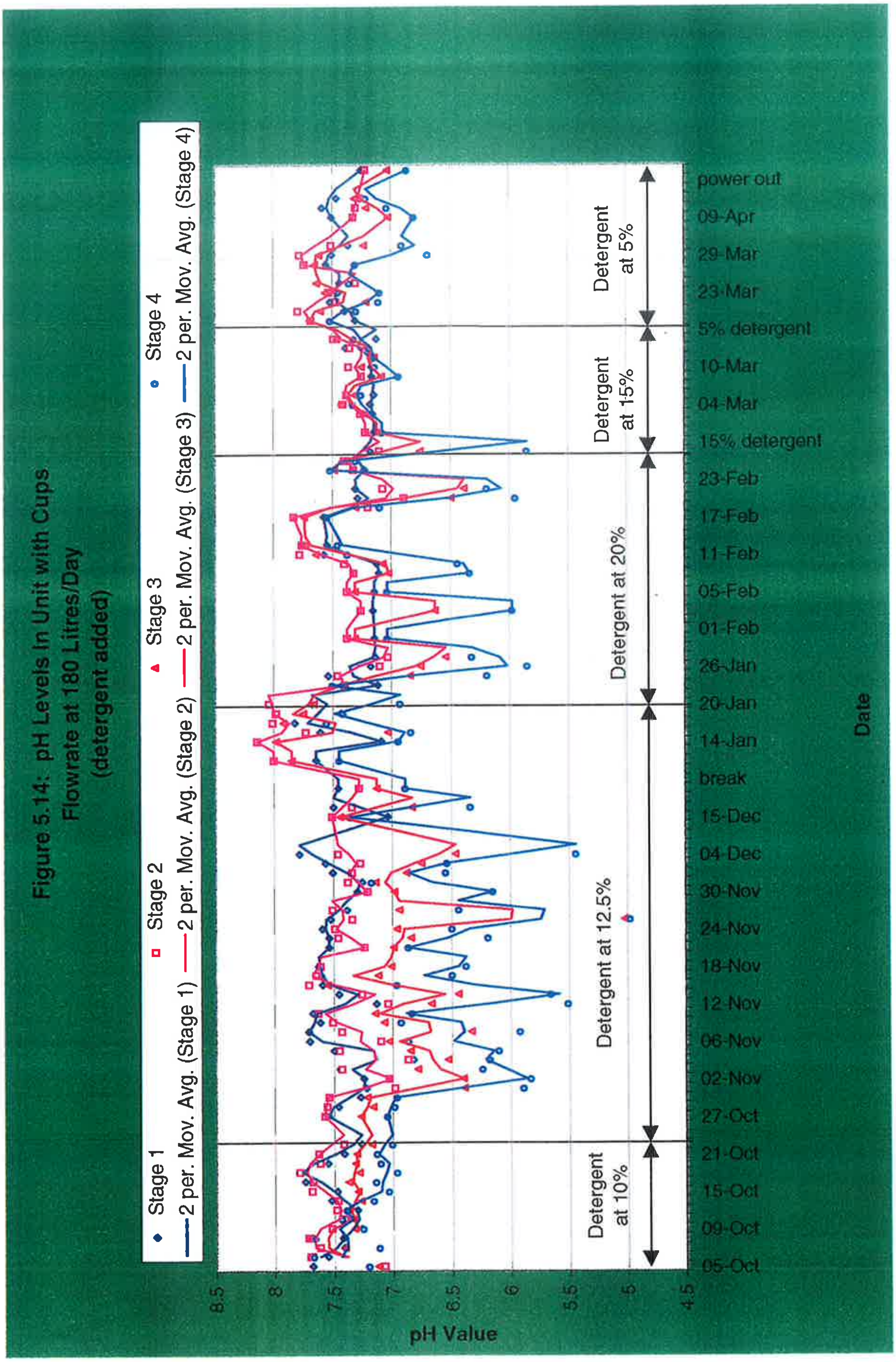
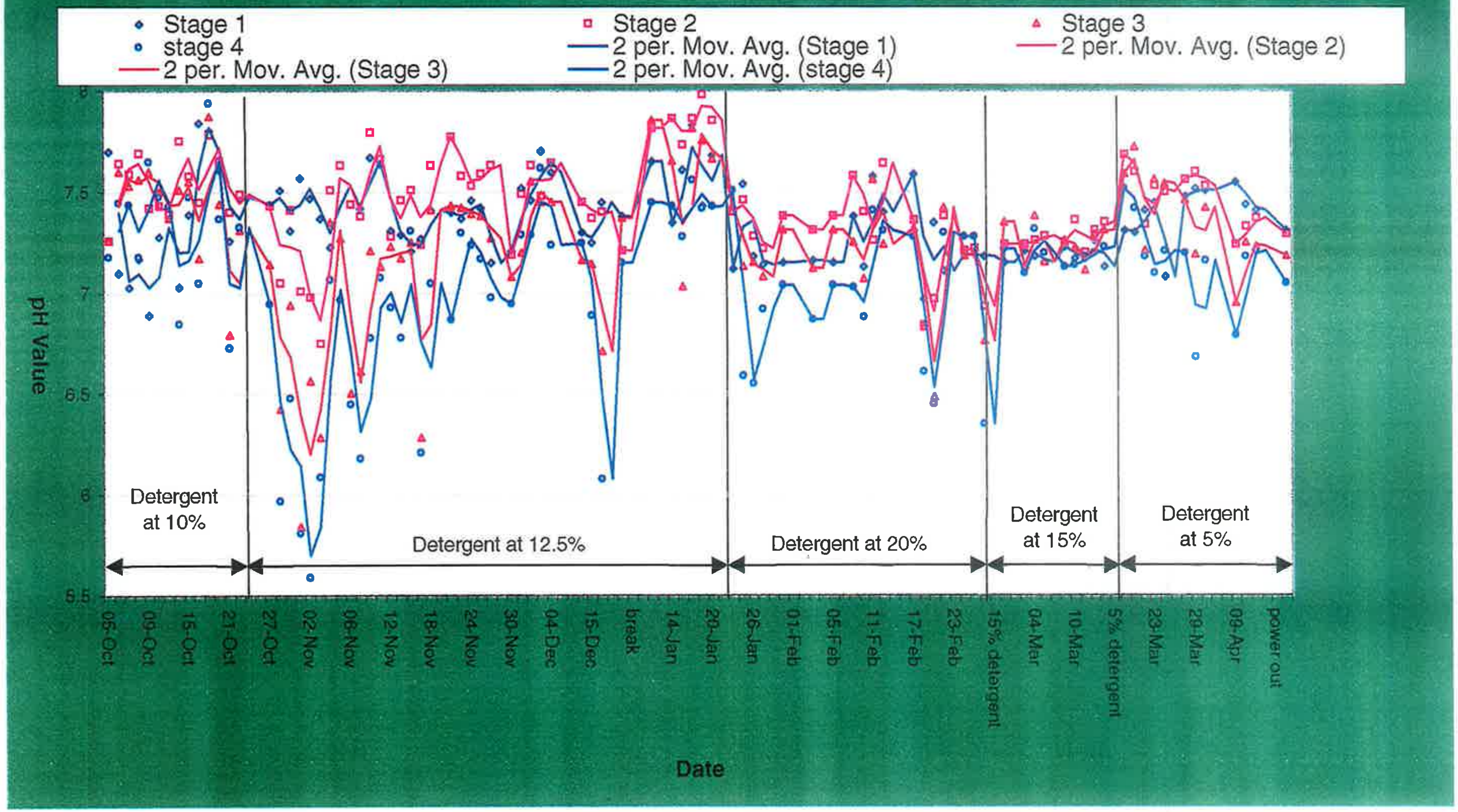


Figure 5.14: pH Levels In Unit with Cups
Flowrate at 180 Litres/Day
(detergent added)

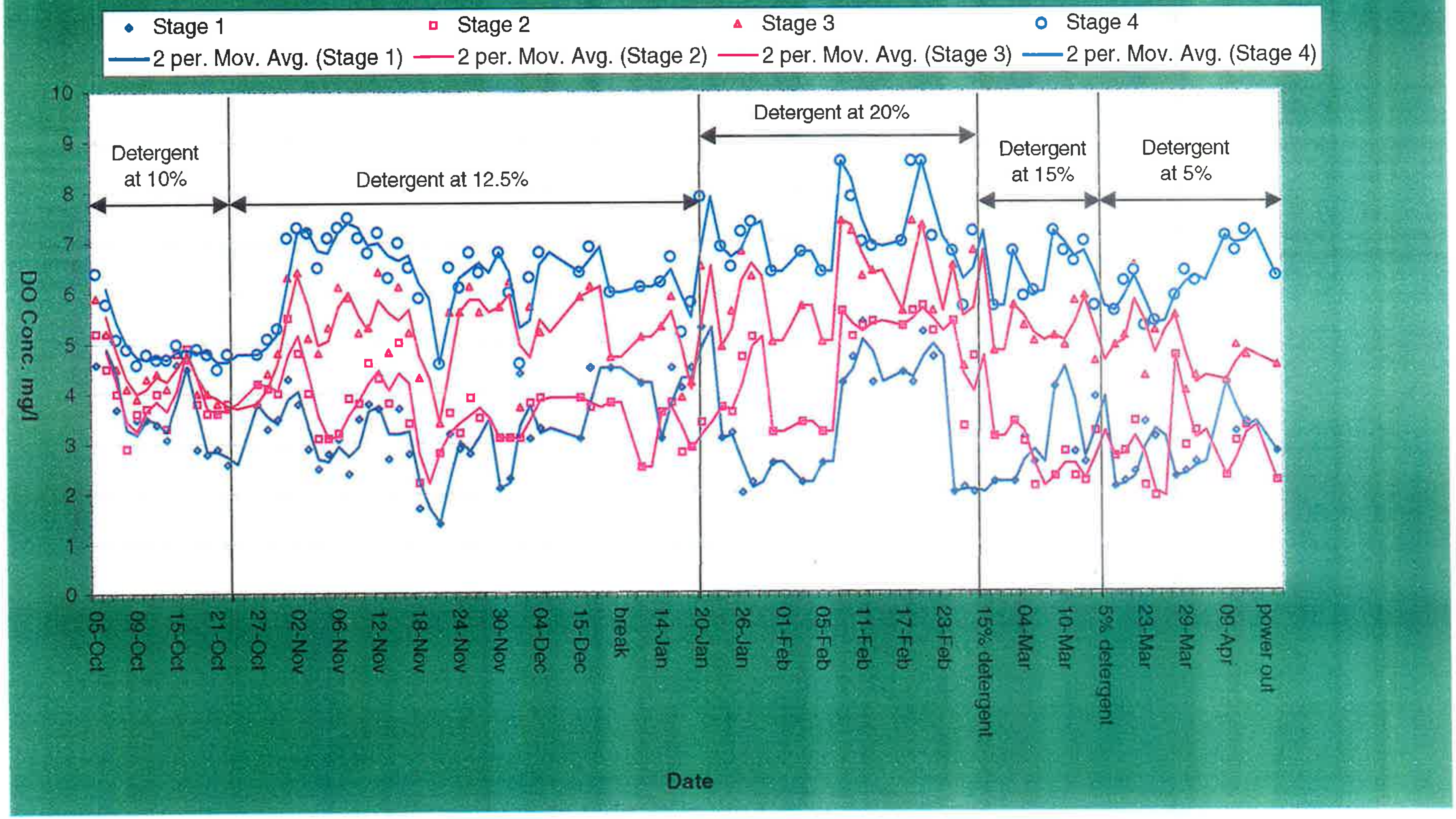
Figure 5.15: pH Levels In Unit Without Cups
Flowrate at 180 Litres/Day
(detergent added)



5.5.5 Dissolved Oxygen

The dissolved oxygen concentrations for the RBC unit with the aeration cups attached are shown in Figure 5.16. As in the first testing regime the general trend was still prevalent i.e. disc stage one generally had the lowest DO concentration while stage four had the highest. However, the DO concentration in disc stage one occasionally exceeded that in stage two. This was due to sloughing off of media from stage one and hence causing stage two to become more active. The DO concentrations for the flat disc unit, Figure 5.17, show a similar trend. Comparison of Figures 5.16 and 5.17 by following the 2 point moving averages shows the unit with the aeration cups attached had a higher DO concentration throughout. This higher DO also contributed to the slightly higher degree of nitrification in the cupped unit when compared to the flat disc unit. The DO concentrations in stage four of the RBC unit with the cups attached were on average above 7 mg/l whereas the corresponding stage in the flat disc unit had concentrations less than 6 mg/l. From both Figures 5.16 and 5.17 it can be seen that when the 10% detergent was added initially, the DO concentration was approximately 4 mg/l in all stages. This may have been due to the micro-organisms requiring extra oxygen to acclimatise to the sudden shock detergent loading.

Figure 5.16: DO Conc. In R.B.C. Unit with Cups
Flowrate at 180 Litres/Day
(detergent added)



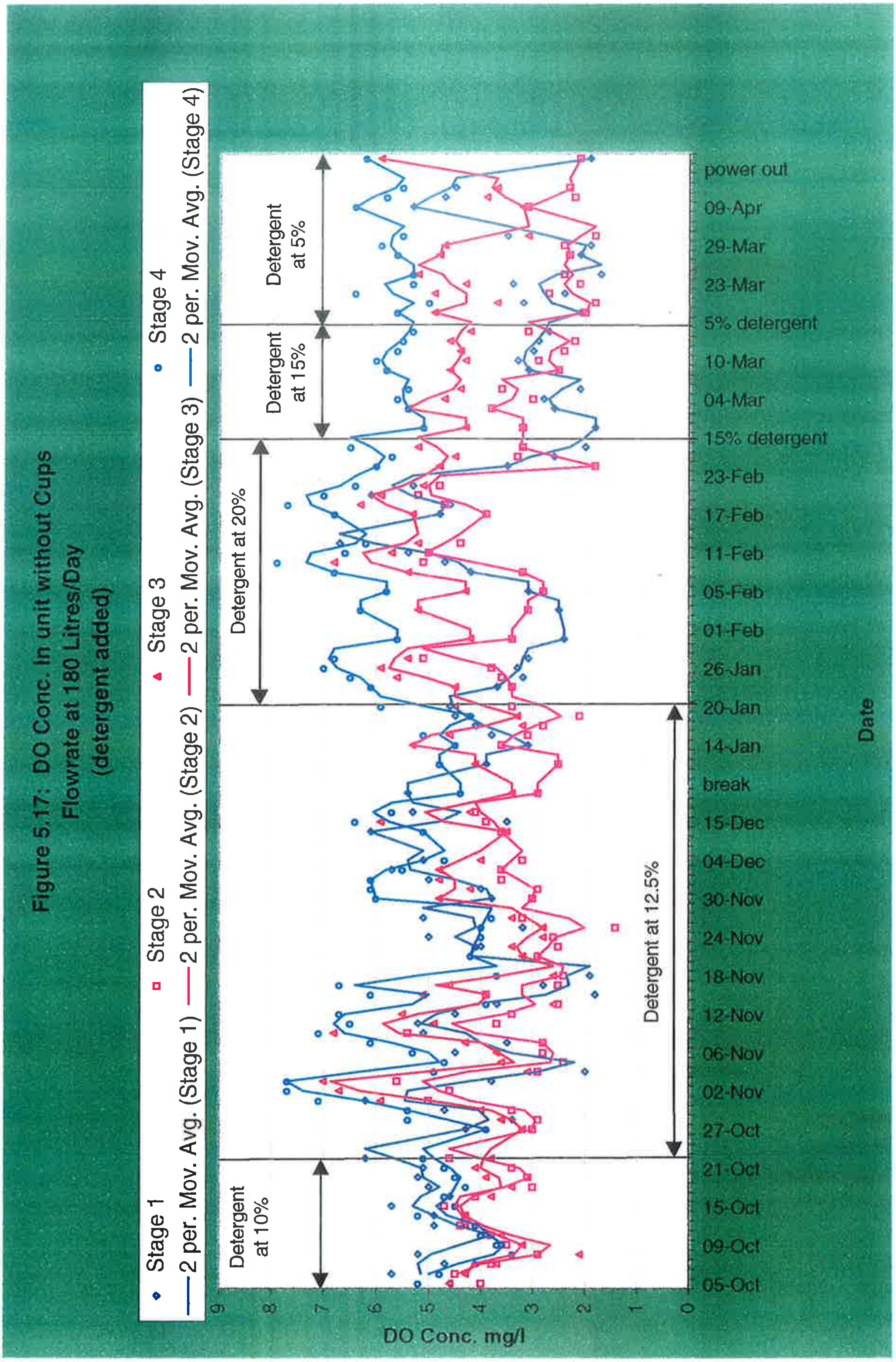


Figure 5.17: DO Conc. In unit without Cups
Flowrate at 180 Litres/Day
(detergent added)

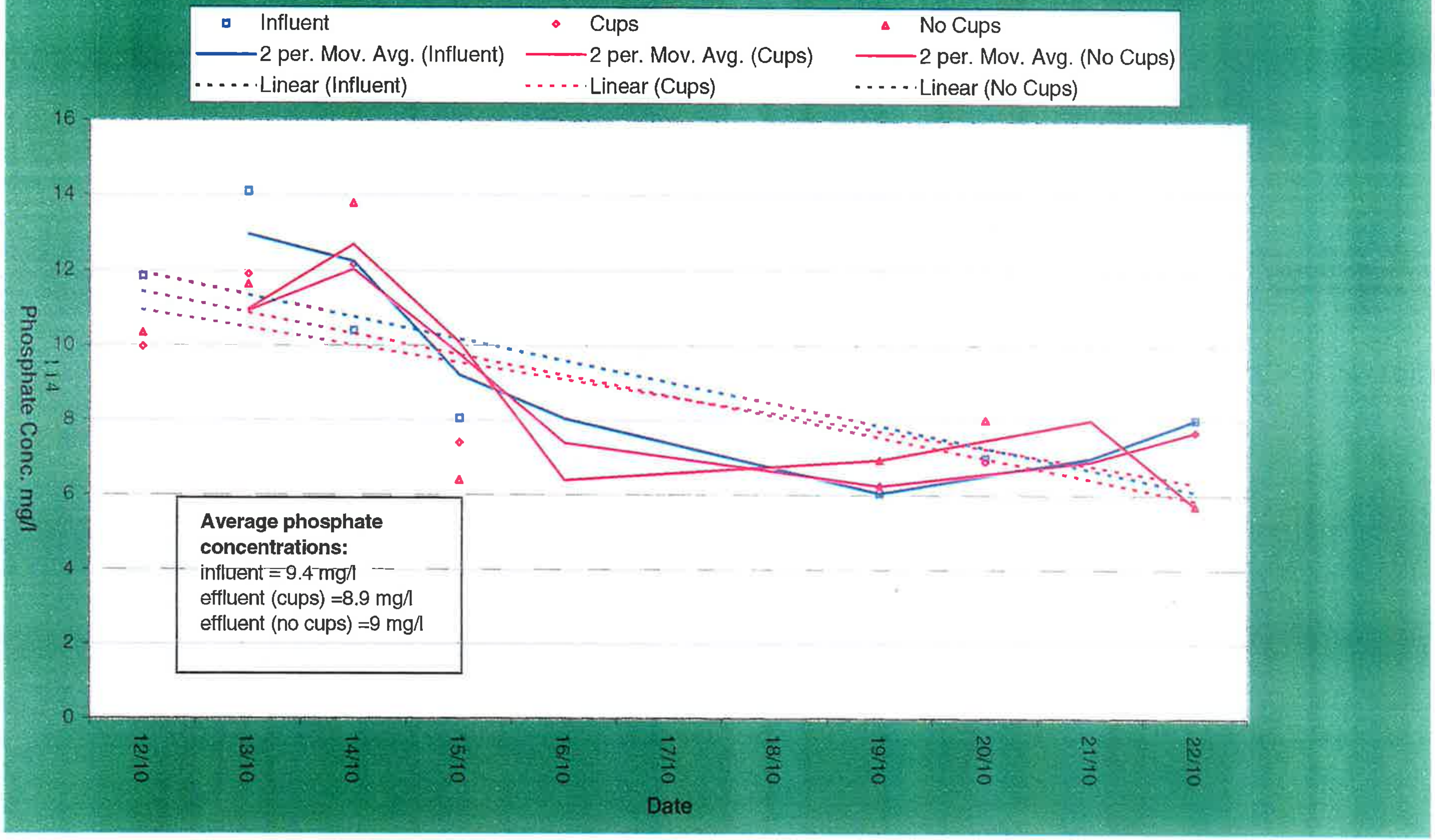
5.5.6 Phosphates

- Figure 5.18 highlights the phosphate results for both units operating with a detergent loading of 10%. Both the 2 point moving average and the linear regression analysis indicate that phosphorus removal had occurred. The average influent phosphate concentration was 9.4 mg/l and the average treated effluent values for the cup and no cup units were 8.9 and 9 mg/l respectively. This accounted for a removal efficiency of 5% in the cupped unit and a removal efficiency of 4.22% in the flat disc unit.

- The phosphate results for both units operating with a detergent loading of 12.5% are shown in Figure 5.19. Phosphorus removal is indicated by linear regression analysis. The average influent phosphate concentration was 13.8 mg/l and the average treated effluent values for the cup and no cup units were 12.3 and 12.2 mg/l respectively. This would account for a removal efficiency of 11% in the cupped unit and a removal efficiency of 11.6% in the flat disc unit.

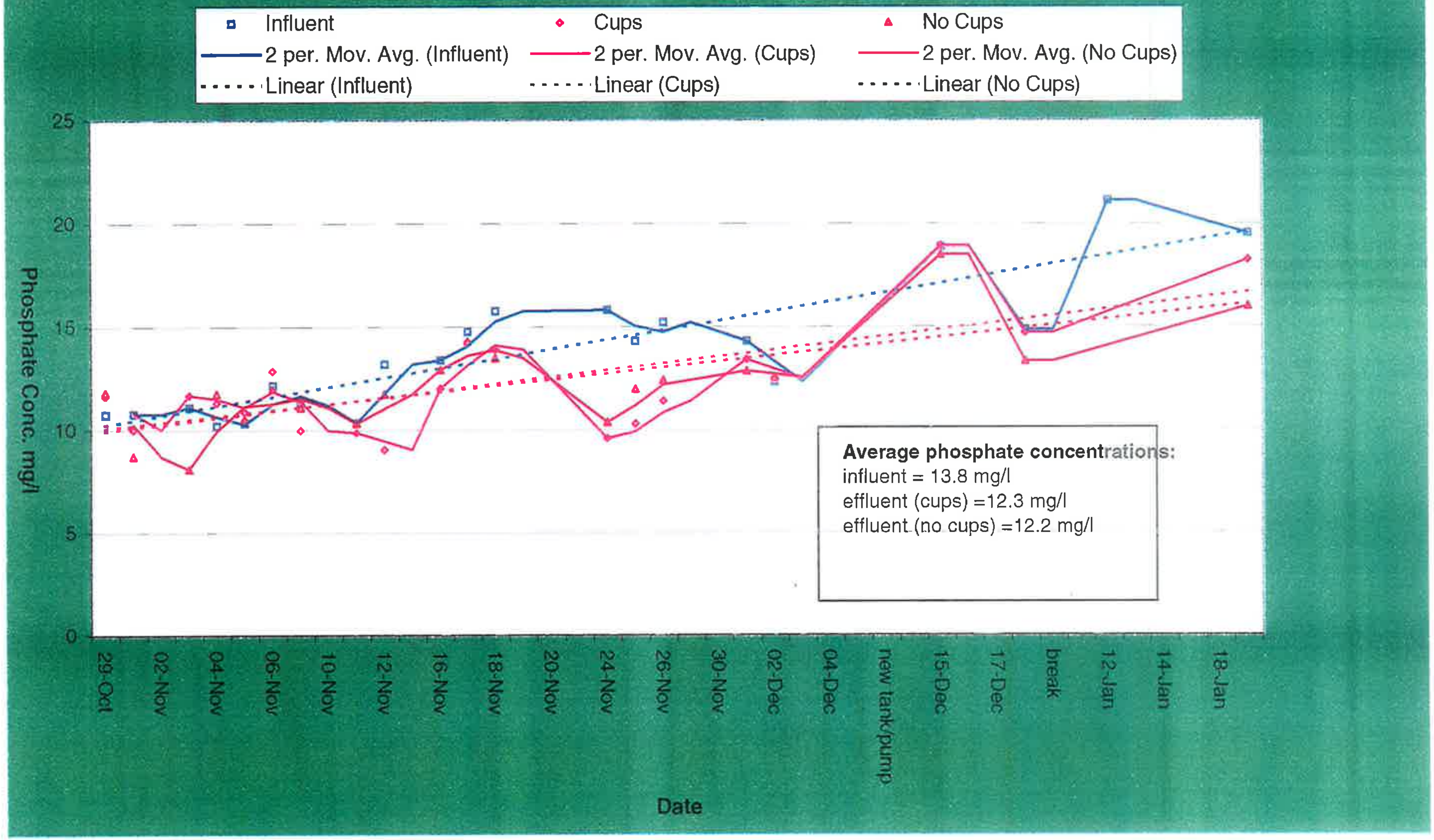
- Figure 5.20 highlights the phosphate results for both units operating with a detergent loading of 20%. Phosphorus removal is indicated by linear regression analysis. The average influent phosphate concentration was 29.7 mg/l and the average treated effluent values for the cup and no cup units were 24 and 26.2 mg/l respectively. This would account for a removal efficiency of 19.4% in the cupped unit and a removal efficiency of 11.8% in the flat disc unit.

Figure 5.18: Influent & Effluent Phosphate Concentrations
Flowrate at 180 Litres/Day
(10% detergent added)



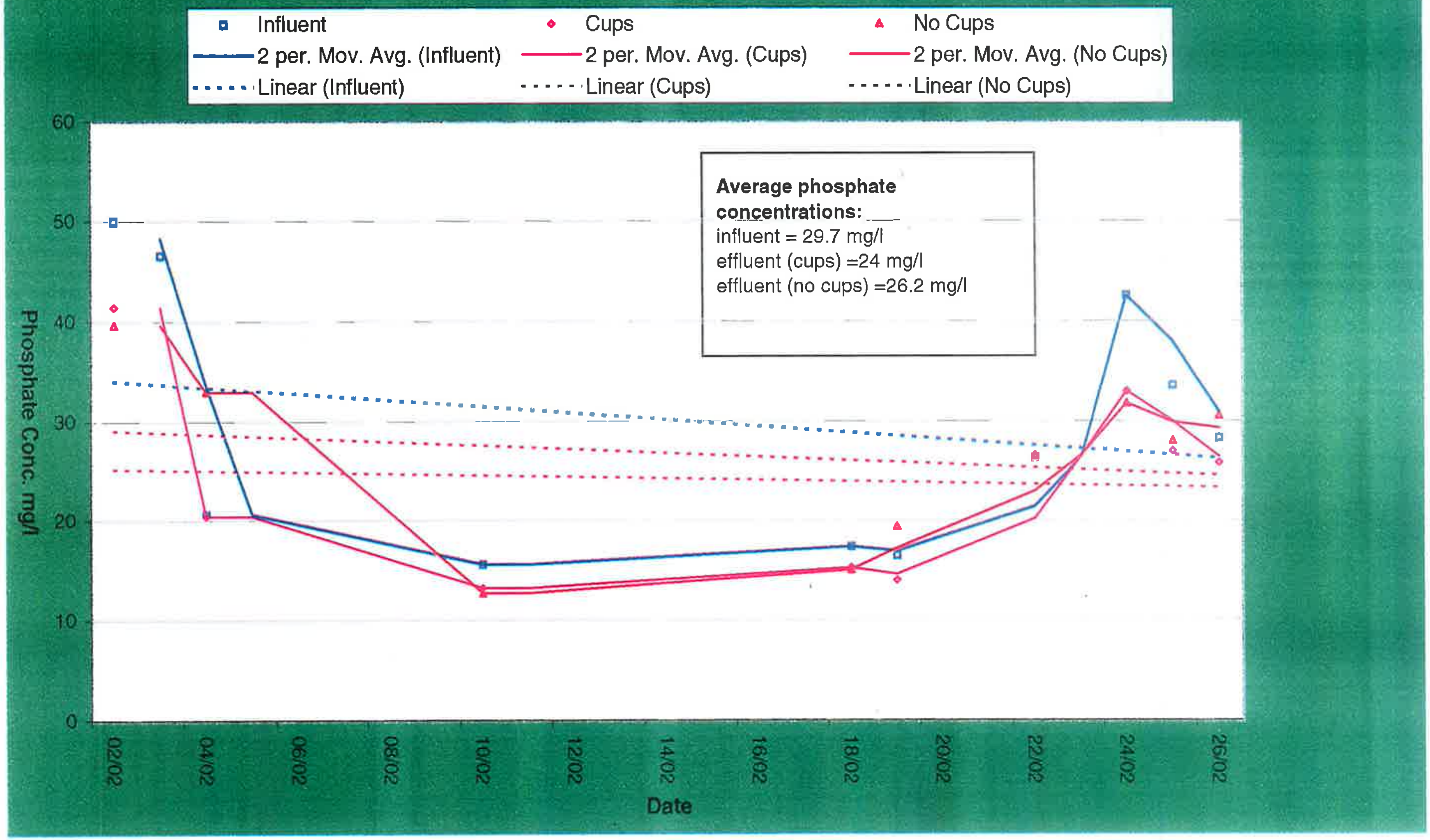
Average phosphate concentrations:
influent = 9.4 mg/l
effluent (cups) =8.9 mg/l
effluent (no cups) =9 mg/l

Figure 5.19: Influent & Effluent Phosphate Concentrations
Flowrate at 180 Litres/Day
(12.5% detergent added)



Average phosphate concentrations:
influent = 13.8 mg/l
effluent (cups) =12.3 mg/l
effluent (no cups) =12.2 mg/l

Figure 5.20: Influent & Effluent Phosphate Concentrations
Flowrate at 180 Litres/Day
(20% detergent added)



Average phosphate concentrations:
influent = 29.7 mg/l
effluent (cups) =24 mg/l
effluent (no cups) =26.2 mg/l

- The phosphate results for both units operating with a detergent loading of 15% are shown in Figure 5.21. Phosphorus removal is indicated by linear regression analysis. The average influent phosphate concentration was 27.5 mg/l and the average treated effluent values for the cup and no cup units were 23.7 and 22.3 mg/l respectively. This would account for a removal efficiency of 14% in the cupped unit and a removal efficiency of 19% in the flat disc unit.

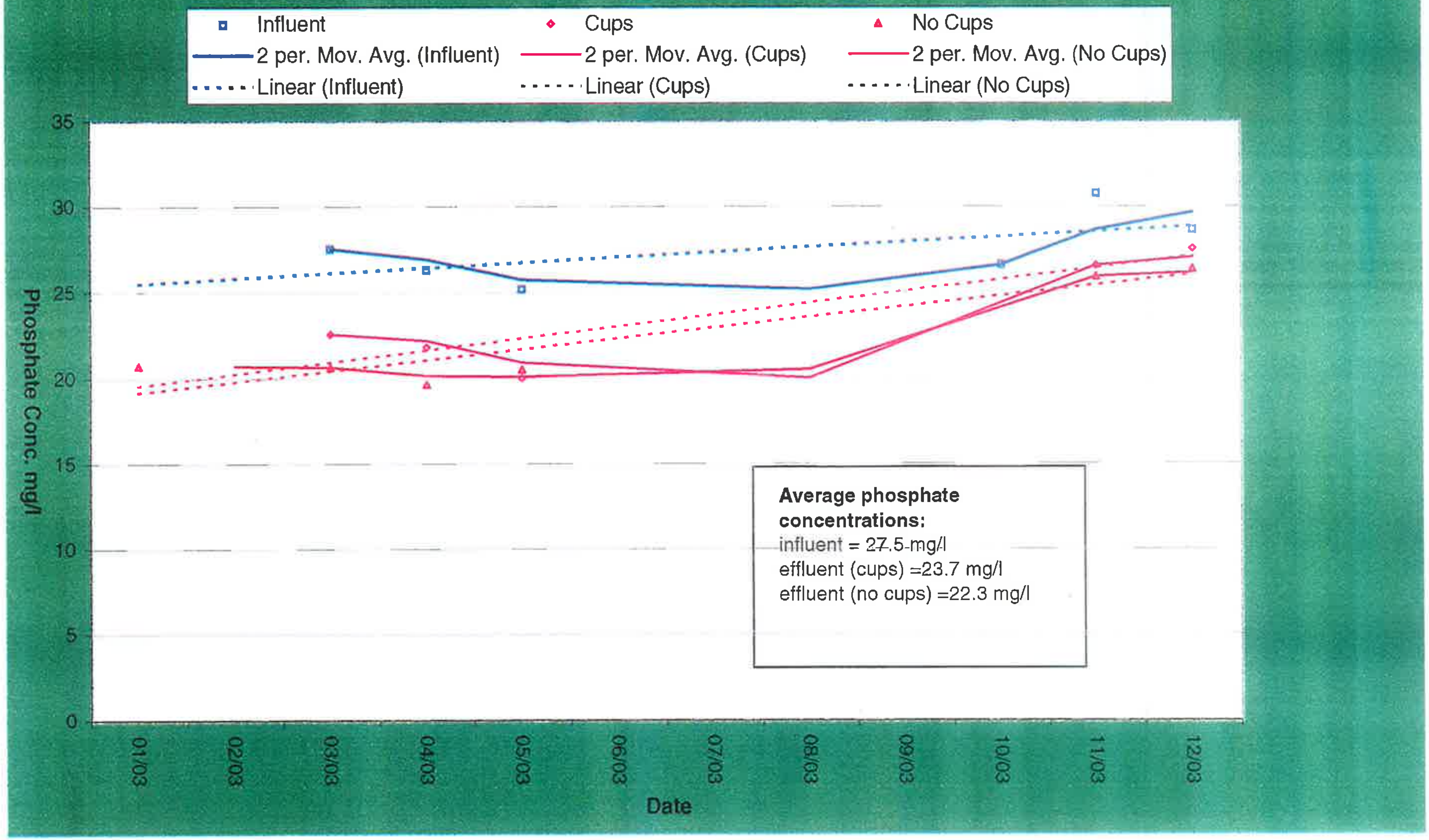
- Figure 5.22 highlights the phosphate results for both units operating with a detergent loading of 5%. Phosphate removal is indicated by linear regression analysis. The average influent phosphate concentration was 12.1 mg/l and the average treated effluent values for the cup and no cup units were 10.6 and 10 mg/l respectively. This accounts for removal efficiencies of 13% and 17% in the cup and no cup units respectively. The influent phosphate concentration was higher at 5% detergent than at 10% detergent which may be due to carryover of residual phosphate from the 15% detergent feed to the 5% detergent feed.

There was little difference found between the reactive and total phosphate reading.

Detergent Concentration	*Average Influent COD Conc. mg/l*	*Average phosphate concentration mg/l*	*Influent COD: Phosphate ratio*
10% detergent	148.1	9.4	16
12.5% detergent	169.8	13.8	12.3
20% detergent	250.3	29.7	12.9
15% detergent	355.6	27.5	12.9
5% detergent	225.9	12.1	18.9

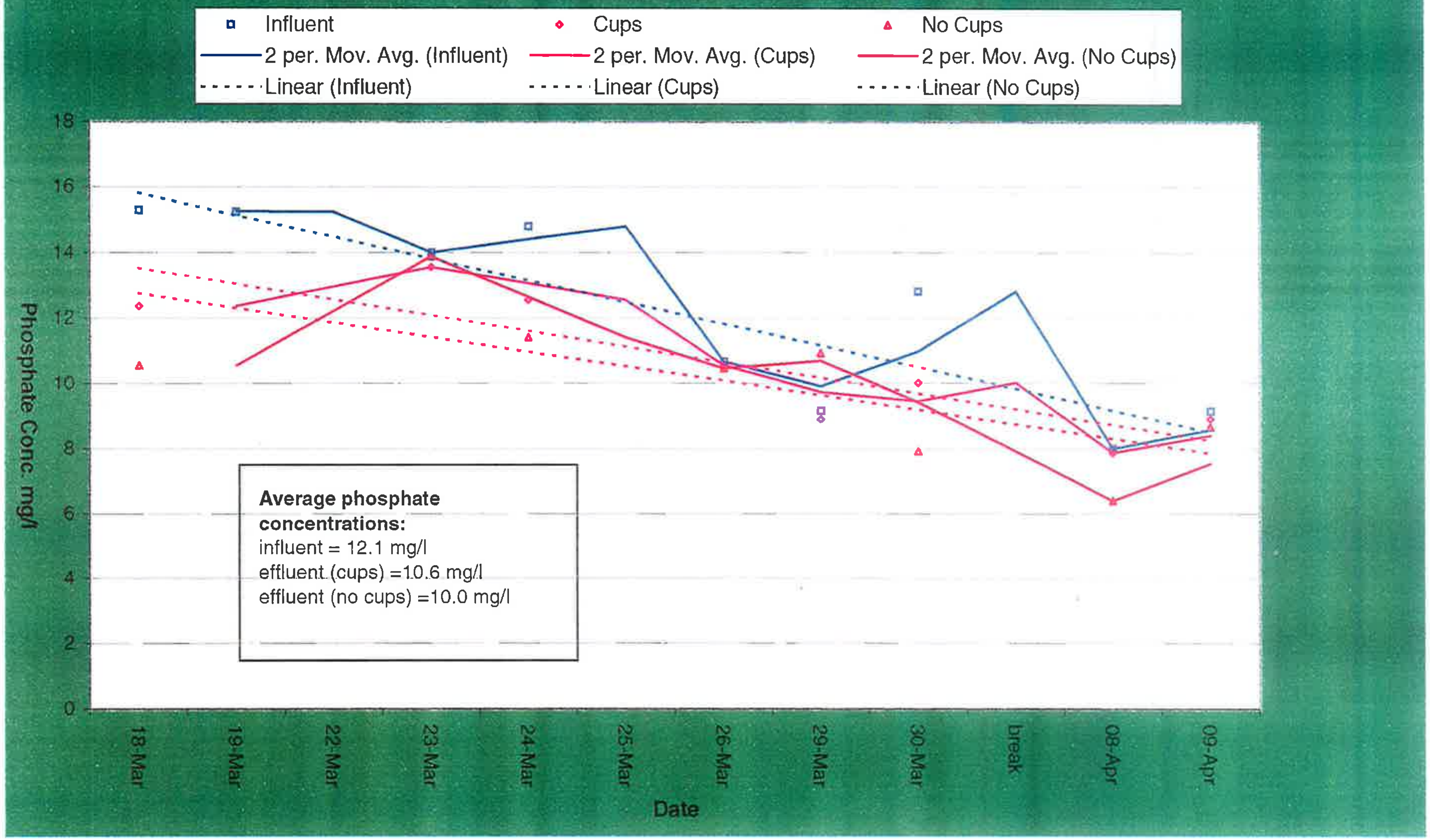
Table 5.18: illustrates the influent to phosphate ratio at varying detergent loadings.

Figure 5.21: Influent & Effluent Phosphate Concentrations
Flowrate at 180 Litres/Day
(15% detergent added)



Average phosphate concentrations:
influent = 27.5 mg/l
effluent (cups) =23.7 mg/l
effluent (no cups) =22.3 mg/l

Figure 5.22: Influent & Effluent Phosphate Concentrations
Flowrate at 180 Litres/Day
(5% detergent added)



Average phosphate concentrations:
influent = 12.1 mg/l
effluent (cups) =10.6 mg/l
effluent (no cups) =10.0 mg/l

5.6 STAGE 3 TEST RESULTS

In Stage 3 the hydraulic loading rate was maintained constantly at 180 l/d, the organic loading rate was however increased significantly and a shock detergent loading was also applied. The period of operation with the high organic loading rate and subsequent detergent addition is highlighted in Table 5.19.

Hydraulic flow-rate	*Period of operation*	*Organic loading*
180 litres/day	20 April to 24 May	22.44g COD/m^2.d
180 litres/day	24 May to 8 June	37.68 to 53.48g COD/m^2.d (with detergent added)

Table 5.19: illustrates the parameters varied for Stage 3.

5.6.1 Influent chemical oxygen demand concentrations

Figure 5.23 shows a plot of the daily influent COD concentrations together with the final effluent concentrations for both units during Stage 3 testing.

Figure 5.24 shows the average influent COD concentration to both units, with standard deviations, for each loading case. The final effluent COD values are also plotted on Figure 5.24. Both units appear to be operating similarly until the addition of the shock detergent loading. The unit with the aeration cups attached achieved a much higher quality COD effluent when compared to the flat disc unit.

- The feed without detergent added was maintained so as to supply an average influent COD concentration of 521 mg/l with a standard deviation of 64 mg/l to each unit.

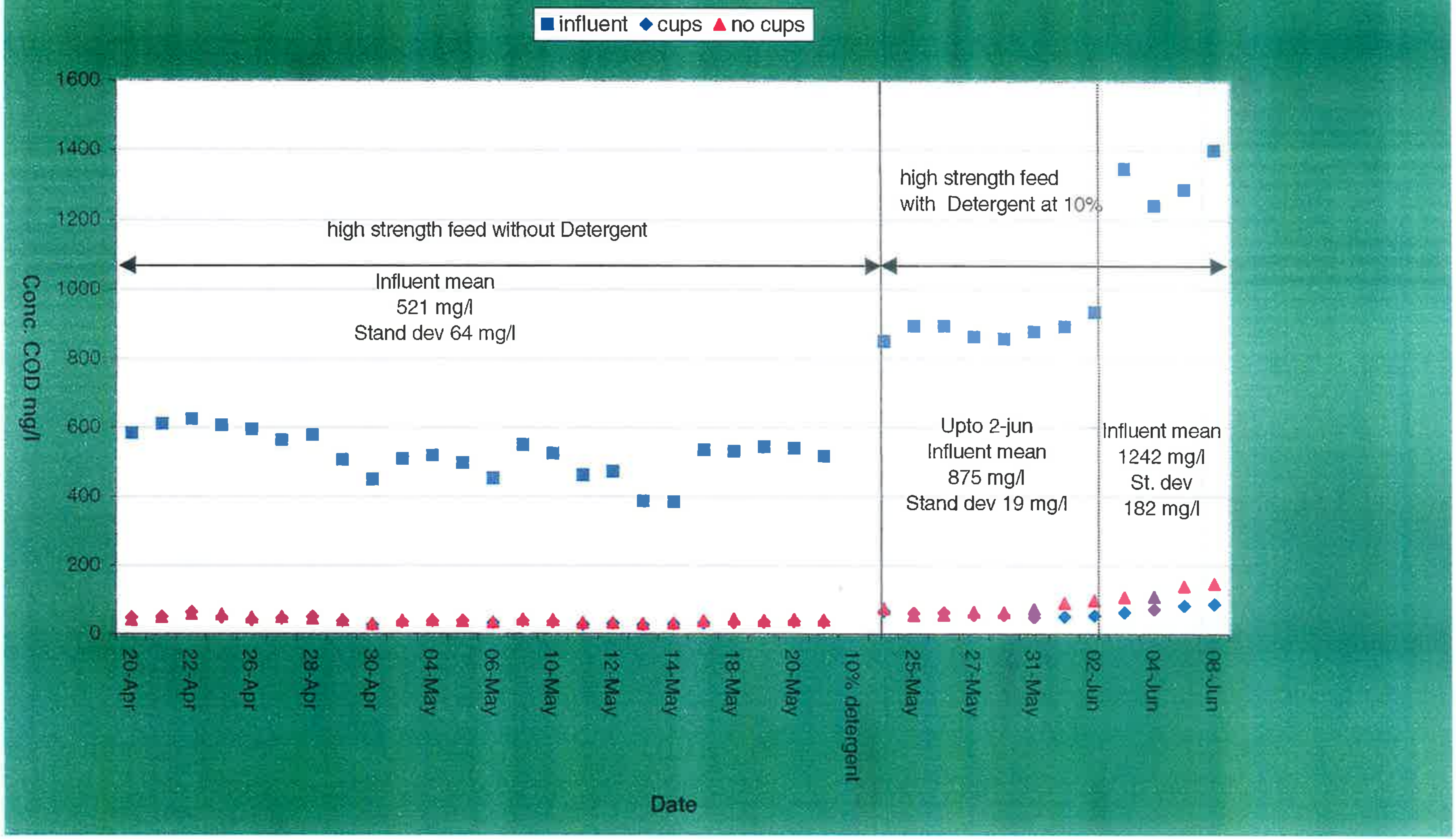
- The feed had a 10% detergent concentration of stock added to supply an average influent COD concentration of 875 mg/l with a standard deviation of 19 mg/l to each unit. This regime was operated between the 24th of May and the 2nd of June. From then until the end of testing on the 8th of June the influent mean was further increased to 1242 mg/l with a standard deviation of 182 mg/l.

5.6.2 COD:BOD relationship

Detergent Concentration	*Influent COD:BOD ratio*	*Cup Unit (effluent) COD:BOD ratio*	*No Cup Unit (effluent) COD:BOD ratio*
0% detergent	1.72	2.32	2.13

Table 5.20: illustrates the COD: BOD relationship for the high organic loading, without detergent addition (refer to Appendix 2 for the actual BOD results).

Figure 5.23: Influent & Effluent COD Concentrations
Flowrate at 180 Litres/Day
(high strength feed)



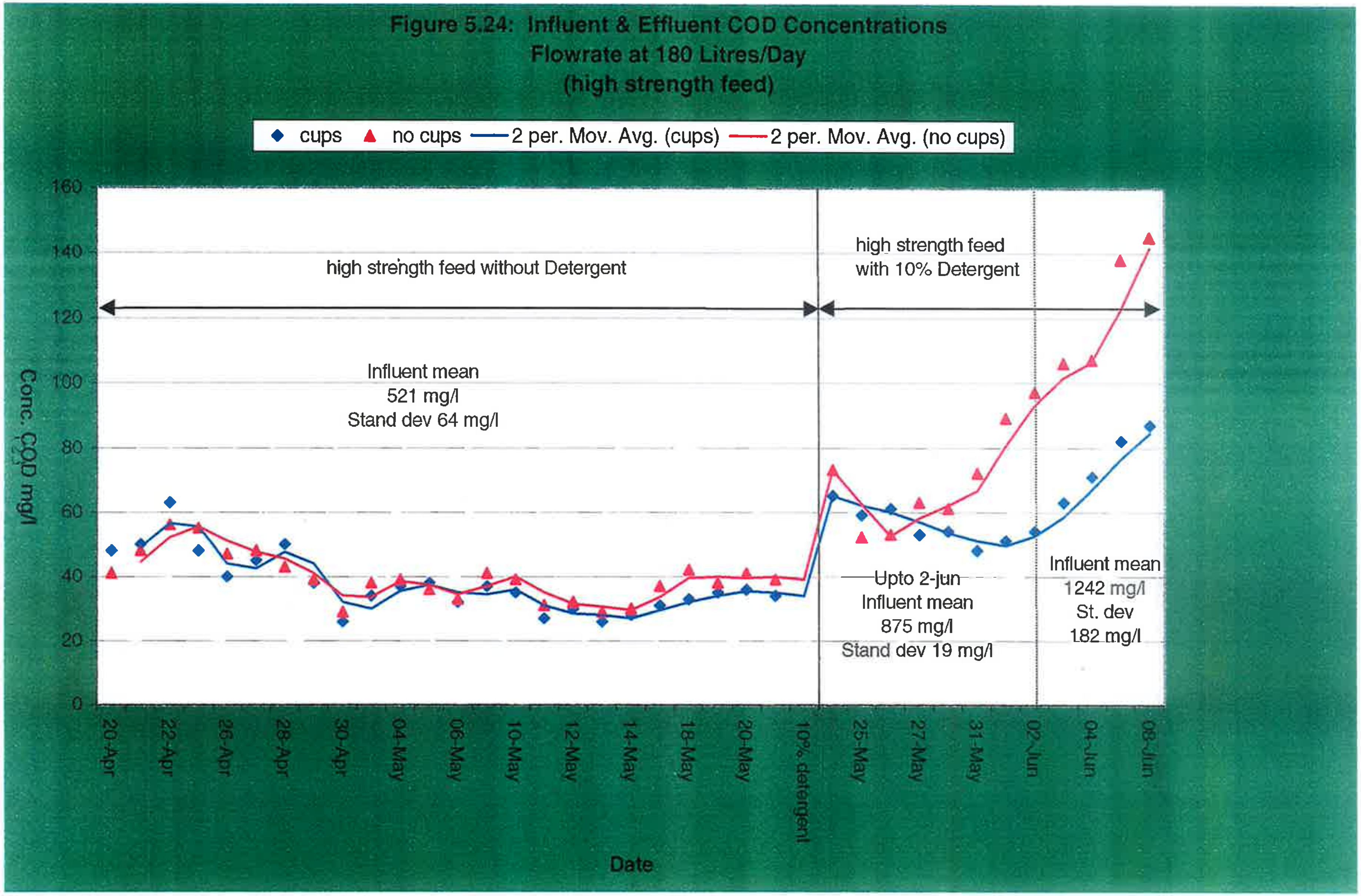


Figure 5.24: Influent & Effluent COD Concentrations
Flowrate at 180 Litres/Day
(high strength feed)

- For the high organic loading without detergent added the full set of results were used as steady state. The average results are summarised in Table 5.21 below (refer to Appendix 2 for full results over this period).

High organic loading	*COD Mean (St. deviation)*	*$gCOD/m^2.d$*
Influent	521 (64) mg/l	22.44
Effluent COD (Cups)	38 (9) mg/l	1.64
Effluent COD (No Cups)	40 (7) mg/l	1.72

Table 5.21: illustrates average steady state results at a detergent high organic loading rate.

- At a high organic loading with 10% detergent added steady state was taken to occur from the 24th May until the 1st June. The average results are summarised in Table 5.22 below (refer to Appendix 2 for full results over this period).

High organic loading with detergent added	*COD Mean (St. deviation)*	*$gCOD/m^2.d$*
Influent	875 (19) mg/l	37.68
Effluent COD (Cups)	56 (6) mg/l	2.41
Effluent COD (No Cups)	66 (13) mg/l	2.84

Table 5.22: illustrates the steady state results for high organic loading with detergent.

- At the highest organic loading with 10% detergent added steady state was taken to occur from the 2nd June until the 8th June. The average results are summarised in table 5.23 below (refer to Appendix 2 for results over this period).

Highest organic loading with detergent added	*COD Mean(St. deviation)*	*$gCOD/m^2.d$*
Influent	1242 (182) mg/l	53.48
Effluent COD (Cups)	71 (14) mg/l	3.06
Effluent COD (No Cups)	119 (21) mg/l	5.12

Table 5.23: illustrates the steady state results for highest organic loading with detergent.

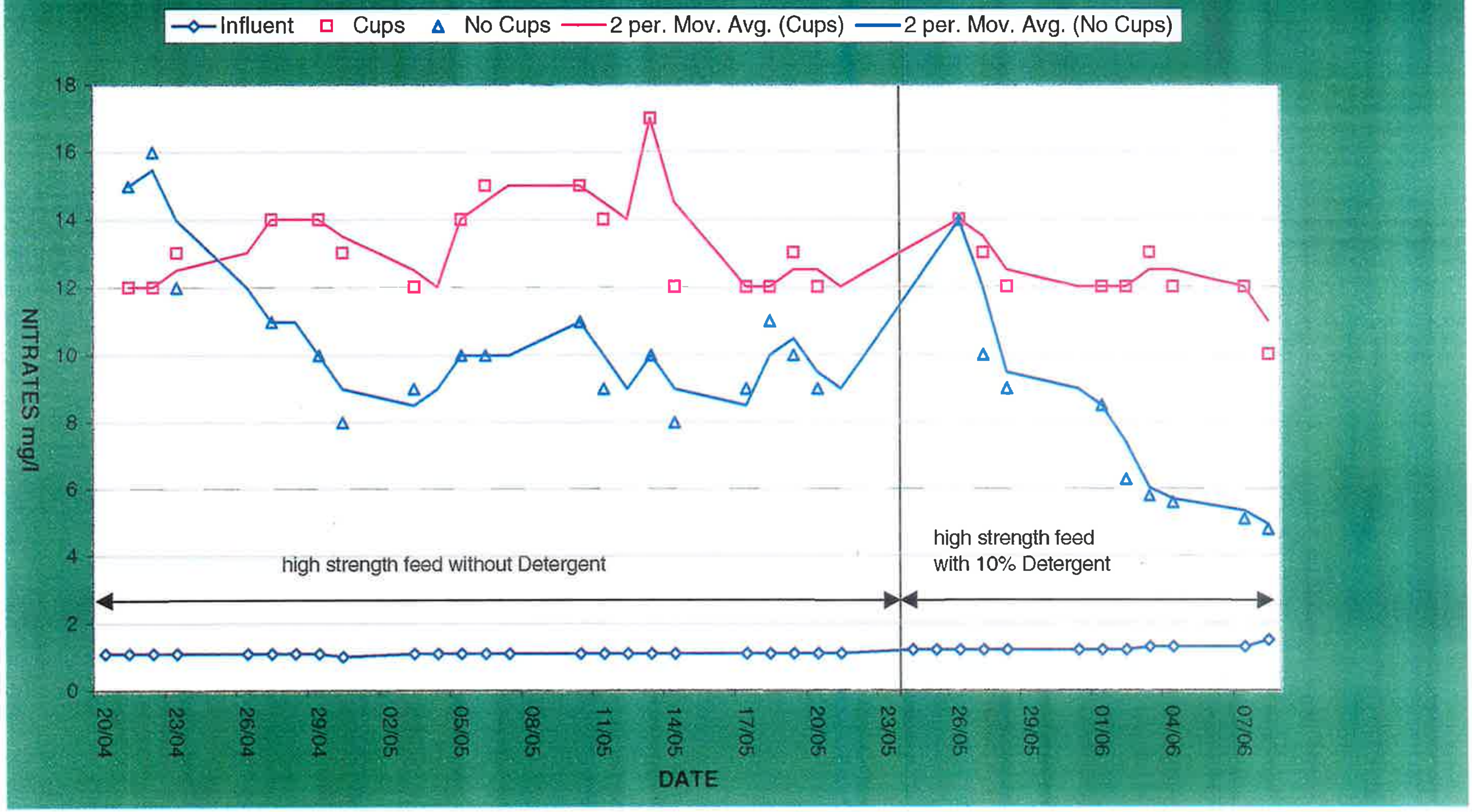
5.6.3 Nitrates

Figure 5.25 shows the varying levels of nitrification achieved by both RBC units during Stage 3 testing (refer to Appendix 2 for daily results).

- The average influent nitrate concentration, throughout the third stage of testing, for the high strength waste with no detergent added was approximately 1.1 mg/l. The treated effluent nitrate values were on average 13 mg/l in the cup unit and 10 mg/l in the flat disc unit. These are relatively low nitrate values. The reason for this may have been due to dominant carbonaceous oxidation taking place.

- The average influent nitrate concentration, throughout the third stage of testing, for the high strength waste with detergent added was approximately 1.3 mg/l. The treated effluent nitrate values were on average 12 mg/l in the cup unit. The treated effluent nitrate values in the flat disc unit rapidly reduced, to below 6 mg/l, as the influent COD concentration increased. The reasons for the reduced nitrification in both units may be that mainly carbonaceous oxidation was taking place and also the detergent may have affected the nitrifying bacteria.

Figure 5.25: NITRATE LEVELS IN TREATMENT UNITS
Flowrate at 180 Litres/Day
(high strength feed)



5.6.4 pH

Figure 5.26 shows the daily pH readings taken within the RBC trough with the aeration cups attached. The trend in general is that the pH is close to 7 in all stages. The same applies to Figure 5.27, for the flat disc unit. In fact in some cases the pH began to rise from stage one to two in the RBC trough and then decreased again from stages three to four. This could be attributed to the production of CO_2, subsequent gas stripping from the wastewater and the onset of nitrification *(Friedman et al. 1979; Surgeoner, 1997).*

5.6.5 Dissolved Oxygen

The dissolved oxygen concentrations for the RBC unit with the aeration cups attached are shown in Figure 5.28. As was the case in the previous testing regimes the general trend was still prevalent i.e. stage one generally had the lowest DO concentration while stage four had the highest. The DO concentrations for the flat disc unit, Figure 5.29, show a similar trend. Comparison of Figures 5.28 and 5.29 while following the 2 point moving averages show that the unit with the aeration cups attached had a higher DO concentration throughout. This factor also contributed to the slightly higher degree of nitrification in the cupped unit when compared to the flat disc unit. The DO concentrations in stage four of the RBC unit with the cups attached were on average above 4 mg/l whereas the corresponding stage in the flat disc unit had concentrations less than 4 mg/l. The DO concentrations in stage one of the unit with the cups attached were on average above 2 mg/l. However, the flat disc unit had levels consistently below 2 mg/l in stage one and as the organic loading increased (with detergent addition) stages two and three in the RBC began to fall below 2 mg/l. This would indicate that the flat disc unit had surpassed its design capacity as poor effluent quality was obtained at the higher organic loading together with a fall-off in the degree of nitrification.

Figure 5.26: pH Levels In Unit with Cups
Flowrate at 180 Litres/Day
(high strength feed)

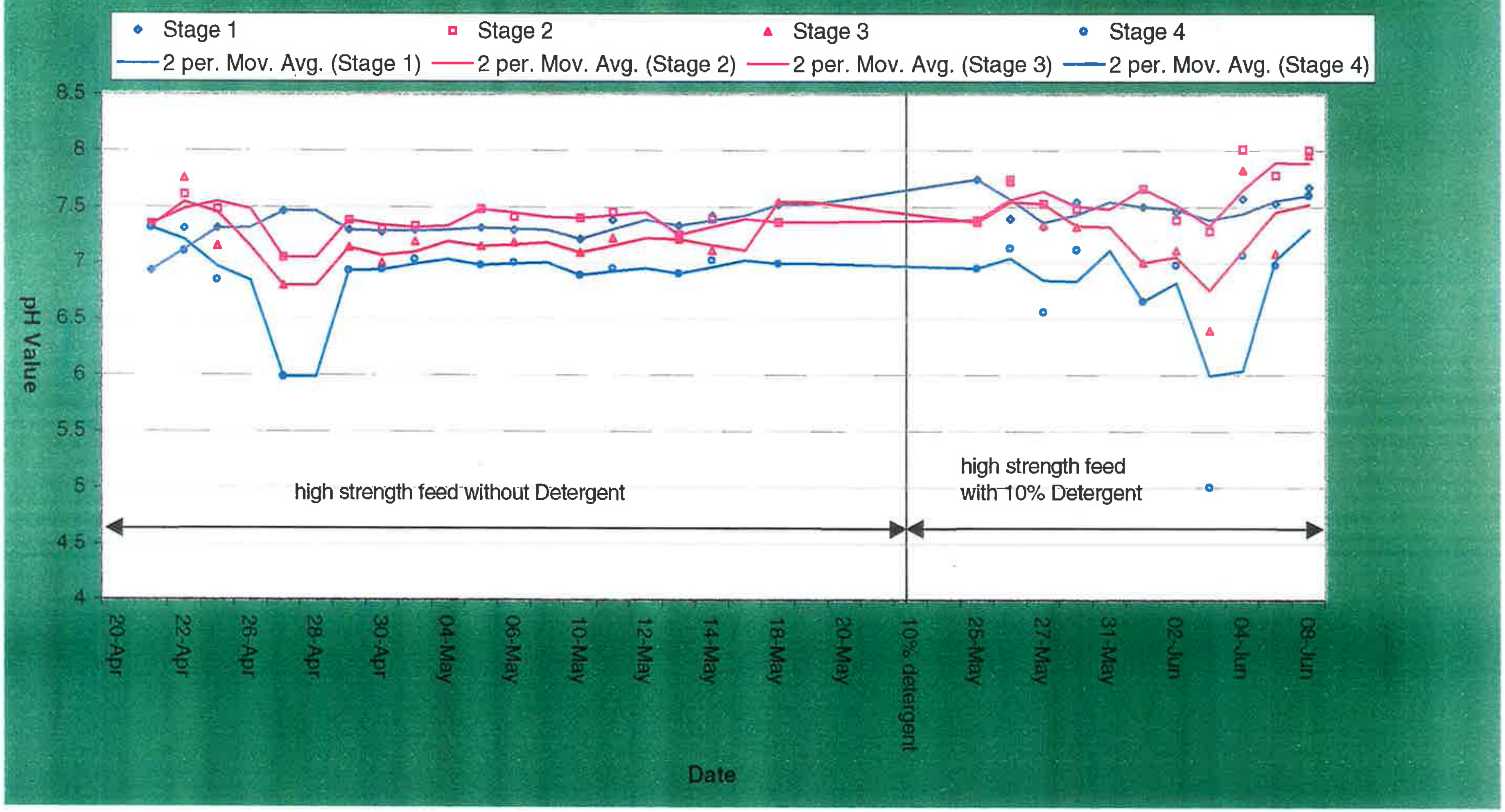


Figure 5.27: pH Levels In Unit Without Cups
Flowrate at 180 Litres/Day
(high strength feed)

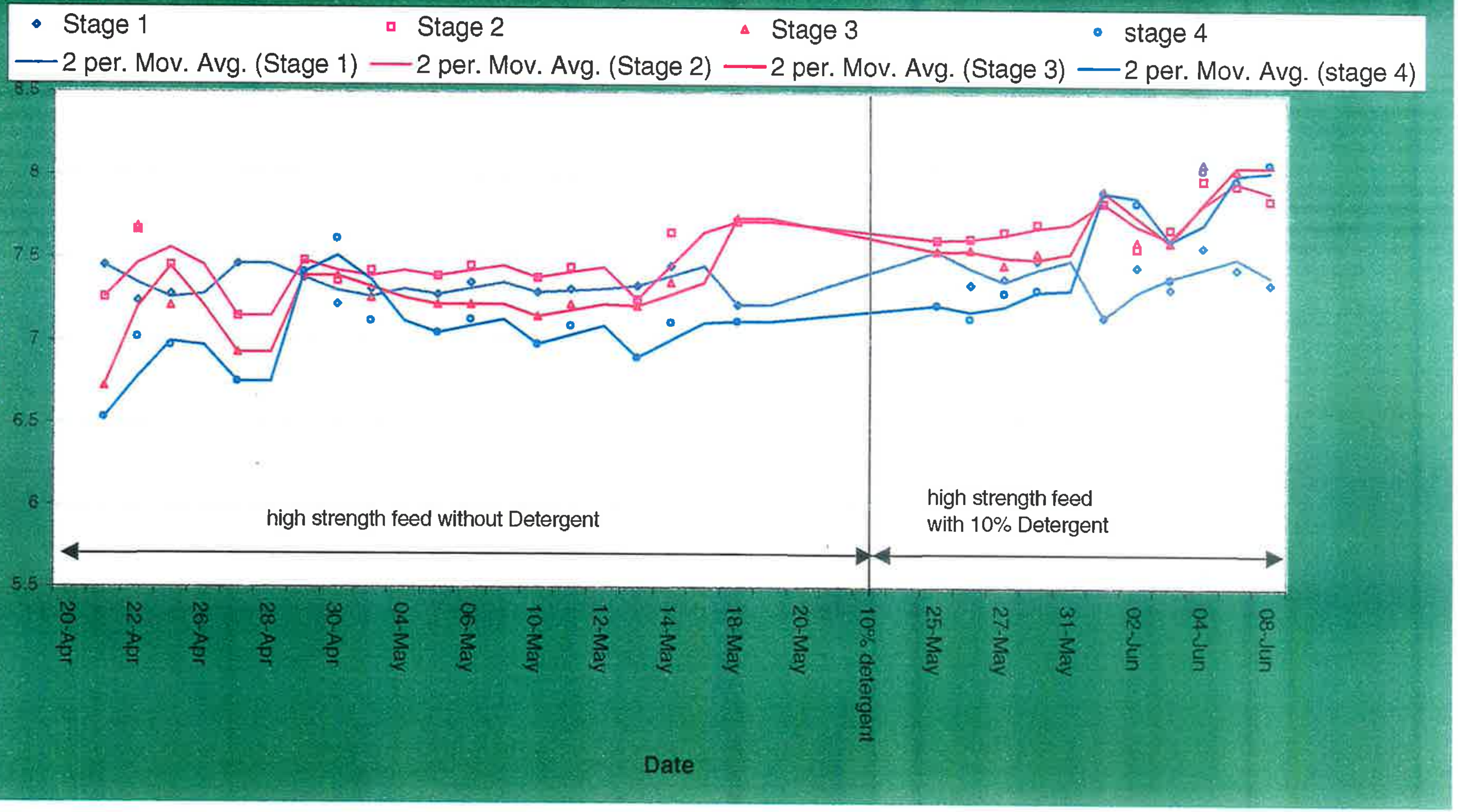


Figure 5.28: DO Conc. In R.B.C. Unit with Cups
Flowrate at 180 Litres/Day
(high strength feed)

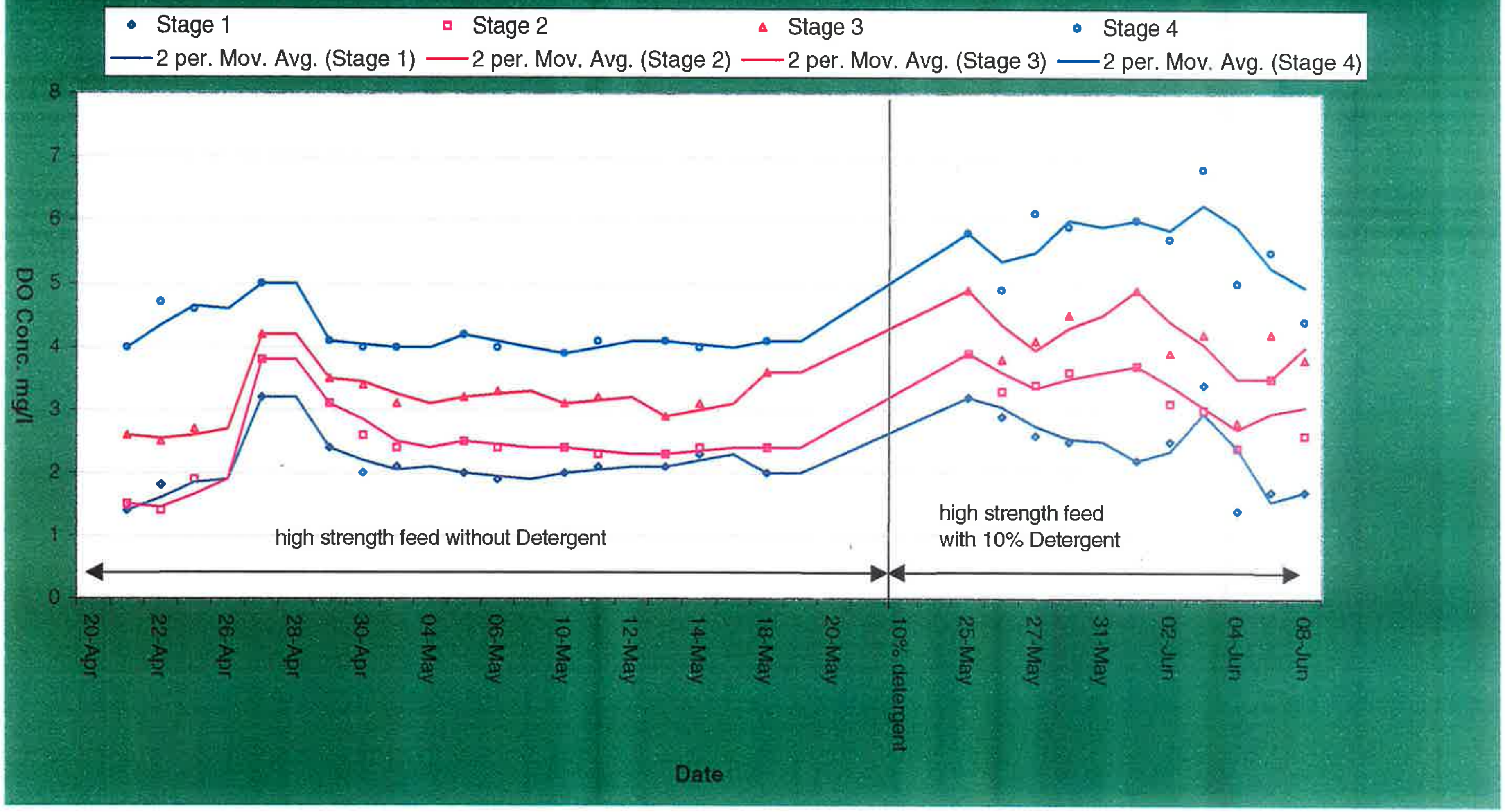
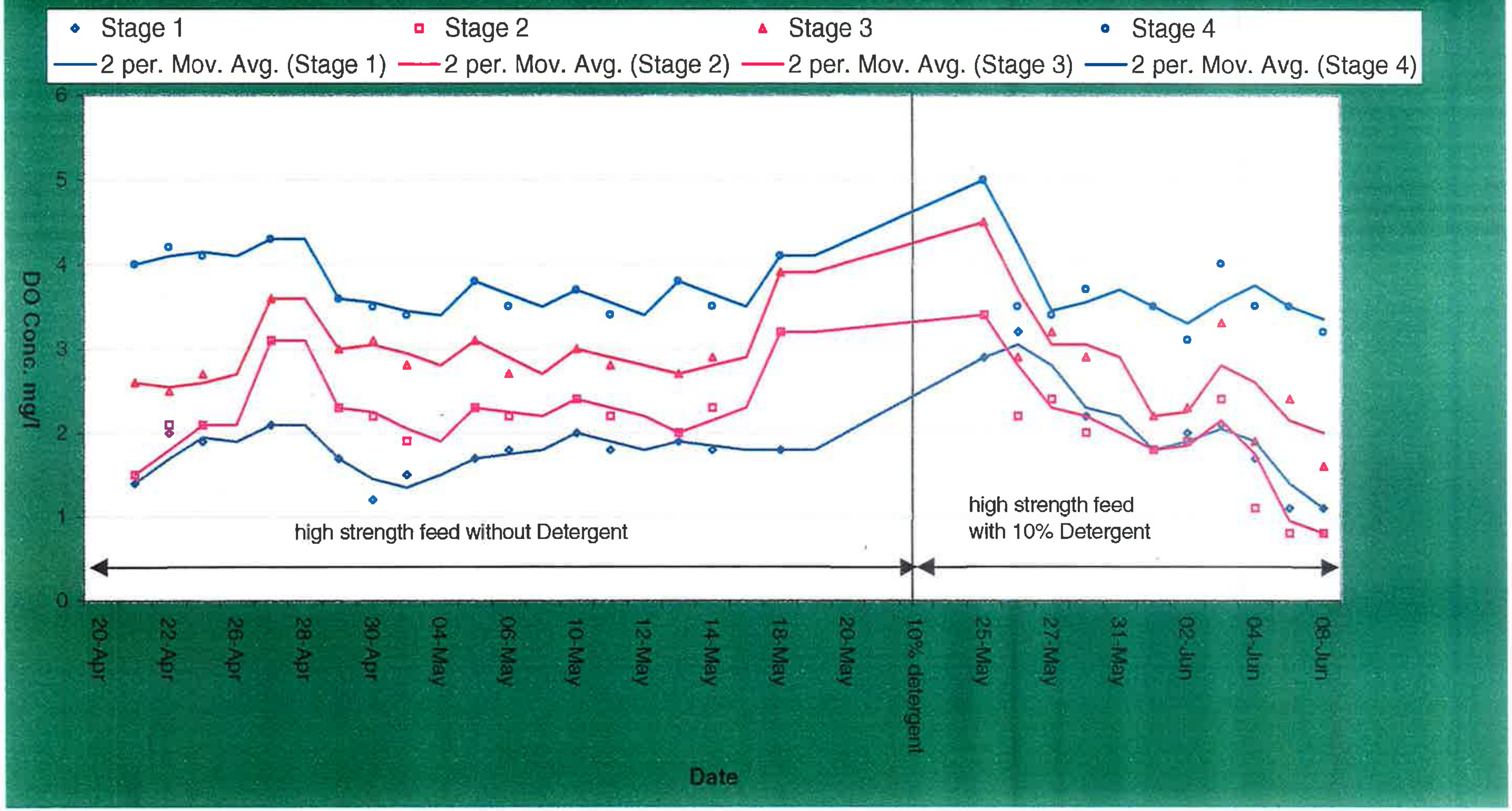


Figure 5.29: DO Conc. In unit without Cups
Flowrate at 180 Litres/Day
(high strength feed)



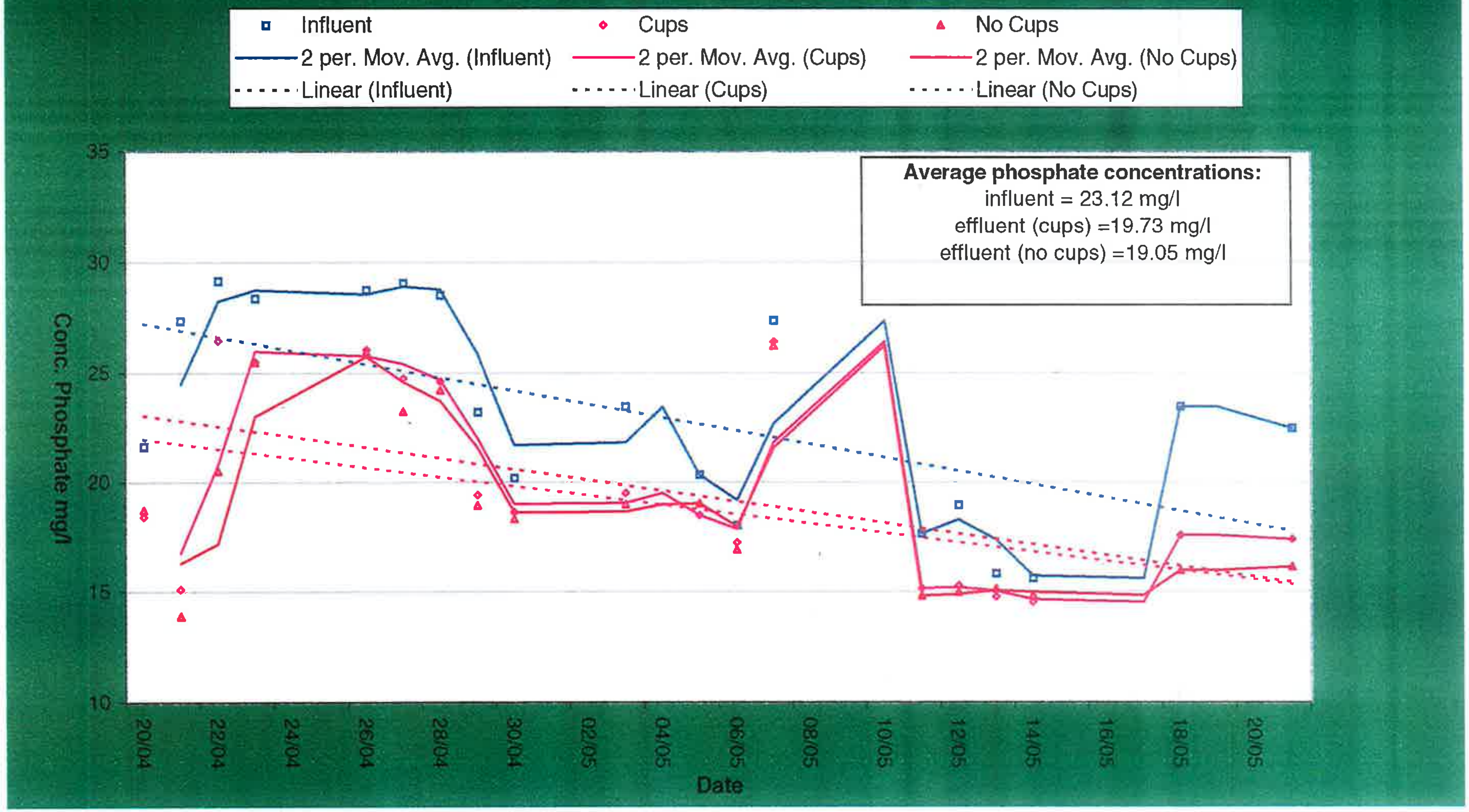
5.6.6 Phosphates

- Figure 5.30 highlights the phosphate results for both units operating at the high organic loading rate (22.44 gCOD/m^2.d) without detergent addition. Phosphorus removal is indicated by linear regression analysis. The average influent phosphate concentration was 23.12 mg/l with the average treated effluent values for the cup and no cup units at 19.73 and 19.05 mg/l respectively. This would account for a removal efficiency of 14.7% in the cupped unit and a removal efficiency of 17.6% in the flat disc unit (the daily phosphate results can be found in Appendix 2).

High organic loading rate	*Average Influent COD concentration mg/l*	*Average influent phosphate concentration mg/l*	*Influent: Phosphate ratio*
No detergent	518.3	23.12	22.8

Table 5.24: illustrates the influent COD to phosphate ratio at a high organic loading.

Figure 5.30: Influent & Effluent Phosphate Concentrations
Flowrate at 180 Litres/Day
(high strength feed - no detergent)



Average phosphate concentrations:
influent = 23.12 mg/l
effluent (cups) =19.73 mg/l
effluent (no cups) =19.05 mg/l

5.7 PARAMETERS COMMON TO BOTH RBC UNITS

5.7.1 Temperature

The temperature of the wastewater for the duration of the research programme varied from a summer high of 19^{0}C to a winter low of 7^{0}C, the daily-recorded temperatures are shown in Appendix 2. Both units were covered to avoid sunlight, from roof lights in the laboratory, affecting the treatment temperature. Operational temperatures between 5 and 15^{0}C have been deemed to have little effect on treatment efficiency *(Forgie, 1984)*.

5.7.2 Microscopic analysis

Once a RBC is seeded a biofilm accumulates a layer of living organisms which are responsible for nutrient removal from an effluent. The biofilm contains a varied microbial community that includes filamentous and unicellular bacteria, protozoa and metazoa. Metazoa forms include nematodes and rotifers *(Kinner et al., 1984)*. Filamentous forms of organisms also found on RBC discs include spaerotilus, beggiotoa, fusarium, nocardia, cladothrix and oscillatoria *(Karsa et al., 1983)*. Scanning electron microscopic analysis of RBC biofilm has found it to be stratified, which comprised of a black anaerobic under layer with an outer aerobic filamentous layer *(Kinner et al, 1983 & 1985)*. Filamentous bacteria give a shaggy texture and creamy-white appearance to the biofilm disc growth. *Sphaerotilus* Natans are the dominant species when RBCs are operating over the winter months. If the loading rates are increased the dissolved oxygen concentrations decrease which provides ideal conditions for *spirillum*. An example of a typical white filamentous type appearance on a RBC disc unit is shown in Plate 5.1. This is taken from a full size RBC unit operating at the Institute of Technology, Sligo.

Plate 5.1 illustrates the white filamentous growth on a RBC unit

Following start up of a RBC a succession in the protozoa and metazoa communities occurs. Initial colonisation of the bacterial film by zooflagellates and small amoebae occurs within one day of start up. Rapid colonisation by nematodes and stalked ciliates then occurs, and finally carnivorous ciliates, rotifers, and large amoebae become established *(Wastewater Biology, 1990).*

Stratification also occurs with free swimming bacteria, dominant in the first compartments where the higher loading rates exist. More diverse and specialised communities inhabit the lightly loaded compartments. A typical example of a protozoan free swimming ciliate is shown in Plate 5.2. This is taken from the first stage of the cupped RBC unit. There are several ways in which protozoa impact on effluent quality: the most important are the removal of bacteria, even pathogenic bacteria, by predation and enhancement of floc formation *(Wastewater Biology 1990).*

Plate 5.2: Free swimming ciliate taken from the cupped RBC unit

Numerous metazoan nematodes and to a lesser extent rotifers were observed in samples taken from both RBC units. The presence of nematodes would normally be an indicator of long retention times in an activated sludge unit, but in the case of the RBC unit they are indicative of a long growth age of the biofilm. In the fixed film process the rotifers aid the sloughing off of biological slime layers. Oxygen is able to penetrate to the lower layers and increased aeration and microbial stabilisation is possible. Rotifers are the next higher form of micro-life beyond the stalked ciliates and are not usually found in heavily polluted environments *(Wastewater Biology, 1990)*.

The presence of certain protozoan and metazoan populations may give an indication of effluent quality. The presence of flagellates and *opercularia* is more frequently observed in the final compartments of RBCs with an effluent BOD_5 greater than 20mg/l. when effluent BOD5 is less than 20mg/l, *arcella, difflugia*, rotifers and annelid worms are most common *(Kinner et al., 1987).*

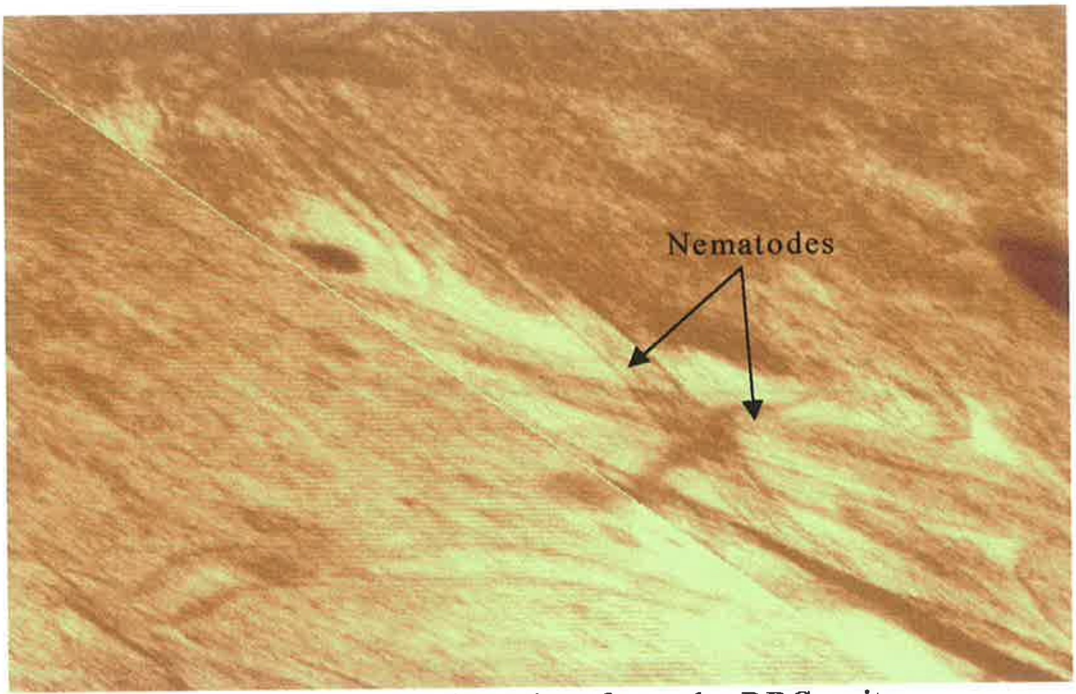


Plate 5.3: Metazoan nematodes taken from the RBC units

5.7.3 Power consumption- cost benefit of using a modified RBC unit

For almost the entirety of this research programme both RBC units were operated at a disc rotational speed of 2 rpm. The power consumption was found not to vary considerably between both units. However on the last day of testing i.e. when a very high organic loading rate was being applied to both units, very low dissolved oxygen (DO) levels were recorded in the flat disc RBC trough. The speed of disc rotation was increased in the flat disc unit to 4 rpm, to maintain comparative DO readings to the modified RBC unit. The associated increase in speed caused an increase in power consumption for the flat disc unit. To assess the financial impacts of an increased disc rotation speed an assessment was first made of the cost of running the RBC model, operating, at 2 rpm. This was then compared to the unit running at 4 rpm. The costing are based on the Electricity Supply Board Tariff System Rates for the early 1990's.

Power Consumption of the RBC

The amperage of both the flat disc and modified disc units operating at 2 rpm was measured and found to be, on average, approximately 0.4A.

- **Power = Voltage x Amperage**

  Voltage = 220V

  Power = 220 x 0.4 = 88 watts

- Tariff charges – Urban Domestic – Private Dwelling

  These charges can either be applied at a standard rate over 24 hours or divided into two; day charges (15hours) and night saver (9 hours).

RBC	Watts	Hours	24hr day kWh	Day *kWh	Night saver kWh
	88	24	2.11	1.32	0.79

*Daytime hours = 15 hours – 8 am to 11 p.m.

Night saver = 9 hours – Hours at E.S.B. discretion – usually 11 p.m. to 8 am

Total kWh (Night) 2 monthly = 0.79 x 61 days = 48.19 kWh

*Total kWh (day) 2 monthly = 1.32 x 61 days = 80.52 kWh

Total kWh (24hr day) 2 monthly = 2.11 x 61 days = 128.71 kWh

Private dwelling - General purpose tariff

Standing charge = £3.35 / 2 monthly

+

kWh Charges @ 7.14p per kWh

Total kWh 24hr charge = 128.71 x 7.14 = £9.19 / 2 monthly

Total = £12.54 / 2 monthly

Added VAT @ 12.5% + £1.57

2 monthly Total = £14.11

Annual cost on 24 hour day charge = £84.66p

<u>Private dwelling - General purpose night saver tariff</u>

Standing charge = £9.55 / 2 monthly

+

Day kWh Charges @ 7.14p per kWh

Total kWh day charge = 80.52 x 7.14 = £5.75 / 2 monthly

+

Night kWh Charges @ 2.85p per kWh

Total kWh 24hr charge = 48.19 x 2.85 = £1.37 / 2 monthly

Total = £16.67 / 2 monthly

Added VAT @ 12.5% + £2.08

2 monthly Total = £18.75

<u>Annual cost on night saver charge</u> = **<u>£112.50p</u>**

The general-purpose tariff is £27.84 cheaper per annum than using the night saver system.

Power Consumption of the flat disc RBC at 4 rpm

The amperage of the flat disc unit operating at 4 rpm was measured and found to be approximately 0.47A.

- **Power = Voltage x Amperage**

  Power = 220 x 0.47 = 103.4 watts

- Tariff charges – Urban Domestic – Private Dwelling

Again these charges can either be applied at a standard rate over 24 hours or divided into two: day charges (15hours) and night saver (9 hours).

RBC	Watts	Hours	24hr day kWh	Day *kWh	Night saver kWh
	103.4	24	2.48	1.55	0.93

*Daytime hours = 15 hours – 8 am to 11 p.m.

Night saver = 9 hours – Hours at E.S.B. discretion – usually 11 p.m. to 8 am

Total kWh (Night) 2 monthly = 0.93 x 61 days = 56.73 kWh

*Total kWh (day) 2 monthly = 1.55 x 61 days = 94.55 kWh

Total kWh (24hr day) 2 monthly = 2.48 x 61 days = 151.28 kWh

Private dwelling - General purpose tariff

Standing charge	=	£3.35 / 2 monthly
	+	
kWh Charges @ 7.14p per kWh		
Total kWh 24hr charge = 151.28 x 7.14	=	£10.80 / 2 monthly
Total	=	£14.15 / 2 monthly
Added VAT @ 12.5%	+	£1.77
2 monthly Total	=	£15.92
Annual cost on 24 hour day charge	=	**£95.52p**

Private dwelling - General purpose night saver tariff

Standing charge = £9.55 / 2 monthly

+

Day kWh Charges @ 7.14p per kWh

Total kWh day charge = 94.55 x 7.14 = £6.75 / 2 monthly

+

Night kWh Charges @ 2.85p per kWh

Total kWh 24hr charge = 56.73 x 2.85 = £1.62 / 2 monthly

Total = £17.92 / 2 monthly

Added VAT @ 12.5% + £2.24

2 monthly Total = £20.16

Annual cost on 24 night saver charge = **£120.96p**

The general-purpose tariff is £25.44 cheaper per annum than using the night saver system.

Chapter 6

Discussion and conclusions

6.1 OXYGEN TRANSFER SOURCES DURING INITIAL AERATION TESTS

Variations in how the six aeration sources contribute to oxygenation of the water, discussed in Section 5.3.2, were assessed at the initial aeration tests period i.e. with the four, five and six aeration cups attached to each disc operated at different speeds. Greater oxygen transfer occurred at higher disc rotational speeds due to increased cup bubbling, turbulence and air entrainment. Examining the K_La values obtained from the aeration tests, Table 5.1 further demonstrates this point. A linear regression analysis of the data (Figure 5.1) shows that oxygen transfer efficiency for each test case approximates to a linear relationship (R^2 =0.9324 for 4 cups; 0.9562 for 5 cups and 0.967 for 6 cups) when KLa is plotted against disc rotational speed.

It was intended at the outset that the main source of oxygen transfer in the system would rely on bubble aeration (Source number 4).

On examination of the Kb values (Table 5.3) the 4-cups/disc gave the highest Kb value, which indicates a more efficient oxygen transfer system. This further verifies that lower cup numbers are more efficient for oxygenation purposes, when related to total cup volume. The other five oxygenation sources described in Section 5.3.2 also contribute substantially to the K_La value *(McCann, 1993)*.

These tests led to the selection of disc cup numbers and arrangements for all three Stages of testing.

6.2 STAGE 1 TEST RESULTS

At a hydraulic flow-rate of 60 l/d the treated effluent COD values were of the lowest standard throughout Stage 1 testing. This is also when the highest degree of nitrification occurred, see Figure 5.4. The high retention time of 12 hours 41 minutes combined with a low flow-rate of 60 l/d may have contributed to the high degree of nitrification. This nitrification together with an associated reduction in pH, Figures 5.5 and 5.6, could have had the effect of suppressing the effluent COD values obtained.

As the hydraulic flow-rate was adjusted to 120 l/d and later to 180 l/d the degree of nitrification decreased with a corresponding increase in pH throughout all four stages of the RBC units.

The highest quality treated effluent COD values were obtained at a hydraulic flow-rate of 180 l/d. The mean COD influent over this period was 174 mg/l with a COD: BOD ratio of 1.7 this would equate to a BOD value of 102 mg/l. The organic loading rates when related to disc area, for both units, was equal to 7.5g COD/m^2.d or 4.4g BOD/m^2.d which is close to the optimum loading rate of 5g BOD/m^2.d specified in BS 6297 (1983). The treated effluent COD values for the cupped unit was on average 31mg/l, with a COD: BOD ratio of 5.52, which would equate to a BOD average of 6 mg/l. The treated effluent COD values for the no cup unit was on average 37mg/l, with a COD: BOD relationship of 5.29, which would yield a BOD average of 7 mg/l.

The percentage COD removal efficiency for both RBC units, at the three different hydraulic flow-rates, cannot easily be compared as the lower the influent COD concentration the more difficult it is to achieve a higher percentage removal. It is also worth noting that as the hydraulic flow-rate increases, the wastewater to be treated is more evenly distributed throughout the biozone. This is particularly relevant to a staged RBC unit when under long hydraulic retention times when there is a greater tendency for the first stage only to remove most of the organic waste, which leaves subsequent stages virtually idle. This was the case in both RBC units at the lower hydraulic loading rate of 60 l/d where biofilm growth was predominant in the first and second stage, with little or no growth in subsequent stages. As the hydraulic loading rates increased the biofilm growth became more evenly distributed.

The suspended solids concentration at low flow-rates went from high values of 56 mg/l and 54 mg/l to low values of 12 mg/l and 14 mg/l in the cup and no cup units respectively. The higher solids concentrations may have been attributable to the longer retention times of 12 hours 41 minutes and 6hours 20 minutes at hydraulic flow-rates of 60l/d and 120 l/d respectively.

The trend in dissolved oxygen concentrations was relatively consistent throughout i.e. the DO concentration increased as each RBC stage progressed. The unit with the cups attached had consistently higher DO levels than the flat disc unit throughout.

The phosphorus removal efficiency, of both units, did not deviate from that expected from an aerobically operated plant. The percentage removal recorded for the cupped unit was at 13.2% for a hydraulic flow-rate of 60 l/d and 24.3% for a hydraulic flow-rate of 180 l/d. The percentage removal for the flat disc unit was 9.6% at 60 l/d and 25.9% at 180 l/d.

The main conclusions from Stage 1 of the study, operating at 3 hydraulic flow-rates, was that the unit with the cups consistently achieved higher degrees of COD removal and nitrification when compared to the conventional flat disc unit.

6.3 STAGE 2 TEST RESULTS

Detergent Concentration	*Influent gCOD/m^2.d*	*Influent gBOD/m^2.d*	*Effluent COD Conc. Cupped Unit*	*Effluent COD Conc. No Cup Unit*
0% detergent	7.5	4.41	31 (4) mg/l	37 (7) mg/l
10% detergent	6.63	3.04	30 (10) mg/l	34 (14) mg/l
12.5% detergent	7.49	3.60	37 (8) mg/l	38 (12) mg/l
20% detergent	10.85	5.34	36 (10) mg/l	39 (10) mg/l
15% detergent	16.62	9.55	37 (6) mg/l	35 (10) mg/l
5% detergent	10.59	5.79	31 (5) mg/l	31 (8) mg/l

Table 6.1 summarises the test results for both units at a flow-rate of 180 l/d (standard deviation in brackets).

Table 6.1 above illustrates the various COD effluent results obtained for the different concentrations of detergent added. In general, the unit with the cups attached gave higher quality treated effluent COD values. The treated effluent values for both units operating without detergents at a hydraulic flow-rate of 180 l/d, during Stage 1 testing have also been included in this table, for comparative purposes. It is evident that the detergent caused treated effluent COD values to deteriorate. The organic loading rate at 0% detergent is 7.5 gCOD/m^2.d (4.41 gCOD/m^2.d), at this loading the cupped unit gives a treated COD effluent of 31 mg/l with a standard deviation of 4 mg/l. From this a maximum treated effluent of (31 ± 2 mg/l) 33 mg/l could be assumed for the cupped unit. If this principle is similarly employed to all the treated effluent COD results then the no cup unit would have a treated effluent value of 40 mg/l at 0% detergent concentration.

At an influent organic loading rate of 6.63 $gCOD/m^2.d$ (3.04 $gCOD/m^2.d$), and with an introduction of 10% detergent, the treated effluent COD value for the cupped unit declined to 35 mg/l for the cupped unit and to 41 mg/l for the no cup unit. Further COD effluent quality deterioration occurred as the detergent loading increased to 12.5% and 20% respectively. The influent organic loading rate for 10% detergent was 7.49 $gCOD/m^2.d$ (3.60 $gBOD/m^2.d$), and 10.85 $gCOD/m^2.d$ (5.34 $gBOD/m^2.d$) for 20% detergent. The treated effluent COD values at 12.5% and 20% were 41 mg/l for the cupped unit and 44 mg/l for the no cup unit, with standard deviations taken into account.

A reduction in the detergent concentration from 20% down to 15% has the effect of causing the quality of the treated effluent COD values to slightly improve. At 15% detergent concentration the influent organic loading rate was 16.62 $gCOD/m^2.d$ (9.55 $gCOD/m^2.d$), and the treated effluent COD value for the cupped unit had improved to 40 mg/l for the cupped unit and 40 mg/l for the no cup unit. These results occurred at a time when the highest organic loading rate was being applied to both units.

A further reduction in the detergent concentration from 15% to 5% leads to a further improvement in treated effluent COD values. At 5% detergent concentration the influent organic loading rate was 10.59 $gCOD/m^2.d$ (5.79 $gCOD/m^2.d$), and the treated effluent COD value for the cupped unit had improved to 33 mg/l for the cupped unit and 35 mg/l for the no cup unit. The treated effluent values, at 5% detergent concentration, were comparable to the treated effluent values obtained when no detergent was added.

The BOD removal efficiencies, Table 6.2, show a similar trend to the COD treated effluent values i.e. the highest degree of treatment, of 96.3%, occurs at a 0% detergent concentration, in the unit with the cups attached. The efficiency in both units declined with the introduction of detergent.

	Detergent Concentration	Influent BOD_5 mg/l	Cup Unit BOD_5 mg/l	No Cup BOD_5 mg/l	% Removal cupped unit	% Removal No cup unit
30-Sep	0%	87	7.6	6.4	91.3	92.6
02-Oct		75	2.8	5.9	96.3	92.1
22-Oct	10%	69	7.6	7.6	89.0	89.0
29-Oct	12.5%	56	6.3	5	88.8	91
25-Feb	20%	150	14	25	90.7	83.3
12-Mar	15%	198	18	32	90.9	83.8
19-Mar	5%	150	9	30	94.0	80.0
09-Apr		90	8	9	91.1	90.0

Table 6.2 illustrates the BOD_5 and % removal values at various detergent concentrations

An improvement in treatment efficiency was seen to occur as the detergent loading was reduced during testing. The poor BOD removal efficiency of 80%, recorded on the 19th of March, at a 5% detergent concentration, could be attributable to a delayed effect of the 15% detergent concentration. The COD: BOD relationship for each detergent concentration is shown in Table 5.12.

The treated effluent nitrate values were on average 13 mg/l in the cup unit and 7mg/l in the flat disc unit (Figure 5.13). These are relatively low nitrate values for treated effluent. Again these values fluctuated downward as detergent concentration increased and upward as the detergent concentration decreased. The associated reduction in pH as the degree of nitrification increased can be seen in Figure 5.14.

The dissolved oxygen concentration values measured during Stage 2 testing followed the trend set in stage 1, i.e. as each stage within the RBC unit progressed the higher the DO readings obtained. This trend varied occasionally, as sloughing off of media in the first

RBC stage would put a greater oxygen demand on the subsequent stages (Figures 5.16 and 5.17).

	influent	*effluent (cups)*	*Effluent (no cups)*
10% detergent	9.4 mg/l	8.9 mg/l	9 mg/l
12.5% detergent	13.8 mg/l	12.3 mg/l	12.2 mg/l
12.5% detergent	29.7 mg/l	24 mg/l	26.2 mg/l
15% detergent	27.5 mg/l	23.7 mg/l	22.3 mg/l
5% detergent	12.1 mg/l	10.6 mg/l	10.0 mg/l

Table 6.3 illustrates the degree of phosphate removal at each detergent loading.

Both RBC units achieved very little phosphate removal throughout Stage 2 testing. The influent phosphate concentration noticeably increased as the detergent concentration increased (Table 6.3). The source of this phosphate was from the added detergent.

6.4 STAGE 3 TEST RESULTS

The Stage 3 treated effluent COD values were obtained at a hydraulic flow-rate of 180 l/d. Initially the mean COD influent was 521 mg/l (standard deviation of 64 mg/l) with a COD: BOD ratio of 1.72, which would equate to a BOD value of 322 mg/l. These organic loading rates, when applied to the disc area of both units, is equal to 22.44g COD/m^2.d or 13.04g BOD/m^2.d which is well in excess of the optimum loading rate of 5g BOD/m^2.d specified in BS 6297 (1983). The treated effluent COD values for the cup unit was on average 42 mg/l, with a COD: BOD ratio of 2.32, which would equate to a BOD average of 18 mg/l. The treated effluent COD values for the no cup unit was on average 44 mg/l, with a COD: BOD ratio of 2.13, which would yield a BOD average of 20.7 mg/l. The flat disc unit reached a stage when it was overloaded, with an unpleasant odour arising from the unit, which is indicative of anaerobiosis.

A shock detergent loading was added to the influent, which further increased the organic loading to both RBC units. Over a period of one week the mean COD influent increased to 875 mg/l (standard deviation of 19 mg/l). The organic loading rate when applied to the disc area, of both units, was equal to 37.68g COD/m^2.d. The treated effluent COD values, for the cup unit, were on average 59 mg/l. The treated effluent COD values, for the no cup unit, were on average 78 mg/l. The organic loading was further increased over a four-day period so that the mean COD influent was 1242 mg/l (standard deviation of 182 mg/l). This organic loading rate when applied to the disc area, of both units, was equal to 53.48g COD/m^2.d. The treated effluent COD values, for the cup unit, were on average 78 mg/l. The treated effluent COD values, for the no cup unit, were on average 130 mg/l. The treated effluent values for this loading did not stabilise and would probably have further deteriorated in the no cup unit as the DO levels had fallen below 2 mg/l in almost all of the RBC stages. For this reason the RBC disc rotational speed was increased from 2 rpm to 4 rpm in the flat disc unit.

The treated effluent nitrate values were on average 13 mg/l in the cup unit and 10 mg/l in the flat disc unit at the initial organic loading rate. These are relatively low nitrate values. The reason for this is that mainly carbonaceous oxidation is taking place.

The treated effluent nitrate values were on average 12 mg/l in the cup unit throughout the third stage of testing, for the high strength waste with detergent added. The treated effluent nitrate values in the flat disc unit rapidly reduced as the influent COD concentration increased.

In some cases the pH began to rise from the first stage to the second in the RBC trough and then decrease again in the third and fourth stages (Figure 5.26). This could be attributable to the production of CO_2, subsequent gas stripping from the wastewater and the onset of nitrification.

The dissolved oxygen concentration values for initial Stage 3 testing followed the trend set in Stages 1 and 2, i.e. as each stage within the RBC unit progressed the higher the DO readings obtained. However as the organic loading further increased the oxygen demands became greater on both units (Figures 5.28 and 5.29).

The average influent phosphate concentration at the high organic loading rate (22.44 gCOD/m^2.d) without detergent addition was 23.12 mg/l (Figure 5.30). The average treated effluent phosphate value for the cup unit was 19.73 mg/l and for the no cup unit was 19.05 mg/l. This accounts for a removal efficiency of 14.7% in the cupped unit and a removal efficiency of 17.6% in the flat disc unit.

6.5 COMPARISON WITH OTHER WORKS

The recommended organic loading rate from BS 6297 is 5g BOD/m^2.d to achieve a final treated effluent value below 20mg/l. Higher values of 9g BOD/m^2.d *(Cheung et al., 1982)* and 7.7g BOD/m^2.d *(Surgeoner, 1998)* have been treated before a deterioration in effluent quality occurred. Surgeoner derived an equation for a particular model, which postulates that the maximum applied load at which treatment longer occurs is 42g COD/m^2.d (23.1g BOD/m^2.day). Organic loading rates in excess of 42g COD/m^2.d were applied to both RBC models, in this study, for a short period of time with very poor treated effluent values recorded. As the higher organic rates were applied only over a short period of time it would be hard to ascertain the applied load at which treatment would no longer occur.

Wastewaters containing a 1 and 5% laundry to 99 and 95% synthetic wastewater mixture have been found to have little effect on BOD removal or microbial activity (Marriott et al. 199?). A wastewater laundry concentration of 10% or higher affects the BOD removal efficiency and 50 and 100% v/v mixtures can inhibit microbial activity (Marriott et al. 199?). The effect, which a 10% (or greater) detergent concentration has on treatment plant efficiency, has been varied in this study.

6.6 POWER COST/CONSUMPTION

When both RBC units were operated at a disc rotational speed of 2 rpm the power consumption was found not to vary considerably. The cost of operating each RBC unit were as follows:

Annual cost on 24 hour day charge = £84.66p

Annual cost on night saver charge = £112.50p

The general-purpose tariff is £27.84 cheaper per annum than using the night saver system.

As the organic loading increased the disc rotational speed of the flat disc unit was increased to 4 rpm and hence the associated increase in power costs were:

Annual cost on 24 hour day charge = £95.52p

Annual cost on 24 night saver charge = £120.96p

The general-purpose tariff is £25.44 cheaper per annum than using the night saver system.

The unit with the cups, operating on the 24-hour day charge at 2 rpm, is clearly the most cost efficient option when compared to the flat disc unit. The flat disc unit operating at 4 rpm is £10.86p per annum more expensive when compared to the cupped unit at the higher organic loading. The difference in operating costs may become even more apparent when operating a full-scale RBC plant.

6.7 CONCLUSIONS

The two main treatment plant parameters influenced by the use of a domestic detergent are the COD/BOD removal efficiency and the phosphate loading.

The use of phosphate free detergents has been advocated in Ireland, in places such as Crossmolina in Co. Mayo *(Lough Conn Progress Report, 1997)*. Phosphate detergent bans have also been implemented to good effect in areas such as Maryland in the USA *(Randall, 1998)*.

However, reports conducted by the Imperial College in England found that phosphate detergent bans would have had little effect in the control of eutrophication *(Randall, 1998)*.

The selection of an alternative detergent ingredient to phosphorus is difficult. The use of micro-powders containing zeolites are preferred in Ireland. In some countries sodium tripolyphosphate has been replaced by sodium nitrilotriacetate (NTA) but concerns over its safety have lead to its disuse in the USA. The advantage of phosphate use in detergents can in some circumstances be justified by its removal at a treatment works by chemical precipitation. Chemical addition in small domestic treatment units such as the septic tank and indeed the RBC unit is not common practice.

The RBC unit on its own does not remove a significant amount of phosphorus in its normal mode of operation. The findings from this work would suggest a maximum achievable phosphate removal of 30%, which would concur with finding for other aerobic biological units.

With maximum phosphorus removal efficiencies of 30%, the use of a proprietary treatment system such as a reed bed system is required to achieve effluent discharge standards, particularly in areas of sensitive waters and where phosphate detergents are used.

The use of powders containing zeolites offer an alternative to the use of phosphate based detergents. However, the overall effect of zeolites on detergent biodegradability should be assessed particularly when using a package treatment unit such as the RBC.

The second and probably most important parameter affected by detergent addition in the RBC system is the COD/BOD removal efficiency.

The introduction of a 10% detergent concentration was found to effect the treatment efficiency of both RBC units. The treated effluent COD values deteriorated from 33 mg/l and 40 mg/l at 0% detergent concentration to 35 mg/l and 41 mg/l at 10% detergent concentration, for the cupped and no cup units respectively. With the addition of higher detergent concentrations of 12.5% and 20% the treated effluent COD values were 41 mg/l for the cupped unit and 44 mg/l for the no cup unit. As the detergent concentration was scaled down to 15% and 5% respectively the final treated effluent COD values were found to gradually improve. At 15% detergent concentration both units achieved a treated effluent COD value of 40mg/l. These values further improved as the detergent concentration was reduced to 5% with 33 mg/l for the cupped unit and 35 mg/l for the no cup unit. The % BOD removal efficiencies would suggest that the unit with aeration cups attached (high of 96% to low of 88%) is more stable than the no cup unit (high of 93% to low of 80%). The unit with the aeration cups attached also achieved a higher degree of nitrification.

The hydraulic loading rate was 180 l/d for all the detergent testing conditions. It is generally found that a variation in the retention times has an effect on aerobic treatment efficiencies with higher degrees of nitrification achieved and lower COD removal efficiencies with longer retention times. The organic loading was increased, with and without detergent addition, from values of 22.44g COD/m^2.d or 13.04g BOD/m^2.d to a high of 53.48g COD/m^2.d in Stage 3 testing. The flat disc unit experienced extremely low dissolved oxygen concentrations (below 2 mg/l) in all RBC stages at the higher organic loading rates. The disc rotational speed was increased to counteract this problem.

The unit with the aeration cups attached operated more successfully than the flat disc unit throughout the entire research program. The addition of detergent did effect the COD treatment efficiency but the cupped unit effluent appeared to be more stable than the flat disc unit. The cupped unit also achieved a higher degree of nitrification throughout and was found to be capable of coping with high strength influent loading at lower disc rotational speeds. Both units achieved little phosphorus removal.

6.8 RECOMMENDATIONS FOR FURTHER WORK

1. A more in depth study into re-aeration and the determination of KLa for different concentrations of detergents would reveal more about the importance of oxygen within the system.
2. It would be advantageous to assess the RBC treatment plant efficiency at higher disc rotational speeds.
3. The treatment plant configurations could be modified i.e. the number of discs in each stage could be varied. The most effective arrangement to improve treatment efficiency could then be ascertained.
4. Scale effects could be investigated by comparing both units to full size units.
5. The development of empirical mathematical relationships could be derived, and further to this a computer model may yield valuable relationships. These relationshipss could be used for predictive and/or comparative purposes, which would be beneficial by virtue of reducing the amount of laboratory work required.
6. The loading rates applied to a full-scale RBC plant should be further assessed. This should include an assessment of the influent concentration together with its time-related flow, from which the organic loading rate per unit area could be obtained. The influent phosphate concentration should also be related to the influent COD concentration, to ascertain if a COD: P ratio exists.
7. The effect of intermittent shock detergent loading could be assessed as opposed to continuously feeding a detergent over a period of time. More practically applicable results, somewhat comparable to large-scale units, may be obtainable.

8. A more extensive microbial study should be undertaken to assess the developments in microbial colonies with time and as test conditions change.

9. More testing methods and procedures could be adopted to further enhance the quality of the work e.g. on-line monitors such as DO probes could be employed with generated results being relayed to a computer.

10. Grab samples were taken from the RBC units at all times, which has inherent drawbacks. Composite sampling of the influent and effluent should be adopted and this could be supplemented by grab samples taken from each stage.

11. Use of plastic as opposed to copper tubing, to protect the metal shaft, may be more desirable from an economic point of view.

12. The RBC unit with the aeration cups attached could be tested against a similarly constructed unit with commercially available discs attached.

13. The costs of aeration could be further assessed on a performance-related basis.

14. The treatment efficiency of both RBC units could be assessed with a number of different detergents. These could encompass the use micro-powders containing zeolites, which are being recommended as replacements for detergent phosphates.

15. Further verification work on the effects of chemical dosing, such as ferric sulphate, to precipitate phosphates could be carried out. The different mixing regime obtained from the cupped RBC unit may improve phosphate removal by this method.

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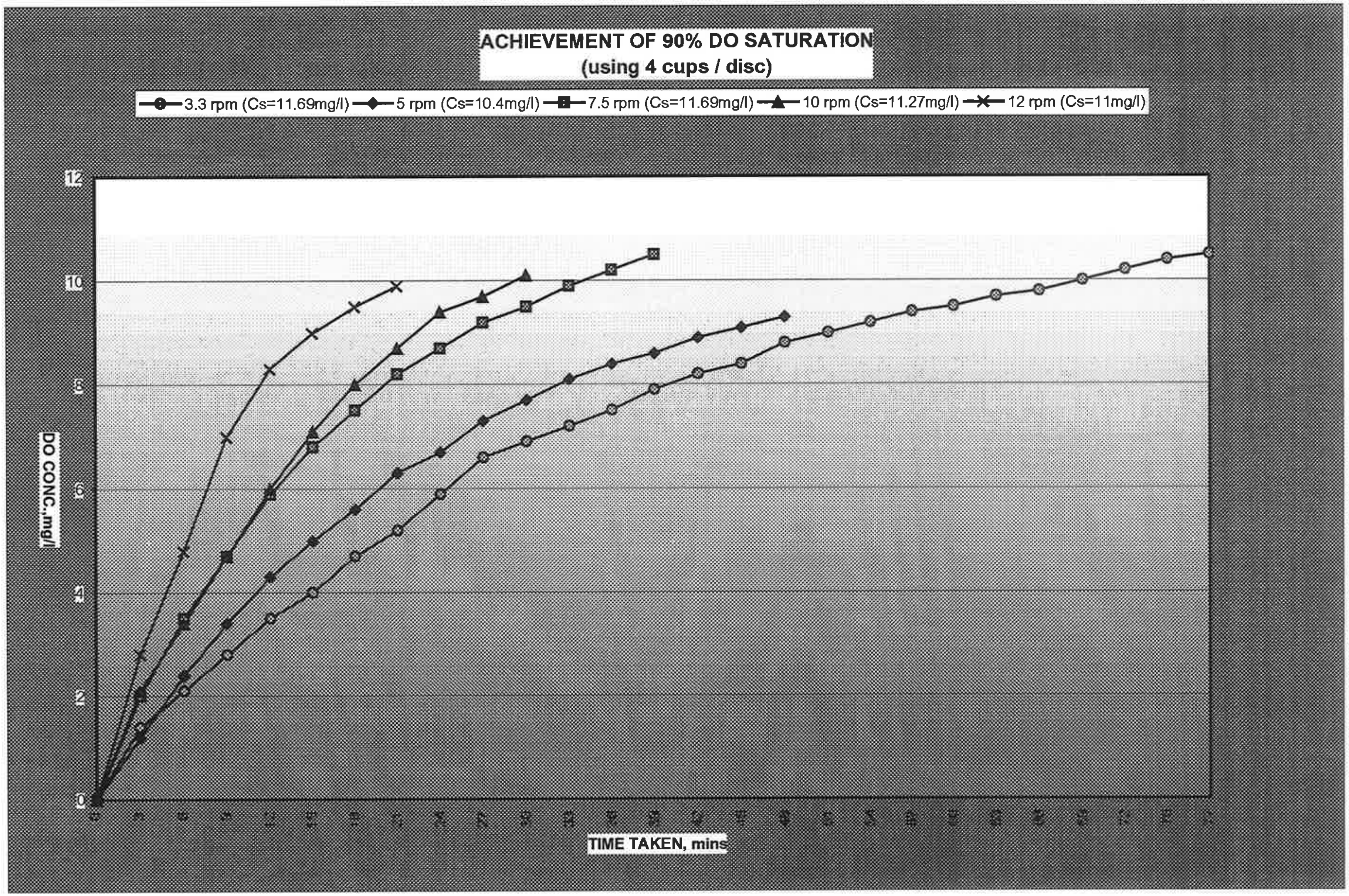
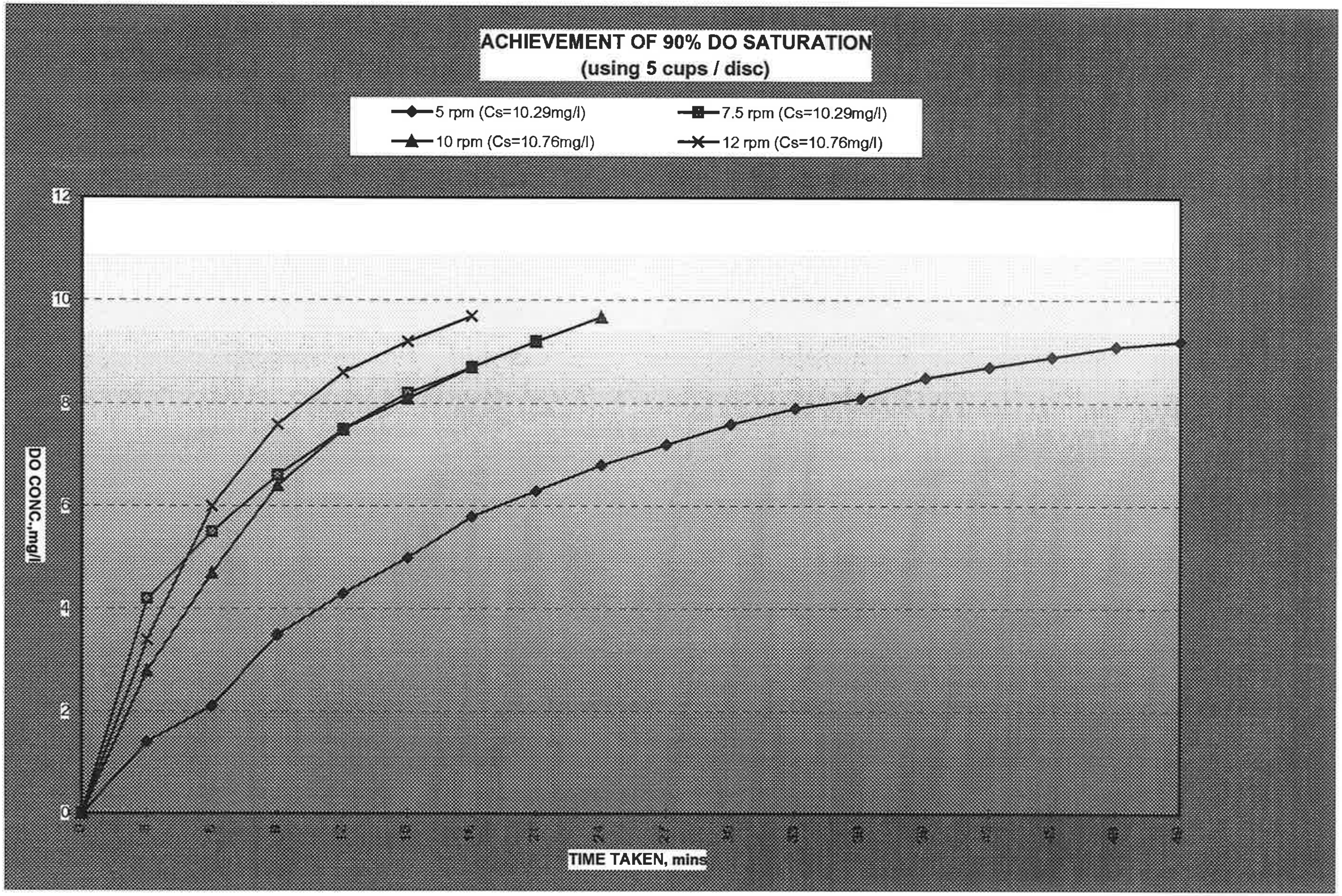
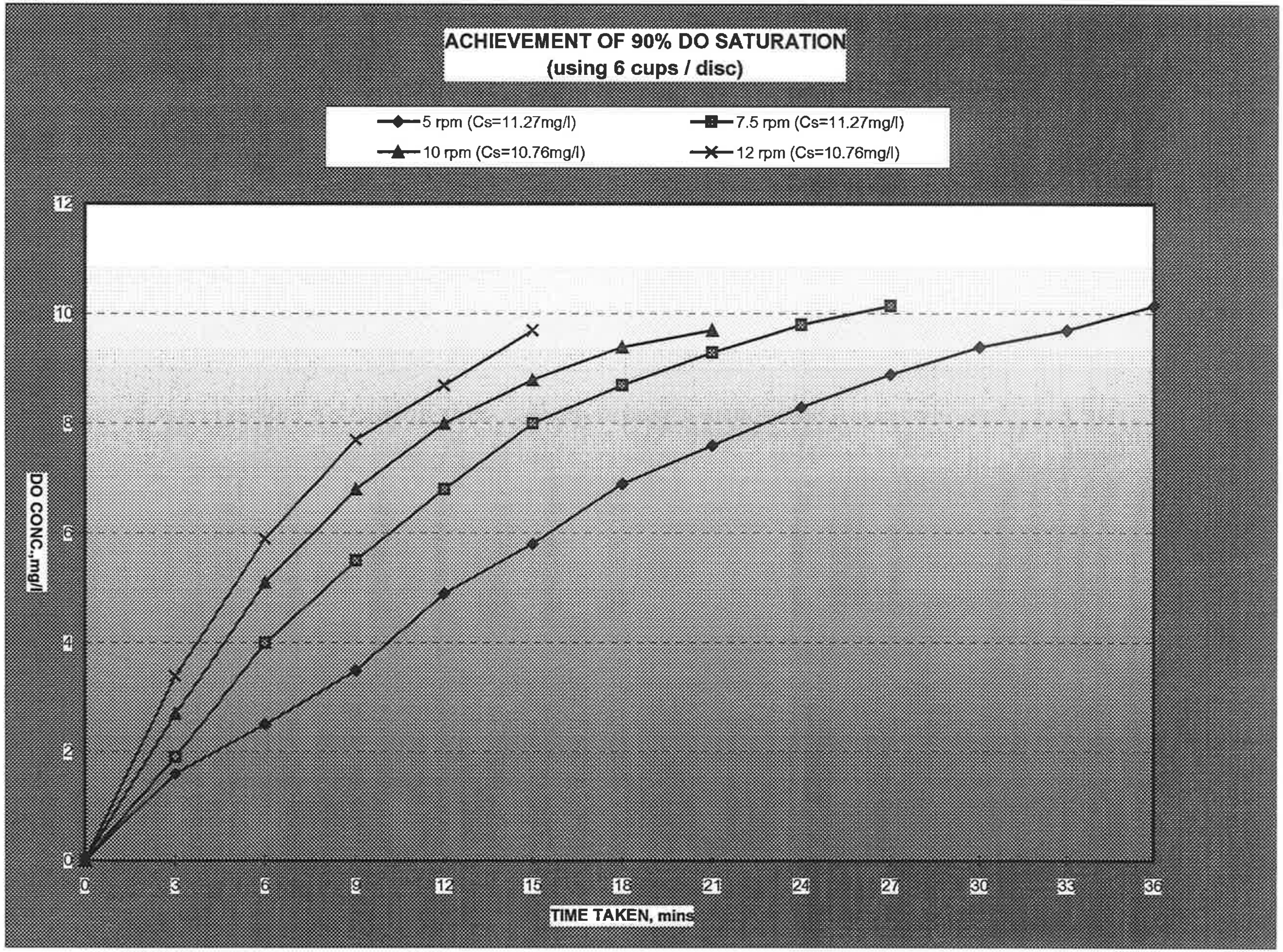
Appendix 1

Re-aeration tests

ACHIEVEMENT OF 90% DO SATURATION
(using 4 cups / disc)
3.3 rpm (Cs=11.69mg/l)
5 rpm (Cs=10.4mg/l)
7.5 rpm (Cs=11.69mg/l)
10 rpm (Cs=11.27mg/l)
12 rpm (Cs=11mg/l)
DO CONC.,mg/l
0
2
4
6
8
10
12
TIME TAKEN, mins
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
57
60
63
66
69
72
75
78



ACHIEVEMENT OF 90% DO SATURATION
(using 5 cups / disc)


ACHIEVEMENT OF 90% DO SATURATION
(using 6 cups / disc)
5 rpm (Cs=11.27mg/l)
7.5 rpm (Cs=11.27mg/l)
10 rpm (Cs=10.76mg/l)
12 rpm (Cs=10.76mg/l)
DO CONC.,mg/l
0
2
4
6
8
10
12
TIME TAKEN, mins
0
3
6
9
12
15
18
21
24
27
30
33
36

Appendix 2

Daily test results

STAGE 1 DAILY TEST RESULTS
FLOWRATE AT 60 LITRES / DAY TO EACH UNIT

Date	COD Influent mg/l	COD Effluent Cups	COD Effluent No Cups	Loading gCOD/m2.d	
23-May				Area =4.18m2	
24-May	635			9.11	
25-May	500	84	122	7.18	
26-May	565	90	116	8.11	
27-May	540	75	75	7.75	
28-May	580	82	86	8.33	
29-May	528	87	87	7.58	
02-Jun	564	90	92	8.10	
03-Jun	521	85	89	7.48	
04-Jun	553	83	96	7.94	
05-Jun	577	118	126	8.28	
08-Jun	630	113	127	9.04	
09-Jun	508	104	119	7.29	
10-Jun		83	75	0.00	
11-Jun	437	88	57	6.27	
12-Jun	461	92	77	6.62	
18-Jun	255	93	108	7.32	120l/d
22-Jun	297	97	100	8.53	
23-Jun	307	100	93	8.81	
24-Jun	290	88	75	8.33	
25-Jun	282	66	85	8.10	
26-Jun	263	69	88	7.55	
pipes clogged					
29-Jun	278	70	83	7.98	
30-Jun	276	62	71	7.92	
01-Jul	257	68	87	7.38	
02-Jul	268	63	78	7.69	
03-Jul	253	68	99	7.26	

06-Jul	175	56	86	5.02				
07-Jul	112	46	35	3.22				
08-Jul	118	36	29	3.39				
09-Jul	158	57	36	4.54				
10-Jul	150	43	34	4.31				
13-Jul	128	40	37	3.67				
14-Jul	115	36	43	3.30				
15-Jul	112	36	36	3.22				
16-Jul	122	36	43	3.50				
17-Jul	130	46	50	3.73				
20-Jul								
21-Jul	194	88	84	5.57				
22-Jul	175	50	47	5.02				
23-Jul	164	36	40	4.71				
24-Jul	247	36	70	7.09	ignore			
27-Jul					180 l/d	power cut	septic look	on discs
28-Jul					made up cod vials			
29-Jul					nitrate electrod	standards		
30-Jul	78	18	11	3.36				
31-Jul	106	46	36	4.56				
bank holiday								
04-Aug	87	38	36	3.75				
05-Aug	180	44	36	7.75				
06-Aug	142	42	37	6.11				
07-Aug	150	40	38	6.46				
10-Aug	85	33	35	3.66				
11-Aug	97	34	31	4.18				
12-Aug	74	30	30	3.19				
13-Aug	70	27	28	3.01				
14-Aug	80	32	31	3.44				
17-Aug	78	30	34	3.36				
detergent					detergents			
19-Aug					detergents			
20-Aug	79	36	38	3.40				

21-Aug	70	25	33	3.01	
24-Aug					mixer causing power cut, took out stirrer.
25-Aug	130	31	46	5.60	
27-Aug	115	67	51	4.95	
28-Aug	120	35	30	5.17	
water cut					
01-Sep	126	41	38	5.43	
02-Sep	85	33	24	3.66	
no detergent					
no detergent					
cleared cups					
08-Sep	118	22	28	5.08	
09-Sep	125	25	29	5.38	
10-Sep	129	30	36	5.56	
11-Sep	120	30	54	5.17	
15-Sep	156	36	41	6.72	
16-Sep	140	33	42	6.03	
17-Sep	168	32	39	7.23	
18-Sep	170	30	44	7.32	
21-Sep	200	28	30	8.61	
22-Sep	205	26	30	8.83	
23-Sep	100	35	35	4.31	
24-Sep	80	27	24	3.44	
25-Sep	80	29	29	3.44	
28-Sep					Mixed 3 litres
Desludged					Septic smell Cleared out units
30-Sep	144	35	33	7.92	No detergent Time to acclimatise after desludging
01-Oct	140	25	42	7.70	
02-Oct	131	18	32	7.21	

STAGE 1 DAILY TEST RESULTS

Date	DO Conc. (mg/l) Cups (Stage 1)	DO Conc. Cups (Stage 2)	DO Conc. Cups (Stage 3)	DO Conc. Cups (Stage 4)	pH Cups (Stage 1)	pH Cups (Stage 2)	pH Cups (Stage 3)	pH Cups (Stage 4)
23-May	4.2	7.3	7.7	7.9	7.52	7.32	7.32	7.32
24-May	3.4	6.1	7	7.6	7.25	7.57	7.61	7.61
25-May	4.5	6.3	7.6	7.8	7.69	7.72	7.75	7.73
26-May	3.4	6.9	7.4	7.4	7.63	7.99	8	8
27-May	4.2	7.5	7.9	8.8	7.78	8.14	8.15	8.11
28-May	4.4	8.1	8.1	8.5	7.63	7.84	7.8	7.8
29-May	4.4	7.6	7.6	8.3	7.81	7.82	7.62	7.42
02-Jun	1.8	4.9	7	7.7	7.74	7.25	6.31	5.8
03-Jun	3.4	6.2	6.4	6.8	7.64	7.34	7.28	7.28
04-Jun	3.2	6.2	6.6	7.8	7.74	7.1	6.27	5.65
05-Jun	3.1	6.3	7.2	7.6	7.67	6.24	5.4	4.6
08-Jun	4.8	7.6	8.4	8.4	6.8	5.81	5.45	4.6
09-Jun	3.1	7.2	7.8	8	7.49	6.32	5.26	5.07
10-Jun	5.7	8.4	8.8	8.7	6.87	5.15	4.45	4.4
11-Jun	5.6	8.8	9.2	9.5	6.21	4.18	4	4.04
12-Jun	6.2	8.6	9.1	9.1	5.82	4.2	4.24	4.21
18-Jun	2.8	4.8	5.6	6.3	6.98	7.26	7.32	7.38
22-Jun	4.2	7.3	7.8	7.8	7.27	6.38	5.2	5.02
23-Jun	3.7	5.8	6	7	7.35	7.19	6.74	6.32
24-Jun	4.4	6.4	7.2	7.8	7.45	6.59	5.6	5.16
25-Jun	3.5	5.9	6.4	7.4	7.42	7.12	6.66	6.23
26-Jun	3.9	7.3	7.3	7.9	7.15	5.97	4.82	4.68
pipes clogged								
29-Jun	5.8	7.2	7.8	8.2	7.3	7.8	7.75	7.8
30-Jun	5.7	7.7	7.9	8.3	7.34	7.95	7.84	7.79
01-Jul	3.4	5.8	6.7	7.4	7.04	7.12	6.88	6.85
02-Jul	3.3	5	5.8	6.8	7.24	7.64	7.57	7.57
03-Jul	3.4	5.3	6	7	7.08	7.13	7.11	7.14
06-Jul	3.4	6.3	8	8.4	7.62	6.79	5.81	8.01
07-Jul	4.9	7.4	8.4	8.7	7.3	6.24	4.92	4.66

08-Jul	4.7	7.4	7.9	8	7.25	5.3	4.98	4.87
09-Jul	4	5.5	7	7.4	7.42	6.95	6.29	5.57
10-Jul	4	5.9	7.1	7.8	7.58	6.98	6.37	5.42
13-Jul	3.4	6	7.1	7.2	7.33	6.37	4.98	4.61
14-Jul	3.9	5.6	6.2	7.1	7.31	7.04	6.8	6.62
15-Jul	3.9	4.8	5.7	6.3	7.41	7.43	7.29	7.23
16-Jul	3.5	5.3	6.4	7.4	7.26	6.92	6.47	6.15
17-Jul	3.5	6	7.2	7.7	7.48	6.93	6.45	6
20-Jul	3.4	5.4	6.2	6.4	7.31	7.2	6.99	6.9
21-Jul	5.1	5.6	6.3	6.7	7.33	7.26	6.98	6.94
22-Jul	4.3	5.6	6.7	7.9	7.12	6.98	6.38	5.96
23-Jul	2.6	4.6	4.8	6	7.04	7.33	7.03	6.98
24-Jul	2.1	4.2	5	6	7.23	7.44	7.07	6.74
27-Jul								
28-Jul	3.1	4.6	5.3	5.9	7.35	7.53	7.39	7.43
29-Jul	2.2	4.9	6.6	7.3	7.1	6.94	5.06	4.86
30-Jul	3.9	3.9	4.7	5.6	7.45	7.48	7.33	7.28
31-Jul	2.8	3.8	4.9	5.9	7.11	7.25	6.95	6.87
ank holiday								
04-Aug	4.1	5.6	7.3	8.1	7.36	7.4	7.6	7.65
05-Aug	3	3	4.1	5	7.17	7.28	7.06	7.01
06-Aug	2.8	3.2	3.9	5.1	7.3	7.31	6.98	6.85
07-Aug	2.9	3.2	4	5.2	7.28	7.25	7	6.87
10-Aug	3.7	2.9	4.3	5.2	7.18	7.09	6.64	6.49
11-Aug	3.8	3.2	4.5	5.8	7.18	7.26	6.92	6.76
12-Aug	3.1	3.7	4.8	5.8	7.2	7.22	7.02	7.03
13-Aug	3.5	3.3	4.8	5.6	7.16	7.19	7.1	7.15
14-Aug	3.6	4	5.4	6.3	7.5	7.54	7.76	7.89
17-Aug	3.4	3.9	4.9	6	7.2	7.14	7.18	7.2
18-Aug								
19-Aug	3.9	3.1	4.3	5.9	6.9	7.04	7.1	7.11
20-Aug	3.1	3.4	5.2	6.3	7.13	7	7.07	7.16
21-Aug	5.2	4.5	5.9	7.2	6.99	6.91	7	7.09
24-Aug								

25-Aug	2.7	3.4	4.9	6.2	7.12	7.05	6.7	6.47
26-Aug	2.6	3.6	5.2	5.8	7.18	6.9	6.51	6.33
27-Aug	2.7	3.5	5.1	5.9	7.09	7.12	7	6.9
28-Aug	2.9	3.5	5	6	7.07	7.1	7.08	7.1
31-Aug								
01-Sep	3.8	3.6	4.5	4.7	7.28	7.29	7.26	7.2
02-Sep	2.8	4	5.7	6.5	7.29	7.07	6.93	7.04
03-Sep								
04-Sep								
07-Sep	3.4	3.3	3.8	4.6	7.34	7.21	7.17	7.2
08-Sep	4	4.1	4.6	5.2	7.43	7.35	7.3	7.32
09-Sep	4	4.2	4.9	5.4	7.32	7.4	7.35	7.4
10-Sep	4.2	4.4	5	5.4	7.36	7.45	7.42	7.46
11-Sep	4.1	4.2	4.9	5.3	7.36	7.4	7.42	7.39
15-Sep	3.9	4.7	5.7	6.2	7.16	7.36	7.43	7.46
16-Sep	4	4.1	5.2	6	7.1	7.26	7.38	7.36
17-Sep	4.6	4.4	4.8	5.4	6.98	7.14	7.29	7.44
18-Sep								
21-Sep	3.1	3.3	4.9	5.4	7.26	7.39	7.36	7.35
22-Sep	3.1	3.4	5	5.7	7.28	7.48	7.38	7.37
23-Sep	4	4.3	5.1	5.3	7.38	7.55	7.55	7.61
24-Sep	3.1	3.5	4.2	4.6	7.22	7.42	7.43	7.37
25-Sep	3.8	3.6	4.3	4.7	7.15	7.28	7.16	7.1

Nitrates	Influent (mg/l)	Cup (mg/l)	No Cup (mg/l)	% Cup	% No Cup
04-Jun	0.8	25	22.5	31	28
05-Jun	0.9	38	31	42	34
08-Jun	1	36	29	36	29
09-Jun	1	34	20	34	20
10-Jun	0.9	33	29	37	32
11-Jun	0.8	35	30	44	38
12-Jun	0.6	34	33	57	55
23-Jun	0.5	32	14	64	28

24-Jun	0.5	33	28	66	56
25-Jun	0.5	34	22	68	44
26-Jun	0.5	32	27	64	54
29-Jun	0.5	28	20	56	40
30-Jun	0.5	25	18	50	36
01-Jul	0.5	26	24	52	48
02-Jul	0.5	25	22	50	44
03-Jul	0.5	23	24	46	48
06-Jul	0.6	32	30	53	50
07-Jul	0.5	27	26	54	52
08-Jul	0.4	26	26	65	65
09-Jul	0.4	27	27	68	68
10-Jul	0.4	26	26	65	65
13-Jul	0.5	21	18	42	36
14-Jul	0.4	19	17	48	43
15-Jul	0.5	21	21	42	42
16-Jul	0.4	21	21	53	53
17-Jul	0.4	25	25	63	63
20-Jul	0.5	25	25	50	50
21-Jul	0.5	21	20	42	40
22-Jul	0.4	23	19	58	48
23-Jul	0.4	19	18	48	45
24-Jul					
27-Jul					
28-Jul					
29-Jul					
30-Jul					
31-Jul	0.6	14	12	13	13
ank holiday					
04-Aug					
05-Aug					
06-Aug	0.5	29	18	58	36
07-Aug					

10-Aug	0.4	26	12	65	30	
11-Aug	0.3	26	12	87	40	
12-Aug	0.4	18	13	45	32.5	
13-Aug	0.3	15	13	50	43	
14-Aug	0.4	24	15	50	43	
17-Aug	0.4	22	17	50	43	
18-Aug						detergent
19-Aug						ignore
20-Aug						
21-Aug						
24-Aug						
25-Aug						
26-Aug						
27-Aug						
28-Aug						
31-Aug						
01-Sep	0.4	13	13	43	43	
02-Sep	0.5	18	12	36	24	
03-Sep	0.4	15	9	38	23	
04-Sep	0.4	12	11	30	28	
07-Sep	0.4	11	10	26	24	
08-Sep	0.3	8	8	25	25	
09-Sep	0.4	11	9	28	23	
10-Sep	0.3	7	7	22	22	
11-Sep	0.4	10	8	25	20	
15-Sep	0.4	11	9	28	23	
16-Sep	0.4	13	9	33	23	
17-Sep	0.4	5	8	14	19	
18-Sep	0.4	12	10	30	25	
21-Sep	0.5	14	9	28	18	
22-Sep	0.4	8	11	20	28	
23-Sep	0.5	7	9	14	18	
24-Sep	0.7	8	7	11	10	
25-Sep	0.6	12	14	20	23	

Date	DO Conc. (mg/l) No Cups (St 1)	DO Conc. No Cups (St 2)	DO Conc. No Cups (St 3)	DO Conc. No Cups (St 4)	pH No Cups (St 1)	pH No Cups (St 2)	pH No Cups (St 3)	pH No Cups (St 4)
23-May	3.6	6.3	7.2	7.6	7.51	7.62	7.62	7.62
24-May	1.4	5.5	6.1	6.1	7.35	7.6	7.66	7.66
25-May	1.5	3.7	4	4.4	7.44	7.92	8.13	8.14
26-May	1.6	4.8	5.3	6.1	7.55	8.06	8.11	8.13
27-May	1.9	5.9	6.6	6.6	7.65	8.12	8.16	8.18
28-May	3.1	6.5	7	7.2	7.62	7.9	7.94	7.99
29-May	3.3	6.5	6.5	6.9	7.77	7.97	7.84	7.83
02-Jun	1.7	3.7	5.1	5.6	7.45	7.67	7.23	6.77
03-Jun	1.9	4.8	5.7	5.9	7.49	7.51	7.63	7.62
04-Jun	2.9	5.3	5.7	5.9	7.66	7.52	7.28	7.22
05-Jun	1.5	4	4.7	5.2	7.33	7.11	6.54	6.24
08-Jun	2.7	6	7.3	7.4	7.83	6.82	5.46	5.06
09-Jun	2.8	6	6.5	7	7.54	6.37	5.17	5.13
10-Jun	3.7	6.1	6.7	6.9	7	5.59	4.55	4.38
11-Jun	3.9	7.6	8.3	8.4	6.81	5.08	4.14	4.13
12-Jun	3.5	6.6	7.7	7.7	6.91	5.77	4.83	4.41
18-Jun	2.2	3.5	4.2	5.4	6.97	6.97	6.89	6.74
22-Jun	3.9	5.5	6.2	6.7	7.2	7.17	6.76	6.22
23-Jun	3.7	5	5.2	5.2	7.36	7.14	7.14	7.14
24-Jun	2.8	4	5	5.8	7.25	7.35	7.12	6.73
25-Jun	3.1	4.7	5.2	5.7	7.43	7.42	7.28	7.11
26-Jun	3.3	5.2	5.8	7.1	7.24	6.67	6	5.51
pipes clogged								
29-Jun	5.4	6.3	6.5	7.4	7.3	7.58	7.7	7.8
30-Jun	5.7	6.4	6.6	7.3	7.38	7.6	7.7	7.83
01-Jul	3.4	5.6	6.4	7	6.77	5.6	5.27	5.58
02-Jul	2.9	5	6.2	7.3	7.23	6.7	6.2	5.38
03-Jul	3.1	5.1	5.8	7.1	7.1	7.21	7.15	7.12
06-Jul	3.5	5.2	6.4	6.8	7.54	6.94	6.25	5.22
07-Jul	2.5	5.3	6.4	6.4	7.4	7.06	6.81	6.58
08-Jul	4.3	6.2	6.8	7.1	7.62	6.55	5.07	4.88
09-Jul	3.6	4.9	5.8	6.6	7.41	6.99	6.5	5.87
10-Jul	3	5.6	6.4	7.3	7.35	6	5	4.89
13-Jul	4	7.1	8	8.1	7.11	5.47	4.67	4.56
14-Jul	3.3	4.3	5.2	5.6	7.28	7.36	7.37	7.36
15-Jul	3.8	4.7	5	5.6	7.32	7.3	7.13	6.99
16-Jul	3.3	4.3	5	5.8	7.27	6.98	6.56	6.22
17-Jul	3.5	4.5	5.4	6.3	7.46	7.02	6.59	6.14
20-Jul	2.9	4.2	4.8	5	7.3	7.25	7.31	7.28
21-Jul	4.4	4.4	5	5.1	7.33	7.53	7.68	7.58
22-Jul	3.3	4.8	5.3	6	7.1	7.03	6.75	6.55
23-Jul	3.1	3.5	4.3	4.7	7.12	7.33	7.21	7.06
24-Jul	3.1	3.2	4	4.6	7.22	7.46	7.35	7.14

27-Jul								
28-Jul	4.9	3.9	4.5	4.8	7.45	7.58	7.67	7.63
29-Jul	3.1	3.4	4.5	4.9	7.2	7.33	7.23	7.19
30-Jul	4.1	3.6	4	4.6	7.56	7.6	7.57	7.57
31-Jul	3.7	2.9	3.6	4.2	7.25	7.37	7.36	7.31
bank holiday								
04-Aug	4.6	4.8	5.9	7.9	7.28	7.36	7.38	7.5
05-Aug	3.2	2.4	3.2	3.8	7.11	7.33	7.38	7.41
06-Aug	3.8	3	3.5	4.1	7.3	7.44	7.41	7.41
07-Aug	3.6	3	3.7	3.9	7.31	7.33	7.38	7.4
10-Aug	4.1	2.9	3.4	3.6	7.29	7.35	7.32	7.27
11-Aug	4	3.1	4.1	5.3	7.22	7.32	7.27	7.31
12-Aug	4.1	3.1	3.6	4.7	7.21	7.28	7.21	7.15
13-Aug	4.6	3.4	3.5	4.2	7.21	7.26	7.15	7.12
14-Aug	4.6	3.4	4.3	5	7.58	7.54	7.67	7.63
17-Aug	4.4	3.6	4.2	4.9	7.28	7.31	7.46	7.5
18-Aug								
19-Aug	4.9	3.1	3.8	4.8	7.03	7.1	7.05	7.1
20-Aug	4.3	3	3.3	4	7.02	7.16	7.1	7.08
21-Aug	6	3.8	4.6	5.1	6.94	7.01	7	7.04
24-Aug								
25-Aug	5	3.5	3.6	4	7.13	7.22	7.18	7.12
26-Aug	4.8	3.4	2.9	3.5	7.12	7.21	7.21	7.19
27-Aug	4.6	3.4	3	4	7.12	7.13	7.18	7.1
28-Aug	4.6	3.5	3.3	4.2	7.1	7.18	7.06	7
31-Aug								
01-Sep	5.3	3.8	3.2	3.6	7.3	7.3	7.14	7.11
02-Sep	5.6	4	3.4	3.9	7.22	7.34	7.22	7.2
03-Sep								
04-Sep								
07-Sep	5.1	3.9	3.2	3.4	7.14	7.23	7.03	7.01
08-Sep	4.8	3.7	3.1	3.2	7.28	7.38	7.18	7.12
09-Sep	5	3.1	3	3.2	7.32	7.4	7.35	7.4
10-Sep	5	2.4	3	3.4	7.31	7.36	7.2	7.12
11-Sep	4.9	2.6	3.1	3.3	7.33	7.34	7.18	7.19
15-Sep	4.8	3.8	4	4.8	7.07	7.23	6.86	6.65
16-Sep	4.7	3.9	4.1	5	7.09	7.2	6.91	6.7
17-Sep	5.8	4.4	3.9	4.3	6.8	7.05	6.94	6.78
18-Sep								
21-Sep	4.2	3.4	3.4	4.5	7.22	7.3	6.89	6.6
22-Sep	4.4	3.4	3.6	4.7	7.24	7.36	6.83	6.57
23-Sep	6.3	5	4.3	5	7.32	7.48	7.17	7.07
24-Sep	4.5	3.7	3.5	3.6	7.17	7.42	7.27	7.23
25-Sep	4.6	4	3.8	4.6	7.08	7.09	6.95	7.06

Phosphates	Influent (mg/l)	Cup (mg/l)	No Cup (mg/l)	% Cup	% No Cup	Influent Tot	Total Cup	Total No Cup
04-Jun	36.4	34.00	36.00	7	1			
05-Jun	35.9	29.40	31.60	18	12			
08-Jun	35.3	31.40		11				
09-Jun								
10-Jun	36	24.80	25.10	31	30			
11-Jun	36.4	27.70	30.00	24	18			
12-Jun								
23-Jun								
24-Jun	36.00	29.46	30.68					
25-Jun	% removal	% removal						
26-Jun	18.2	14.8						
29-Jun								
30-Jun								
01-Jul								
02-Jul								
03-Jul								
06-Jul								
07-Jul								
08-Jul								
09-Jul								
10-Jul								
13-Jul								
14-Jul								
15-Jul								
16-Jul								
17-Jul								
20-Jul								
21-Jul								
22-Jul								
23-Jul	11.6					13.3		
24-Jul								
27-Jul								
28-Jul								
29-Jul								
30-Jul								
31-Jul								
bank holiday								
04-Aug								
05-Aug								
06-Aug								
07-Aug								
10-Aug								
11-Aug		7.10	5.90				7.3	6.6
12-Aug	3.4							
13-Aug	4.7					5.4		
14-Aug	2.65					2.8		
17-Aug								

18-Aug							detergent		
19-Aug									
20-Aug									
21-Aug									
24-Aug									
25-Aug									
26-Aug									
27-Aug									
28-Aug									
water cut									
01-Sep									
02-Sep									
no detergent									
no detergent									
cleared cups									
08-Sep	5.5	7.53	7.83			7			
09-Sep	7.3	6.82	6.91						
10-Sep	7.5	6.24	6.93			8.1			
11-Sep	7	6.89	7.02			10.3			
15-Sep	11.5	5.73	5.98						
16-Sep	8.01	7.68	5.7						
17-Sep	11.3	5.56	5.4			11.83	7.36	6.94	
18-Sep	11.1	6	8			11.53	7.38	9.04	
21-Sep	12.54	7.3	7.1						
22-Sep	12.96	8.3	6.7						
23-Sep	5.03	4.32	4.14			5.4	4.94	4.32	
24-Sep	4.8	5.68	5.08			5.02	5.72	5	
25-Sep	4.72	4.7	4.2			5.14	5.12	4.5	

8.40	6.37	6.23
% removal	% removal	
24.3	25.9	

STAGE 2 DAILY TEST RESULTS

flowrate 180 l/d

Date	COD Influent mg/l	COD Effluent [illegible]	COD Effluent No [illegible]	Loading gCOD/m2/d	
06-Oct	152	28	30	6.55	Detergent 10%
07-Oct	180	43	48	7.75	
08-Oct	218	42	47	9.39	
09-Oct	212	40	45	9.13	
12-Oct	200	29	20	8.61	
13-Oct	216	38	29	9.30	
14-Oct	143	28	36	6.16	
15-Oct	146	21	28	6.29	
16-Oct	134	25	15	5.77	Desludged both units
19-Oct	100	34	30	4.31	
20-Oct	120	31	53	5.17	
21-Oct	126	12	59	5.43	
22-Oct	112	13	19	4.82	Flow problems
23-Oct	100	33	23	4.31	Flow problems
Detergent 12.5%					Detergent 12.5%
27-Oct	95	19	22	4.09	
28-Oct	105	51	40	4.52	
29-Oct	130	30	25	5.60	
30-Oct	110	24	14	4.74	
02-Nov	112	40	50	4.82	flowrate fixed at 180l/d
03-Nov	135	33	30	5.81	
04-Nov	133	35	34	5.73	
05-Nov	128	19	18	5.51	
06-Nov	158	34	34	6.80	
09-Nov	147	35	37	6.33	
10-Nov	140	31	28	6.03	
11-Nov	144	49	43	6.20	
12-Nov	165	30	28	7.11	
13-Nov	165	39	36	7.11	
16-Nov	168	36	40	7.23	
17-Nov	179	32	22	7.71	
18-Nov	175	35	33	7.54	
19-Nov	173	38	39	7.45	
20-Nov	195	47	48	8.40	
23-Nov	210	43	51	9.04	
24-Nov	201	37	48	8.66	
25-Nov	157	26	34	6.76	
26-Nov	170	42	66	7.32	

27-Nov	163	37	43	7.02
30-Nov	150	38	53	6.46
01-Dec	173	46	48	7.45
02-Dec	158	35	58	6.80
03-Dec	154	37	64	6.63
04-Dec	144	39	39	6.20
flow problems				
new tank/pump				
14-Dec				
15-Dec				
16-Dec				
17-Dec	265	51	32	11.41
18-Dec	166	40	22	7.11
break				
11-Jan	165	42	22	7.11
12-Jan	278	32	38	11.97
13-Jan				
14-Jan				
15-Jan	265	51	32	11.41
18-Jan	290	42	51	12.49
19-Jan	297	43	53	12.79
20-Jan	270	43	48	11.63
[illegible]				
22-Jan	310	47	32	13.35
25-Jan	216	39	37	9.30
26-Jan				
27-Jan	216	39	35	9.30
28-Jan				
29-Jan	300	55	49	12.92
01-Feb	263	40	39	11.33
02-Feb	298	37	41	12.83
03-Feb	265	28	37	11.41
04-Feb				
05-Feb	301	35	40	12.96
08-Feb				
09-Feb	169	38	47	7.28
10-Feb	169	25	22	7.28
11-Feb	230	25	32	9.90
12-Feb	270	17	33	11.63
15-Feb				
16-Feb				
17-Feb	253	36	40	10.89
18-Feb	156	25	33	6.72
19-Feb				

22-Feb				
23-Feb				
24-Feb	320	50	66	13.78
25-Feb	304	35	48	13.09
26-Feb	240	34	40	10.33
[illegible]				
01-Mar	364	43	41	15.67
02-Mar	354	41	40	15.24
03-Mar	353	37	27	15.20
04-Mar	350	39	23	15.07
05-Mar	335	35	33	14.43
08-Mar	328	39	28	14.12
09-Mar	345	35	37	14.86
10-Mar	346	24	30	14.90
11-Mar	374	31	26	16.11
12-Mar	367	46	54	15.80
15-Mar	348	38	49	14.99
[illegible]				
18-Mar	258	28	32	11.11
19-Mar	264	31	42	11.37
22-Mar	265	36	36	11.41
23-Mar	275	31	43	11.84
24-Mar	239	38	30	10.29
25-Mar	253	30	28	10.89
26-Mar	251	34	30	10.81
29-Mar	200	23	21	8.61
30-Mar	230	25	27	9.90
break				
08-Apr	152	21	20	6.55
09-Apr	164	23	22	7.06
12-Apr	211	25	21	9.09
13-Apr	204	34	26	8.78
power out				
power out				
19-Apr	238	21	29	10.25

New flow Date	DO Conc Cups (Stage 1)	DO Conc Cups (Stage 2)	DO Conc Cups (Stage 3)	DO Conc Cups (Stage 4)	pH Cups (Stage 1)	pH Cups (Stage 2)	pH Cups (Stage 3)	pH Cups (Stage 4)
05-Oct	4.6	5.2	5.9	6.4	7.69	7.07	7.13	7.21
06-Oct	5.2	4.5	5.2	5.8	7.56	7.7	7.69	7.68
07-Oct	3.7	4	4.5	5.1	7.42	7.62	7.41	7.12
08-Oct	2.9	2.9	4.1	4.9	7.43	7.72	7.7	7.67
09-Oct	3.5	3.6	3.9	4.6	7.27	7.52	7.33	7.26
12-Oct	3.5	3.7	4.3	4.8	7.32	7.41	7.34	7.44
13-Oct	3.4	4	4.4	4.7	7.31	7.48	7.38	7.4
14-Oct	3.1	3.3	4.1	4.7	7.53	7.47	7.27	7.17
15-Oct	4.6	4.8	4.9	5	7.48	7.69	7.3	7.04
16-Oct	4.5	4.9	4.7	4.8	7.75	7.68	7.38	7.15
19-Oct	2.9	3.8	4	4.9	7.8	7.79	7.29	6.97
20-Oct	2.8	3.6	4	4.8	7.56	7.62	7.32	7.11
21-Oct	2.9	3.6	3.8	4.5	7.42	7.63	7.31	7.14
22-Oct	2.6	3.8	3.7	4.8	7.27	7.42	7.18	7.01
23-Oct								
[illegible] 12.5%								
27-Oct	3.8	4.2	3.8	4.8	7.55	7.59	7.27	7.05
28-Oct	3.3	4.1	4.4	5.1	7.47	7.56	7.17	6.99
29-Oct	3.5	4	4.8	5.3	7.28	7.54	7.22	6.97
30-Oct	4.3	5.5	6.3	7.1	7.23	6.98	6.39	5.89
02-Nov	3.8	4.8	6.4	7.3	7.25	7.03	6.4	5.83
03-Nov	2.9	4	5.1	7.2	7.45	7.43	6.79	6.24
04-Nov	2.5	3.1	4.8	6.5	6.83	6.87	6.53	6.18
05-Nov	2.8	3.1	5.3	7.1	7.5	7.45	6.85	6.1
06-Nov	3.1	3.2	6.1	7.3	7.71	7.1	7.03	6.87
09-Nov	2.4	3.9	5.9	7.5	7.72	7.43	6.33	5.92
10-Nov	3.5	3.8	5.2	7.1	7.62	7.51	7.07	6.93
11-Nov	3.8	4.6	5.3	6.8	7.68	7.63	7.15	6.84
12-Nov	3.7	4.3	6.4	7.2	7.14	7.04	6.67	5.51
13-Nov	2.7	3.8	4.8	6.3	7.46	7.26	6.44	5.66
16-Nov	3.7	5	6.1	7	7.6	7.71	7.55	6.97
17-Nov	2.8	3.4	5.2	6.5	7.61	7.65	7.12	6.5
18-Nov	1.7	2.2	4.3	5.9	7.63	7.61	7.01	6.38
19-Nov								
20-Nov	1.4	2.8	3.4	4.6	7.54	7.24	6.99	6.87
23-Nov	3.2	3.6	5.6	6.5	7.54	7.46	6.84	6.19
24-Nov	2.9	3.2	5.6	6.1	7.6	7.49	6.96	6.5
25-Nov	2.8	3.9	6.1	6.8	7.53	7.34	5.02	4.98
26-Nov	3.5	3.5	5.8	6.4	7.39	7.51	6.94	6.44
27-Nov								
30-Nov	2.1	3.1	5.7	6.8	7.3	7.21	6.96	6.15
01-Dec	2.3	3.1	6.2	6	7.26	7.38	7.14	7.18

02-Dec	4.4	3.1	3.7	4.6	7.51	7.34	6.88	6.55
03-Dec	3.1	3.8	5.7	6.3	7.57	7.27	6.75	6.54
04-Dec	3.3	3.9	5.2	6.8	7.79	7.46	6.46	5.44
flow problems								
new tank/pump								
14-Dec								
15-Dec	3.1	3.9	5.9	6.4	7.04	7.51	7.44	7.36
16-Dec	4.5	3.7	6.1	6.9	7.5	7.34	6.83	6.34
17-Dec								
18-Dec	4.5	3.8	4.7	6	7.46	7.28	7.13	6.89
break								
11-Jan								
12-Jan	4.2	2.5	5.1	6.1	7.86	8	7.85	7.45
13-Jan								
14-Jan	3.1	3.6	5.3	6.2	7.09	8.14	7.98	6.95
15-Jan	4.5	3.8	5.9	6.7	7.61	7.73	7.03	6.84
18-Jan	4.1	2.8	3.9	5.2	7.83	8.01	7.92	7.56
19-Jan	4.5	2.9	4.2	5.8	7.43	7.98	7.75	7.42
20-Jan	5.3	3.4	6.5	7.9	7.68	8.04	7.66	6.93
[illegible]								
22-Jan	3.1	3.7	4.9	6.9	7.12	7.4	7.43	7.51
25-Jan	3.2	3.6	5.6	6.5	7.54	7.46	6.84	6.19
26-Jan	2	4.7	6.8	7.2	7.18	7.1	6.75	5.85
27-Jan	2.2	5.1	6.3	7.4	7.14	7.03	6.54	6.32
28-Jan								
29-Jan	2.6	3.2	5	6.4	7.15	7.38	7.31	7.04
01-Feb								
02-Feb								
03-Feb	2.2	3.4	5.7	6.8	7.16	7.26	6.63	5.98
04-Feb								
05-Feb	2.6	3.2	5	6.4	7.15	7.38	7.31	7.04
08-Feb								
09-Feb	4.2	5.6	7.4	8.6	7.11	7.32	7.02	6.34
10-Feb	4.7	5.1	7.2	7.9	7.13	7.4	7.07	6.44
11-Feb	5.4	5.3	6.3	7	7.58	7.78	7.64	7.38
12-Feb	4.2	5.4	6.4	6.9	7.55	7.76	7.73	7.46
15-Feb								
16-Feb								
17-Feb	4.4	5.3	5.6	7	7.58	7.83	7.74	7.55
18-Feb	4.2	5.6	7.4	8.6	7.11	7.2	7.3	7.1
19-Feb	5.2	5.7	7.3	8.6	7.29	6.89	6.49	5.95
22-Feb	4.7	5.2	5.6	7.1	7.31	7.07	6.38	6.19
23-Feb								
24-Feb	2	5.4	6.5	6.8	7.23	7.32	7.48	7.52

25-Feb	2.1	3.3	4.5	5.7	7.33	7.4	7.38	7.31
26-Feb	2	4.7	6.8	7.2	7.18	7.1	6.75	5.85

[illegible]								
01-Mar	2.2	3.1	4.8	5.7	7.15	7.22	7.12	7.08
02-Mar								
03-Mar	2.2	3.4	5.7	6.8	7.16	7.26	7.22	7.17
04-Mar	3.1	3	5.3	5.9	7.18	7.41	7.42	7.33
05-Mar	2.6	2.1	5	6	7.15	7.38	7.31	7.26
08-Mar								
09-Mar	4.1	2.3	5.1	7.2	7.17	7.25	7.08	6.94
10-Mar	4.9	2.8	4.9	6.8	7.17	7.36	7.25	7.14
11-Mar	2.8	2.3	5.8	6.6	7.17	7.14	7.14	7.16
12-Mar	2.6	2.2	5.9	7	7.39	7.35	7.21	7.19
15-Mar	3.9	3.2	4.6	5.7	7.13	7.49	7.46	7.32
[illegible]								[illegible]
18-Mar	2.1	2.7	4.9	5.6	7.31	7.68	7.69	7.52
19-Mar	2.2	2.8	5.1	6.2	7.4	7.79	7.6	7.3
22-Mar	2.4	3.4	6.5	6.4	7.52	7.47	7.21	7.11
23-Mar	3.4	2.1	4.3	5.3	7.45	7.53	7.56	7.1
24-Mar	3.1	1.9	5.2	5.4	7.44	7.3	7.63	7.36
25-Mar								
26-Mar	2.3	4.7	5.5	5.9	7.56	7.74	7.65	7.31
29-Mar	2.4	2.9	4	6.4	7.51	7.78	7.61	6.69
30-Mar	2.6	3.2	4.3	6.2	7.37	7.51	7.23	6.91
break								
08-Apr								
09-Apr	4.2	2.3	4.2	7.1	7.51	7.32	7.02	6.81
12-Apr	3.2	3	4.9	6.8	7.59	7.3	7.21	7.04
13-Apr	3.4	3.3	4.7	7.2	7.47	7.26	7.31	7.22
power out								
power out								
19-Apr	2.8	2.2	4.5	6.3	7.26	7.22	7.03	6.87

[illegible] Date	DO Conc No Cups (Stg 1)	DO Conc No Cups (Stg 2)	DO Conc No Cups (Stg 3)	DO Conc No Cups (Stg 4)	pH No Cups (Stg 1)	pH No Cups (Stg 2)	pH No Cups (Stg 3)	pH No Cups (Stg 4)
05-Oct	4.6	4	4.6	5.2	7.7	7.26	7.26	7.18
06-Oct	5.7	4.5	4.3	4.8	7.1	7.64	7.6	7.45
07-Oct	4.7	3.8	3.7	4.1	7.03	7.59	7.53	7.44
08-Oct	5.2	2.9	2.1	3.4	7.17	7.69	7.56	7.18
09-Oct	3.6	3.5	3.2	3.7	6.89	7.42	7.6	7.65
12-Oct	4	3.8	3.6	4	7.28	7.43	7.5	7.48
13-Oct	4.9	4.4	4.3	4.1	7.38	7.39	7.37	7.43
14-Oct	4.9	4.3	4.3	5.2	7.03	7.75	7.51	6.85
15-Oct	5.7	4.7	4.5	4.5	7.39	7.58	7.55	7.48
16-Oct	4.6	4.1	3.8	4.7	7.84	7.45	7.17	7.05
19-Oct	5	3	3.4	4.3	7.8	7.78	7.87	7.94
20-Oct	5.2	3.1	3.9	4.5	7.61	7.65	7.44	7.37
21-Oct	5.1	3.4	4.1	4.7	7.26	7.4	6.79	6.73
22-Oct	6.2	4.6	3.8	5.1	7.48	7.49	7.31	7.33
23-Oct								
[illegible]								
27-Oct	4.3	3	3.2	3.9	7.44	7.43	7.14	6.85
28-Oct	3.4	2.9	3.6	5.4	7.51	7.05	6.42	5.97
29-Oct	4.7	3.4	4	5.4	7.31	7.41	6.94	6.48
30-Oct	6.2	5	5.9	7.1	7.57	7.01	5.84	5.81
02-Nov	4.6	4.6	6.7	7.7	7.47	6.98	6.56	5.59
03-Nov	3.8	5.6	7	7.7	7.37	6.75	6.28	6.09
04-Nov	2	2.9	3.1	4.9	7.23	7.51	7.35	7.07
05-Nov	2.4	2.4	3.6	4.7	7.63	7.63	7.27	6.97
06-Nov	4.5	2.8	3.7	5.3	7.44	7.44	6.5	6.45
09-Nov	3.5	2.8	4.3	6.1	7.42	7.38	6.61	6.18
10-Nov	5.1	5.4	6.8	7.1	7.67	7.79	7.21	6.78
11-Nov	5.2	3.7	4.9	6.5	7.64	7.66	7.13	7.08
12-Nov	4.5	3.4	5.5	6.7	7.31	7.28	7.23	6.93
13-Nov	3.7	2.5	2.6	3.9	7.29	7.46	7.17	6.78
16-Nov	1.8	3.9	5.1	6.1	7.21	7.51	7.25	7.31
17-Nov	2.8	2.5	4.6	6.7	7.27	7.24	6.28	6.21
18-Nov	1.9	2.4	2.6	3.7	7.41	7.63	7.41	7.05
19-Nov								
20-Nov	4.2	2.9	3.2	4.2	7.4	7.77	7.43	6.87
23-Nov	4	2.5	3.4	4.1	7.37	7.58	7.42	7.3
24-Nov	5	2.6	2.8	4	7.46	7.53	7.39	7.24
25-Nov	3.2	1.4	2.8	4	7.42	7.59	7.38	7.17
26-Nov	5.1	3.2	3.4	3.8	7.15	7.63	7.27	6.98
27-Nov								
30-Nov	3.8	3	4.8	6	7.21	7.19	7.08	6.95
01-Dec	4	2.9	4.2	6.1	7.52	7.49	7.2	7.29

02-Dec	5	3.6	4.8	6.1	7.46	7.63	7.55	7.29
03-Dec	5.7	3.6	4.8	5.5	7.7	7.48	7.45	7.62
04-Dec	5.1	3.2	4	4.7	7.6	7.64	7.45	7.24
flow problems								
new tank/pump								
14-Dec	6.1	3.6	3.5	5.1	7.3	7.45	7.16	7.25
15-Dec	3.5	3.9	5.9	6.4	7.25	7.37	7.14	6.89
16-Dec	5.3	4.1	4.2	5.7	7.45	7.4	6.71	6.08
17-Dec								
18-Dec	5.4	2.9	3.4	4.4	7.38	7.21	7.37	7.15
break								
11-Jan								
12-Jan	3.9	2.5	4.1	4.8	7.65	7.81	7.85	7.45
13-Jan								
14-Jan	3.1	3.6	5.3	4.5	7.35	7.86	7.65	7.43
15-Jan	3.8	3.1	4.6	5.1	7.61	7.73	7.03	7.28
18-Jan	4.1	2.8	3.2	4.1	7.83	7.86	7.81	7.56
19-Jan	4.5	2.1	3.3	4.2	7.43	7.98	7.75	7.42
20-Jan	4.6	3.4	4.5	5.9	7.68	7.85	7.66	7.43
[illegible]								
22-Jan	3.7	3.4	4.5	6.1	7.12	7.4	7.43	7.51
25-Jan	3.2	3.6	5.6	6.5	7.54	7.46	7.13	6.59
26-Jan	3.3	3.8	5.9	7	7.18	7.28	7.15	6.55
27-Jan	3.1	5.1	5.4	6.8	7.14	7.22	7.08	6.92
28-Jan								
29-Jan	2.4	3.4	4.2	5.6	7.15	7.38	7.31	7.04
01-Feb								
02-Feb								
03-Feb	2.5	3.1	5.2	6.3	7.16	7.31	7.12	6.87
04-Feb								
05-Feb	3.1	2.8	4.3	5.8	7.15	7.38	7.31	7.04
08-Feb								
09-Feb	4.2	3.2	5.4	6.8	7.38	7.58	7.25	7.03
10-Feb	4.7	5.1	6.8	7.9	7.13	7.4	7.07	6.88
11-Feb	5.4	5	5.7	6.6	7.58	7.26	7.56	7.41
12-Feb	6.7	4.4	5.2	6.2	7.4	7.64	7.24	7.31
15-Feb								
16-Feb								
17-Feb	4.8	3.9	5.3	6.8	7.59	7.36	7.32	7.28
18-Feb	4.6	4.7	6.3	7.7	6.97	6.84	6.83	6.61
19-Feb	6.1	5.2	5.9	7	7.36	6.97	6.48	6.45
22-Feb	5.3	4.8	5.1	6.4	7.11	7.38	7.42	7.3
23-Feb								
24-Feb	3.5	1.8	4.8	6	7.19	7.21	7.18	7.28

25-Feb	2.6	3.3	4.5	5.7	7.19	7.22	7.2	7.28
26-Feb	2	3.2	5.2	6.5	7.18	6.93	6.76	6.35
10% detergent								
01-Mar	1.8	3.2	4.3	5.1	7.15	7.24	7.35	7.22
02-Mar								
03-Mar	2.6	3.8	5.4	5.4	7.21	7.24	7.13	7.1
04-Mar	2.3	3	4.7	5.6	7.18	7.26	7.38	7.32
05-Mar	2.1	3.6	4.4	5.4	7.15	7.28	7.15	7.2
08-Mar								
09-Mar	3.1	2.5	4.6	5.8	7.23	7.25	7.26	7.13
10-Mar	3.3	2.9	4.3	6	7.17	7.36	7.22	7.14
11-Mar	3	2.4	4.4	5.6	7.17	7.2	7.11	7.18
12-Mar	2.9	2.2	4.6	5.5	7.26	7.31	7.29	7.2
15-Mar	2.7	3.1	4.2	5.3	7.13	7.35	7.31	7.23
[illegible]								
18-Mar	2.1	2	4.9	5.6	7.31	7.68	7.59	7.52
19-Mar	3.2	1.8	3.7	5	7.3	7.6	7.72	7.42
22-Mar	2.4	2.7	4.9	6.4	7.41	7.34	7.21	7.18
23-Mar	3.4	2.1	4.3	5.3	7.45	7.53	7.56	7.1
24-Mar	1.7	2.4	5.2	5.3	7.08	7.5	7.54	7.21
25-Mar								
26-Mar	2.1	2.3	4.8	5.6	7.48	7.56	7.46	7.2
29-Mar	1.9	2.4	4.7	5.9	7.52	7.6	7.19	6.68
30-Mar	3.5	1.8	3.1	5.5	7.51	7.53	7.42	7.16
break								
08-Apr								
09-Apr	5.3	3.1	3.2	6.4	7.55	7.24	6.95	6.79
12-Apr	4.7	2.2	3.9	5.8	7.44	7.33	7.25	7.18
13-Apr	4.5	2.3	3.7	5.5	7.41	7.37	7.23	7.21
power out								
power out								
19-Apr	1.9	2.1	5.9	6.2	7.31	7.29	7.18	7.05

[illegible]	Influent	[illegible]	[illegible]	[illegible]	[illegible]
05-Oct					
06-Oct	0.9	11	5.4	7.68	0.70
07-Oct	1	15	6.3	7.12	0.47
08-Oct	1.1	14.4	6.6	7.67	0.53
09-Oct	1.1	14.4	6	7.26	0.50
12-Oct	1	12.3	9.3	7.44	0.60
13-Oct	1.1	11.1	11.1	7.4	0.67
14-Oct	1	15	7.2	7.17	0.48
15-Oct	1.1	12.9	9	7.04	0.55
16-Oct	1	9.9	9	7.15	0.72
19-Oct	0.9	9	10	6.97	0.77
20-Oct	1	8.4	7.8	7.11	0.85
21-Oct	1	11	10	7.14	0.65
22-Oct	0.9	12.9	10.5	7.01	0.54
23-Oct	0.9	12	10.2		
Detergent 12.5%					
27-Oct	1	15	9.9	7.05	0.47
28-Oct	0.9	15	11.7	6.99	0.47
29-Oct	0.9	14	14.1	6.97	0.50
30-Oct	0.9	13.5	12.8	5.89	0.44
02-Nov	0.8	12.6	15	5.83	0.46
03-Nov	0.8	16.9	15.6	6.24	0.37
04-Nov	1	20	18.2	6.18	0.31
05-Nov	1	18	16.4	6.1	0.34
06-Nov	1.2	20	20	6.87	0.34
09-Nov	1	20	20	5.92	0.30
10-Nov	1.1	18	17	6.93	0.39
11-Nov					
12-Nov	1.1	18	18	5.51	0.31
13-Nov	1.1	18.8	16	5.66	0.30
16-Nov	1.1	22	18.8	6.97	0.32
17-Nov	1	26	24.5	6.5	0.25
18-Nov	1.1	21	20.5	6.38	0.30
19-Nov					
20-Nov	1.1	25	25	6.87	0.27
23-Nov	0.9	25	25	6.19	0.25
24-Nov	1	25	20	6.5	0.26
25-Nov	0.9	25	20	4.98	0.20
26-Nov	1	25	24.5	6.44	0.26
27-Nov					
30-Nov	1	25	25	6.15	0.25
01-Dec	1	17.5	13.5	7.18	0.41
02-Dec	1	23.5	25	6.55	0.28

10% detergent

03-Dec	1	21	15	6.54	0.31
04-Dec	1	23	22	5.44	0.24
flow problems					
new tank/pump					
14-Dec	0.8	20.5	14.5		
15-Dec					
16-Dec	1.1	25	25	6.34	0.25
17-Dec	1	25	22		
18-Dec	0.8	25	17	6.89	0.28
break					
11-Jan					
12-Jan	0.9	18	15	7.45	0.41
13-Jan	1.1	15	14		
14-Jan	1.1	21	18	6.95	0.33
15-Jan					
18-Jan					
19-Jan	1.2	15	13.5	7.42	0.49
20-Jan	1.1	21.5	24	6.93	0.32
20% detergent					
22-Jan	1.2	12	11	7.51	0.63
25-Jan	1	20	22	6.19	0.31
26-Jan	1	23	22	5.85	0.25
27-Jan	1	25	25	6.32	0.25
28-Jan					
29-Jan	1.2	15	14	7.04	0.47
01-Feb					
02-Feb	1.2	11.5	11.5		
03-Feb	1.1	19	19	5.98	0.31
04-Feb	1	20	18		
05-Feb	1.2	15	14	7.04	0.47
08-Feb					
09-Feb	0.9	20	18	6.34	0.32
10-Feb	0.9	18	15.5	6.44	0.36
11-Feb	1	15	14	7.38	0.49
12-Feb	1	16.5	12	7.46	0.45
15-Feb					
16-Feb					
17-Feb	1	13.5	20	7.55	0.56
18-Feb	0.8	12.5	24	7.1	0.57
19-Feb	1.1	19	20	5.95	0.31
22-Feb	1.1	15	10.5	6.19	0.41
23-Feb					
24-Feb	1.3	12	10	7.52	0.63
25-Feb	1	11	10	7.31	0.66

25-Feb	1	20.5	18.5	5.85	0.29	

10% detergent					
01-Mar	1.2	15	14	7.08	0.47
02-Mar					
03-Mar	1.1	13	14	7.17	0.55
04-Mar	1	11.5	11.5	7.33	0.64
05-Mar	1	14	13	7.26	0.52
08-Mar	1	12	10		
09-Mar		19	18	6.94	0.37
10-Mar	1.1	18	15	7.14	0.40
11-Mar	1.2	17	16	7.16	0.42
12-Mar	1.2	19	17	7.19	0.38
15-Mar					
5% detergent					
18-Mar	0.9	15	14	7.52	0.50
19-Mar	1	18	12.5	7.3	0.41
22-Mar	1.2	25	25	7.11	0.28
23-Mar	1.1	23	22	7.1	0.31
24-Mar	1	21	19.5	7.36	0.35
25-Mar					
26-Mar	1.1	16.5	18	7.31	0.44
29-Mar	1.1	25	23	6.69	0.27
30-Mar	0.9	23	17	6.91	0.30
break					
08-Apr	1	17	15.5		
09-Apr	1.1	21	17.5	6.81	0.32
12-Apr	0.8	12	12	7.04	0.59
13-Apr	1	14	13	7.22	0.52
power out					
power out					
19-Apr	0.8	17.5	21	6.87	0.39

Date	Phosphates Influent mg/l	Phosphates Effluent Cups	Phosphates Effluent No Cups	Loading influent	RATIO IN:TP
06-Oct					
07-Oct					
08-Oct					
09-Oct					
12-Oct	11.84	9.96	10.32	200	16.9
13-Oct	14.1	11.88	11.61	216	15.3
14-Oct	10.41	12.15	13.77	143	13.7
15-Oct	8.04	7.38	6.39	146	18.2
16-Oct					
19-Oct	6.06	6.24	6.93	100	16.5
20-Oct	7	6.89	7.98	120	17.1
21-Oct					
22-Oct	8.01	7.68	5.7	112	14.0
	9.4	8.9	9.0	148.1	16.0
Detergent 12.5%					
27-Oct					
28-Oct					
29-Oct	10.77	11.64	11.79	130	12.1
30-Oct	10.8	10.02	8.72	110	10.2
02-Nov					
03-Nov	11.12	11.68	8.1	135	12.1
04-Nov	10.24	11.32	11.76	133	13.0
05-Nov	10.35	10.86	10.53	128	12.4
06-Nov	12.16	12.82	11.98	158	13.0
09-Nov	11.21	9.96	11.06	147	13.1
10-Nov					
11-Nov	10.36	9.86	10.3		
12-Nov	13.2	9.04	11.72	165	12.5
13-Nov					
16-Nov	13.4	12	12.9	168	12.5
17-Nov	14.76	14.26	14.27	179	12.1
18-Nov	15.75	13.89	13.47	175	11.1
19-Nov					
20-Nov					
23-Nov					
24-Nov	15.8	9.56	10.36	201	12.7
25-Nov	14.3	10.28	11.96	157	11.0
26-Nov	15.2	11.38	12.4	170	11.2
27-Nov					
30-Nov					
01-Dec	14.3	13.4	12.84	173	12.1
02-Dec	12.35	12.48	12.52	158	12.8

03-Dec					
04-Dec					
flow problems					
new tank/pump					
14-Dec					
15-Dec	18.86	18.9	18.46		
16-Dec					
17-Dec					
18-Dec	14.84	14.68	13.3	165	11.1
break					
11-Jan					
12-Jan	21.1			278	13.2
13-Jan					
14-Jan					
15-Jan					
18-Jan					
19-Jan	19.54	18.2	15.94	297	15.2
	13.8	12.3	12.2	169.8	12.3
20% detergent					
22-Jan					
25-Jan					
26-Jan					
27-Jan					
28-Jan					
29-Jan					
01-Feb					
02-Feb	50	41.3	39.6	298	6.0
03-Feb	46.56			265	5.7
04-Feb	20.65	20.35	32.9		
05-Feb					
08-Feb					
09-Feb					
10-Feb	15.63	13.15	12.65	169	10.8
11-Feb					
12-Feb					
15-Feb					
16-Feb					
17-Feb					
18-Feb	17.4	15.15	14.98	166	9.0
19-Feb	16.5	13.88	19.3		
22-Feb	26.35	26.4	26.5		
23-Feb					
24-Feb	42.5	32.9	31.7	320	7.5
25-Feb	33.54	26.9	27.9	304	9.1

25-Feb	28.3	25.75	30.5	240	8.5
	29.7	24.0	26.2	250.3	8.1
[illegible]					
01-Mar			20.7	364	
02-Mar					
03-Mar	27.58	22.55	20.65	353	12.8
04-Mar	26.32	21.8	19.65	350	13.3
05-Mar	25.22	20	20.5	335	13.3
08-Mar					
09-Mar					
10-Mar	26.63			346	13.0
11-Mar	30.75	26.54	25.89	374	12.2
12-Mar	28.65	27.5	26.34	367	12.8
	27.5	23.7	22.3	355.6	12.9
[illegible]					
18-Mar	15.3	12.35	10.55	258	16.9
19-Mar	15.25			264	17.3
22-Mar					
23-Mar	14	13.55	13.87	275	19.6
24-Mar	14.8	12.55	11.4	239	16.1
25-Mar					
26-Mar	10.67	10.55	10.45	251	23.5
29-Mar	9.15	8.89	10.91	200	21.9
30-Mar	12.8	10	7.9	230	18.0
break					
08-Apr	8	7.86	6.38	152	19.0
09-Apr	9.15	8.9	8.65	164	17.9
	12.1	10.6	10.0	225.9	18.9

STAGE 3 DAILY TEST RESULTS

high strength feed

Date	COD Influent mg/l	COD Effluent Cups	COD Effluent No Cups	Loading gCOD/m2/d
20-Apr	584	48	41	25.15
21-Apr	610	50	48	26.27
22-Apr	622	63	56	26.78
23-Apr	604	48	55	26.01
26-Apr	593	40	47	25.54
27-Apr	561	45	48	24.16
28-Apr	576	50	43	24.80
29-Apr	504	38	39	21.70
30-Apr	448	26	29	19.29
03-May	507	34	38	21.83
04-May	516	37	39	22.22
05-May	495	38	36	21.32
06-May	452	32	33	19.46
07-May	548	37	41	23.60
10-May	523	35	39	22.52
11-May	461	27	31	19.85
12-May	471	30	32	20.28
13-May	385	26	29	16.58
14-May	384	28	30	16.54
17-May	533	31	37	22.95
18-May	528	33	42	22.74
19-May	542	35	38	23.34
20-May	538	36	41	23.17
21-May	515	34	39	22.18
[illegible]				
24-May	850	65	73	36.60
25-May	894	59	52	38.50
26-May	894	61	53	38.50
27-May	863	53	63	37.16
28-May	857	54	61	36.90
31-May	877	48	72	37.77
01-Jun	893	51	89	38.45
02-Jun	935	54	97	40.26
03-Jun	1347	63	106	58.00
04-Jun	1242	71	107	53.48
07-Jun	1288	82	138	55.46
08-Jun	1400	87	145	60.29

New Flow Date	DO Conc Cups (Stage 1)	DO Conc Cups (Stage 2)	DO Conc Cups (Stage 3)	DO Conc Cups (Stage 4)	pH Cups (Stage 1)	pH Cups (Stage 2)	pH Cups (Stage 3)	pH Cups (Stage 4)
20-Apr								
21-Apr	1.4	1.5	2.6	4	6.93	7.35	7.33	7.31
22-Apr	1.8	1.4	2.5	4.7	7.3	7.61	7.75	7.1
23-Apr	1.9	1.9	2.7	4.6	7.31	7.48	7.15	6.84
26-Apr								
27-Apr	3.2	3.8	4.2	5	7.46	7.05	6.8	5.96
28-Apr								
29-Apr	2.4	3.1	3.5	4.1	7.29	7.38	7.14	6.93
30-Apr	2	2.6	3.4	4	7.27	7.3	7	6.94
03-May	2.1	2.4	3.1	4	7.29	7.33	7.19	7.03
04-May								
05-May	2	2.5	3.2	4.2	7.31	7.48	7.15	6.98
06-May	1.9	2.4	3.3	4	7.29	7.41	7.18	7
07-May								
10-May	2	2.4	3.1	3.9	7.21	7.4	7.09	6.89
11-May	2.1	2.3	3.2	4.1	7.38	7.45	7.22	6.96
12-May								
13-May	2.1	2.3	2.9	4.1	7.33	7.25	7.21	6.9
14-May	2.3	2.4	3.1	4	7.42	7.39	7.11	7.02
17-May								
18-May	2	2.4	3.6	4.1	7.52	7.36	7.54	6.99
19-May								
20-May								
21-May								
[illegible]								
24-May								
25-May	3.2	3.9	4.9	5.8	7.74	7.38	7.36	6.95
26-May	2.9	3.3	3.8	4.9	7.39	7.74	7.72	7.13
27-May	2.6	3.4	4.1	6.1	7.32	7.53	7.34	6.55
28-May	2.5	3.6	4.5	5.9	7.54	7.48	7.32	7.11
31-May								
01-Jun	2.2	3.7	4.9	6	7.5	7.66	7	6.65
02-Jun	2.5	3.1	3.9	5.7	7.45	7.38	7.11	6.98
03-Jun	3.4	3	4.2	6.8	7.31	7.28	6.39	5
04-Jun	1.4	2.4	2.8	5	7.57	8.01	7.82	7.07
07-Jun	1.7	3.5	4.2	5.5	7.53	7.78	7.06	6.98
08-Jun	1.7	2.6	3.8	4.4	7.67	8	7.96	7.6

new flow Date	DO Conc No Cups (Stg 1)	DO Conc No Cups (Stg 2)	DO Conc No Cups (Stg 3)	DO Conc No Cups (Stg 4)	pH No Cups (Stg 1)	pH No Cups (Stg 2)	pH No Cups (Stg 3)	pH No Cups (Stg 4)
20-Apr								
21-Apr	1.4	1.5	2.6	4	7.45	7.26	6.72	6.53
22-Apr	2	2.1	2.5	4.2	7.24	7.66	7.68	7.02
23-Apr	1.9	2.1	2.7	4.1	7.28	7.45	7.21	6.97
26-Apr								
27-Apr	2.1	3.1	3.6	4.3	7.46	7.15	6.93	6.75
28-Apr								
29-Apr	1.7	2.3	3	3.6	7.38	7.48	7.39	7.41
30-Apr	1.2	2.2	3.1	3.5	7.22	7.36	7.39	7.61
03-May	1.5	1.9	2.8	3.4	7.31	7.42	7.26	7.12
04-May								
05-May	1.7	2.3	3.1	3.8	7.28	7.39	7.22	7.05
06-May	1.8	2.2	2.7	3.5	7.36	7.45	7.22	7.13
07-May								
10-May	2	2.4	3	3.7	7.29	7.38	7.15	6.98
11-May	1.8	2.2	2.8	3.4	7.31	7.44	7.22	7.09
12-May								
13-May	1.9	2	2.7	3.8	7.33	7.25	7.21	6.9
14-May	1.8	2.3	2.9	3.5	7.45	7.65	7.35	7.11
17-May								
18-May	1.8	3.2	3.9	4.1	7.22	7.72	7.74	7.12
19-May								
20-May								
21-May								
[illegible]								
24-May								
25-May	2.9	3.4	4.5	5	7.54	7.61	7.54	7.22
26-May	3.2	2.2	2.9	3.5	7.34	7.62	7.55	7.14
27-May	2.4	2.4	3.2	3.4	7.38	7.66	7.46	7.29
28-May	2.2	2	2.9	3.7	7.49	7.71	7.53	7.31
31-May								
01-Jun	1.8	1.8	2.2	3.5	7.15	7.84	7.91	7.9
02-Jun	2	1.9	2.3	3.1	7.45	7.56	7.6	7.84
03-Jun	2.1	2.4	3.3	4	7.32	7.68	7.6	7.38
04-Jun	1.7	1.1	1.9	3.5	7.57	7.98	8.08	8.04
07-Jun	1.1	0.8	2.4	3.5	7.44	7.95	8.04	7.98
08-Jun	1.1	0.8	1.6	3.2	7.35	7.86	8.08	8.08

[illegible]	[illegible]	[illegible]	[illegible]
20-Apr	1.1		
21-Apr	1.1	12	15
22-Apr	1.1	12	16
23-Apr	1.1	13	12
26-Apr	1.1		
27-Apr	1.1	14	11
28-Apr	1.1		
29-Apr	1.1	14	10
30-Apr	1	13	8
03-May	1.1	12	9
04-May	1.1		
05-May	1.1	14	10
06-May	1.1	15	10
07-May	1.1		
10-May	1.1	15	11
11-May	1.1	14	9
12-May	1.1		
13-May	1.1	17	10
14-May	1.1	12	8
17-May	1.1	12	9
18-May	1.1	12	11
19-May	1.1	13	10
20-May	1.1	12	9
21-May	1.1		
24-May	1.2		
25-May	1.2		
26-May	1.2	14	14
27-May	1.2	13	10
28-May	1.2	12	9
31-May	1.2		
01-Jun	1.2	12	8.5
02-Jun	1.2	12	6.3
03-Jun	1.3	13	5.8
04-Jun	1.3	12	5.6
07-Jun	1.3	12	5.1
08-Jun	1.5	10	4.8

10% detergent

Date	Phosphate Influent mg/l	Phosphates Effluent Cups	Phosphates Effluent No Cups	Influent	Inf/Phos Ratio
20-Apr	21.63	18.4	18.7	584	27.00
21-Apr	27.35	15.1	13.85	610	22.30
22-Apr	29.15	26.45	20.5	622	21.34
23-Apr	28.37	25.5	25.48	604	21.29
26-Apr	28.76	26.03	25.97	593	20.62
27-Apr	29.05	24.75	23.2	561	19.31
28-Apr	28.51	24.6	24.2	576	20.20
29-Apr	23.21	19.38	18.92	504	21.71
30-Apr	20.2	18.6	18.3	448	22.18
03-May	23.44	19.48	18.97	507	21.63
04-May					
05-May	20.32	18.46	19.02	495	24.36
06-May	18.02	17.21	16.89	452	25.08
07-May	27.36	26.4	26.21	548	20.03
10-May					
11-May	17.63	15.11	14.79	461	26.15
12-May	18.93	15.23	14.95	471	24.88
13-May	15.8	14.75	15.1	385	24.37
14-May	15.6	14.5	14.8	384	24.62
17-May					
18-May	23.45	17.55	15.95	528	22.52
19-May					
20-May					
21-May	22.45	17.35	16.1	515	22.94
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	% removal 14.7	% removal 17.6			

	BOD	BOD	BOD	COD	COD	COD	COD/BOD	COD/BOD	COD/BOD	
	Influent	Cup	No Cup	Influent	Cup	No Cup	Influent	Cup	No Cup	
30-Sep	87	7.6	6.4	144	35	33	1.66	4.61	5.16	
02-Oct	75	2.8	5.9	131	18	32	1.75	6.43	5.42	
07-Oct	75	5.6	3.9	180	43	46	2.40	7.68	11.79	10%detergent
14-Oct	57	5.2	4.4	143	28	36	2.51	5.38	8.18	
22-Oct	69	7.6	7.6	112	13	19	1.62	1.71	2.50	
28-Oct	44			105			2.39			12.5%detergent
29-Oct	56	6.3	4	130	30	25	2.32	4.76	6.25	
04-Nov	78	12	4.4	133	35	34	1.71	2.92	7.73	
06-Nov	91	9.2	5	158	34	34	1.74	3.70	6.80	
13-Nov	117		5.7	165	39	36	1.41		6.32	
25-Nov	75			157			2.09			
25-Feb	150	14	25	304	35	48	2.03	2.50	1.92	20%detergent
05-Mar	207	25	19	335	35	33	1.62	1.40	1.74	15%detergent
12-Mar	198	18	32	367	46	54	1.85	2.56	1.69	
19-Mar	150	9	30	264	31	42	1.76	3.44	1.40	5%detergent
25-Mar	132	20	15	253	30	28	1.92	1.50	1.87	
09-Apr	90	8	9	164	23	22	1.82	2.88	2.44	
30-Apr	294	14	17	448	26	29	1.52	1.86	1.71	high strength feed
07-May	360	14	20	548	37	41	1.52	2.64	2.05	
14-May	204	11	13	384	24	30	1.88	2.18	2.31	
21-May	264	13	16	515	34	39	1.95	2.62	2.44	

Date	Amperage	Temperature °C
27-May		15
28-May		16
29-May		15
02-Jun		17
03-Jun		17
04-Jun		17
05-Jun		18
08-Jun		16
09-Jun	0.39	16
11-Jun	0.4	15
18-Jun	0.4	19
22-Jun	0.4	19
23-Jun	0.39	19
24-Jun	0.4	18
25-Jun	0.4	18
26-Jun	0.39	17
30-Jun	0.39	16
01-Jul	0.4	18
02-Jul	0.39	18
03-Jul	0.4	18
06-Jul	0.41	17
07-Jul	0.39	16
10-Jul	0.4	17
13-Jul	0.39	17
14-Jul	0.4	17
15-Jul	0.4	17
16-Jul	0.4	17
17-Jul	0.41	16
20-Jul	0.4	16
21-Jul	0.42	16
22-Jul	0.4	17
23-Jul	0.41	16
24-Jul	0.41	16
29-Jul	0.41	17
30-Jul	0.4	17
04-Aug	0.4	17
05-Aug	0.4	19
06-Aug	0.4	18
11-Aug	0.41	19
12-Aug	0.41	18
13-Aug	0.4	17
14-Aug	0.41	17
19-Aug	0.42	17
21-Aug	0.39	17
24-Aug	0.39	17
25-Aug	0.4	17
28-Aug	0.4	16
01-Sep	0.39	18
02-Sep	0.39	17
08-Sep	0.4	17
09-Sep	0.39	17
10-Sep	0.39	16

15-Sep	0.39	16
21-Sep	0.4	17
22-Sep	0.4	17
23-Sep	0.4	18
25-Sep	0.4	18
30-Sep	0.39	15
01-Oct	0.4	14
02-Oct	0.41	16
06-Oct	0.37	14
07-Oct	0.39	15
08-Oct	0.4	17
09-Oct	0.38	17
12-Oct	0.39	16
13-Oct	0.38	16
14-Oct	0.39	14
15-Oct	0.39	14
16-Oct	0.4	15
19-Oct	0.4	14
20-Oct	0.4	14
21-Oct	0.39	15
22-Oct	0.39	16
23-Oct	0.4	14
27-Oct	0.38	13
28-Oct	0.4	12
29-Oct	0.38	12
30-Oct	0.38	12
02-Nov	0.37	11
03-Nov	0.37	11
04-Nov	0.37	12
05-Nov	0.37	12
06-Nov	0.39	14
09-Nov	0.37	13
10-Nov	0.37	11
11-Nov	0.37	10
12-Nov	0.39	12
13-Nov	0.39	11
16-Nov	0.38	12
17-Nov	0.37	13
18-Nov	0.38	14
20-Nov	0.38	15
23-Nov	0.4	13
24-Nov	0.37	15
25-Nov	0.38	15
26-Nov	0.36	14
01-Dec	0.37	13
02-Dec	0.4	15
03-Dec	0.39	15
15-Dec	0.38	14
16-Dec	0.39	15
11-Jan	0.39	7
12-Jan	0.4	10
13-Jan	0.39	10
14-Jan	0.38	10

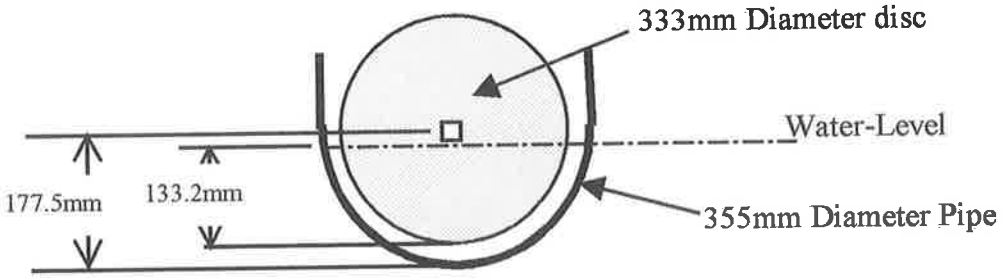
18-Jan	0.38	10
19-Jan	0.37	11
20-Jan	0.38	11.5
22-Jan	0.39	12
25-Jan	0.39	11
26-Jan	0.39	12
01-Feb	0.39	12
02-Feb	0.4	13
03-Feb	0.39	14
09-Feb	0.4	10.5
10-Feb	0.39	11
11-Feb	0.39	12
12-Feb	0.39	13
15-Feb	0.4	11.5
16-Feb	0.39	13
17-Feb	0.39	12
19-Feb	0.39	13
22-Feb	0.39	13
23-Feb	0.39	13
24-Feb	0.39	13
25-Feb	0.4	13
26-Feb	0.38	13
03-Mar	0.4	13
04-Mar	0.39	13
05-Mar	0.38	12
08-Mar	0.38	12
10-Mar	0.38	10
11-Mar	0.38	12
12-Mar	0.39	12
18-Mar	0.38	13
19-Mar	0.37	12
22-Mar	0.39	12
23-Mar	0.38	14
24-Mar	0.4	13
25-Mar	0.37	12
26-Mar	0.4	12
29-Mar	0.39	13
30-Mar	0.39	13
08-Apr	0.38	15
09-Apr	0.37	15
12-Apr	0.4	12
13-Apr	0.38	11
19-Apr	0.39	11
20-Apr	0.42	12
21-Apr	0.39	15
22-Apr	0.39	15
28-Apr	0.38	16
29-Apr	0.4	15
30-Apr	0.39	15
04-May	0.39	18
05-May	0.38	16
06-May	0.39	16
07-May	0.39	16

11-May	0.39	16
12-May	0.39	17
13-May	0.4	16
14-May	0.4	16
18-May	0.4	15
19-May	0.4	16
20-May	0.4	15
25-May	0.4	13
26-May	0.39	15
27-May	0.4	17
07-Jun	0.4	18
08-Jun	0.47	18

Appendix 3

Volume and retention times

VOLUME OF WASTEWATER IN RBC TROUGH



Cross-section through RBC trough.

- The RBC disc is at 40% submergence in the wastewater:

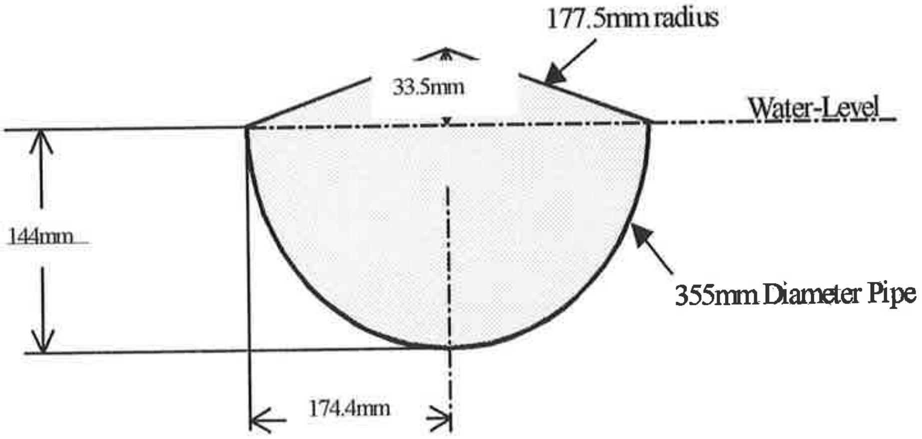
  ⇒ 333 x 0.4 = 133.2mm from the bottom of the disc.

- Radius of Trough = 177.5mm Radius of Disc = 166.7mm

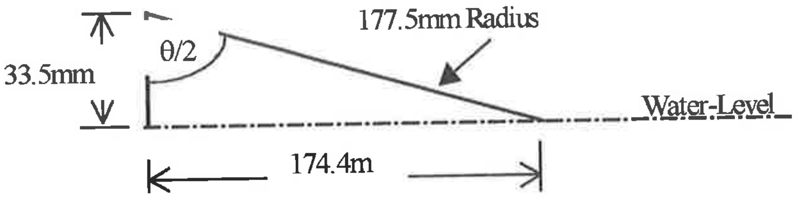
  Space between Disc and Trough: ⇒ 177.5 – 166.7 = 10.8mm

- Depth of wastewater in trough = 133.2 + 10.8 = 144mm.

- Area of segment of circle: ⇒ ½ $R^2\theta$ (θ is in radians).



Radius (R) = 177.5mm.



$\text{Cosine}\ {}^{\theta}/_{2} = {}^{33.5}/_{177.5}$ $\Rightarrow {}^{\theta}/_{2} = \text{Cos}^{-1}\ {}^{33.5}/_{177.5}$

$\Rightarrow {}^{\theta}/_{2} = 79.187^{0}$ $\Rightarrow \theta = 158.374^{0}$ or $\theta = 2.7642$ Radians

Area of segment of circle: $\Rightarrow$ $\frac{1}{2} R^2\theta$ (θ is in radians).

$\Rightarrow \frac{1}{2}(177.5)^2 \times 2.7642$ $\Rightarrow 0.0435454\ m^2$ (Shaded area).

Area of triangle to be excluded from segment = $\frac{1}{2}(174.4) \times 33.5 \times 2 \Rightarrow 0.0058059\ m^2$

Area of trough = $0.0377395\ m^2$.

The volume of wastewater in each stage of the RBC units can now be calculated.

Stage 1 Refer to Figure 4.2 (b).

Length = 60 + (9 spaces x 18) + (10 discs x 5) + 60 $\Rightarrow$ 0.332m

Since the discs do not contribute to the liquid volume it is more accurate to use:

Length = 60 + (9 x 18) + 60 $\Rightarrow$ 0.282m

Volume of stage 1 trough = 0.0377395 x 0.282 $\Rightarrow$ $0.0106425\ m^3$.

Stage 2 Refer to Figure 4.2.(b)

Length = 60 + (5 spaces x 18) + (6 discs x 5) + 60 ⇒ 0.240m

Since the discs do not contribute to the liquid volume it is more accurate to use:

Length = 60 + (5 x 18) + 60 ⇒ 0.210m

Volume of stage 2 = 0.0377395 x 0.210 ⇒ 0.00793 m^3.

Stages 3 & 4 Refer to Figure 4.2 (b).

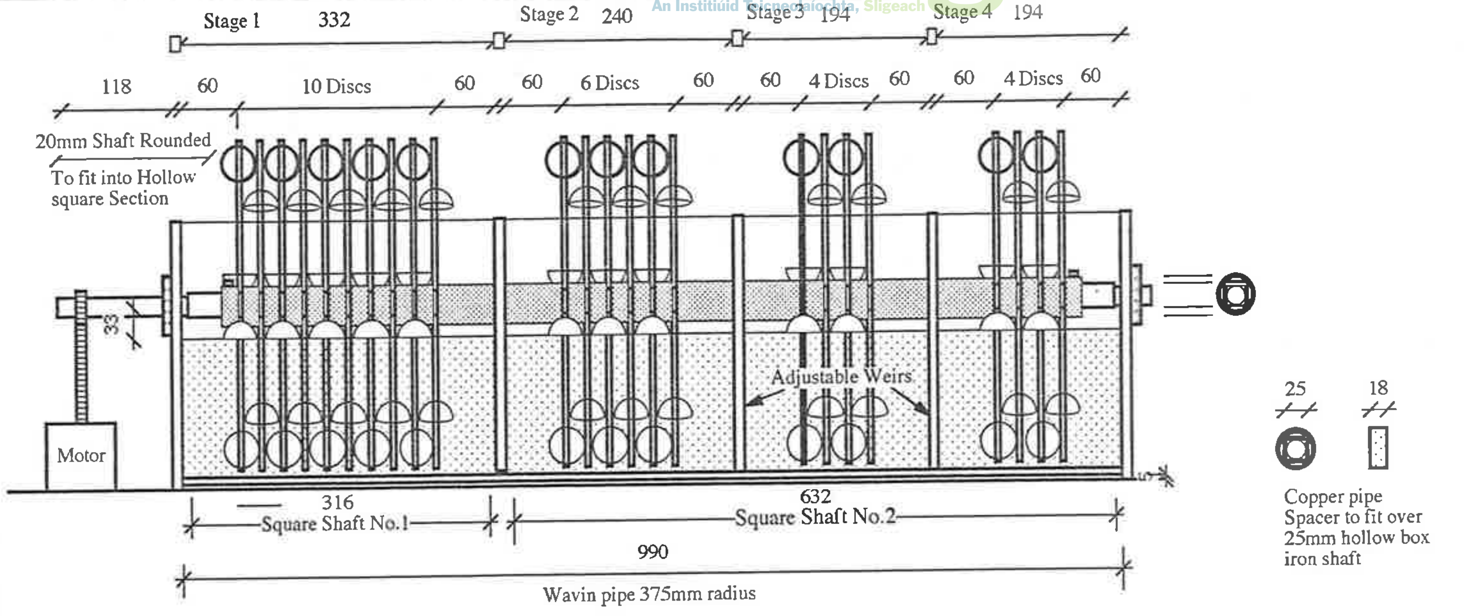
Length = 60 + (3 spaces x 18) + (4 discs x 5) + 60 ⇒ 0.194m

Since the discs do not contribute to the liquid volume it is more accurate to use:

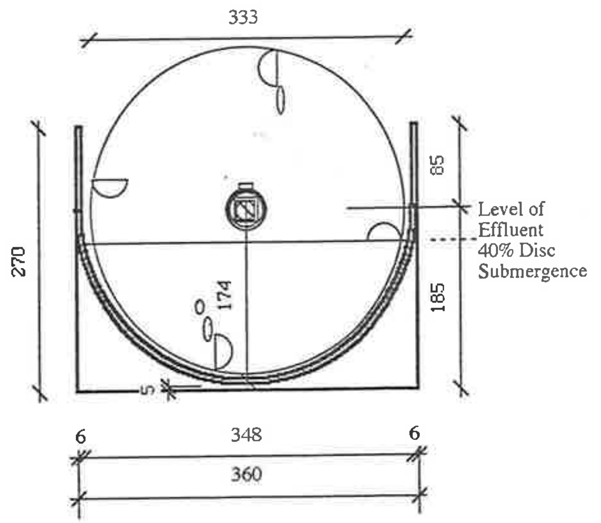
Length = 60 + (3 x 18) + 60 ⇒ 0.174m

Volume of each of stages 3 and 4 = 0.0377395 x 0.174 ⇒ 0.00657 m^3.

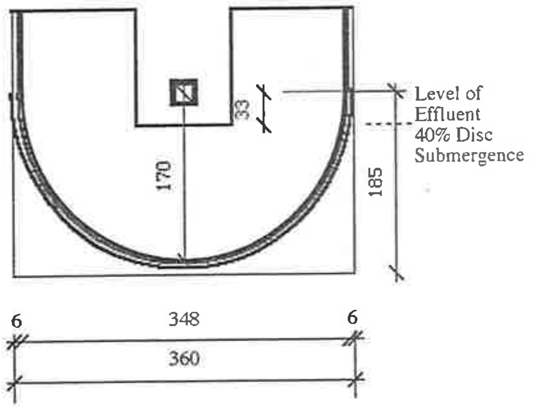
Flow-rate		60 litres.d^{-1}	120 litres.d^{-1}	180 litres.d^{-1}
Stage Number	Volume	Retention Time	Retention Time	Retention Time
1	0.0106425	4 hrs 15 mins	2 hrs 7 mins	1 hr 25 mins
2	0.079252	3 hrs 10 mins	1 hr 35 mins	1 hr 3 mins
3	0.0065666	2 hrs 38 mins	1 hr 19 mins	0 hr 53 mins
4	0.0065666	2 hrs 38 mins	1 hr 19 mins	0 hr 53 mins
Total	0.0317009	12 hrs 41 mins	6 hrs 20 mins	4 hrs 14 mins



SECTIONAL ELEVATION OF ROTATING BIOLOGICAL CONTACTOR MODEL



SECTION THROUGH TROUGH



SECTION OF ADJUSTABLE WEIR

Notes:

ONE MODEL WITH CUPS
ONE MODEL WITHOUT CUPS
DISCS 5MM THICK
(POLYETHELENE)

ADJUSTABLE WEIRS AND
END SECTION MADE
FROM 10MM THICK
PERSPEX

Revision No. 4

Figure 4.2 (b).

Title:
R.B.C. Design

Designed By:
Patrick Cunningham B.Eng.

Client:
Sligo Institute of Technology
Ballinode, Sligo.

Scale 1:5
Date 19-3-99

Appendix 4

E.S.B. tariffs

ELECTRICITY SUPPLY BOARD

TARIFF SYSTEMS

- APPROPRIATE TO ENERGY MANAGEMENT
FROM AN
ENGINEERING PERSPECTIVE

(Domestic system included for comparative purposes)

(Rates given for early 90's - check with ESB for update)

Urban Domestic

Private Dwellings - General Purpose Tariff

Standing charge £3.35 per two monthly period

+

kWh charges 7.14p per kWh

Storage heating night saver 2.90p per kWh *

-usually for a 9 hour period specified by the ESB, controlled by a time switch.

* 2.38p in government designated smoke control zones.

Urban Domestic

Private Dwellings

General Purpose Night Saver Tariff

Two-month standing charge £9.55

+

kWh Charges	Day kWh:	7.14p per kWh
	Night kWh:	2.85p per kWh *

Conditions:

1. Hours at ESB's discretion - usually 11pm to 8 am (night)

2. Applies only to domestic use where maximum demand < 30 kVA

3. Storage heating may only be connected during night hours

............................etc.

* 2.38p for smoke control zones.