A STUDY OF THE FATE OF CADMIUM IN WASTEWATER EFFLUENTS IN CONSTRUCTED WETLAND SYSTEMS

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การศึกษาการลดลงของแคดเมี่ยมในน้ำเสียในพื้นที่ชุ่มน้ำประดิษฐ์

นางสาวณัฐฐาวดี สมอคำ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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Suranaree University of Technology Council has approved this thesis submitted in partial fulfillment of the requirement for Master's Degree

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การวิจัยครั้งนี้เป็นการศึกษาการลดลงของแคดเมี่ยมในน้ำเสีย โดยใช้พื้นที่ชุ่มน้ำประดิษฐ์ โดยมีสภาพแวดล้อมที่ต่างๆกันและเปรียบเทียบประสิทธิภาพของพื้นที่ชุ่มน้ำประดิษฐ์แบบไหลบนพื้นผิวและไหลใต้ดิน บ่อทดลองถูกสร้างขึ้นที่บริเวณหลังอาคารเครื่องมือ 5 ของมหาวิทยาลัยเทคโนโลยีสุรนารี ซึ่งประกอบไปด้วย บ่อทดลองทำด้วยแผ่นสังกะสีจำนวน 4 บ่อขนาดกว้าง 0.25 เมตร ยาว 4 เมตร และสูง 1 เมตรโดยใช้ตัวกลางคือ ทราย, หิน, กรวด สำหรับทั้งสองระบบของพื้นที่ชุ่มน้ำประดิษฐ์ใช้พืชคือ ธูปฤาษี (*Typha angustifolia.*) น้ำเสียที่ใช้สำหรับทั้งสี่บ่อทดลองคือน้ำเสียสังเคราะห์ ระยะเวลากักเก็บน้ำที่ใช้คือ 5.5 วัน ความสามารถของระบบทั้งสองถูกประเมินโดยใช้น้ำเสียที่เข้าระบบคือ น้ำเสียสังเคราะห์ผสมด้วยแคดเมี่ยมที่ความเข้มข้นต่างๆ คือ 1, 5, 10, และ 20 มิลลิกรัมต่อลิตร ประสิทธิภาพในการบำบัด COD, TKN, TP, TSS, VSS ของพื้นที่ชุ่มน้ำประดิษฐ์ทั้งสองระบบอยู่ในช่วง 78-92%, 65-91%, 62-90%, 68-91%, และ 50-84% ตามลำดับ กระบวนการในการกำจัดได้แก่ การกรอง, การตกตะกอน, การดูดซับ, กระบวนการทางชีววิทยา, ปฏิกิริยาไนตริฟิเคชั่น และ ดีไนตริฟิเคชั่น ประสิทธิภาพในการบำบัด แคดเมี่ยมของทั้งสองระบบ มีประสิทธิภาพที่สูงถึง 98.6-99.9% กระบวนการในการกำจัดแคดเมี่ยมพื้นที่ชุ่มน้ำประดิษฐ์ คือ การตกตะกอนในรูปของออกไซด์, ไฮดรอกไซด์, การเกิดสารประกอบเชิงซ้อน, การดูดซับโดยดิน และโดยการดูดซึมโดยธูปฤาษี กระบวนการหลักในการกำจัดแคดเมี่ยมในการศึกษาครั้งนี้คือ การตกตะกอน พื้นที่ชุ่มน้ำประดิษฐ์แบบไหลใต้ดิน มีประสิทธิภาพในการบำบัดมลภาวะต่างๆได้ดีกว่าพื้นที่ชุ่มน้ำประดิษฐ์แบบไหลบนพื้นผิวเพียงเล็กน้อย แต่ประสิทธิภาพในการบำบัดแคดเมี่ยมจะไม่แตกต่างกันในทั้งสองระบบ

สาขาวิชาวิศวกรรมสิ่งแวดล้อม	ลายมือชื่อนักศึกษา……………………………....
ปีการศึกษา 2545	ลายมือชื่ออาจารย์ที่ปรึกษา………………….......

NATTAVADEE SAMORKHOM: A STUDY OF THE FATE OF CADMIUM IN WASTEWATER EFFLUENTS IN CONSTRUCTED WETLAND SYSTEMS THESIS ADVISOR : ASSIST. PROF. RANJNA JINDAL, Ph.D. 189 PP. ISBN 974-533-177-5

CONSTUCTED WETLANDS/CADMIUM/CATTAIL PLANTS

This study was conducted to investigate the fate of cadmium in wastewater effluents by constructed wetland systems under different environmental conditions, and to compare the efficiency of cadmium removal through lab scale experiments in free water surface and subsurface flow wetland systems. Laboratory scale experimental set-up was located at a site near F5 of Suranaree University of Technology (SUT) and consisted four reactor units made of zinc sheets, with dimensions of 4x0.25x1m. The media used were sand, coarse gravel and rock. The cattail plants (*Typha angustifolia.*) were chosen for all reactors of the two wetland systems. The synthetic wastewater was prepared for four reactors. The hydraulic retention time (HRT) was about 5.5 days for the both constructed wetland systems. The influent cadmium concentrations for the four experimental runs were 1, 5, 10 and 20 mg/l. Performance of free water surface and subsurface flow wetland systems were evaluated and compared for different cadmium concentrations in the synthetic wastewater used for this study. The removal efficiencies of COD, TKN, TP, TSS, VSS ranged between 78-92%, 65-91%, 62-90%, 68-91%, and 50-84%, respectively for the two wetland systems. The major mechanisms of the removal were filtration, sedimentation, adsorption, biological processes, as well as nitrification and denitrification reactions. High cadmium removal efficiencies of about 98.6-99.9 % were obtained for both types of wetlands. Out of the various mechanisms of cadmium removal, the precipitation, complexation, soil adsorption and cattail plants uptake, the precipitation seemed to be predominant in present study . The subsurface flow wetland showed slightly better performance than free water surface flow wetland in terms of various pollutants' removal. However, there was no significant difference in the cadmium removal efficiencies of the two wetland systems.

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา………………………………..

ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา……………………......

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Nattavadee Samorkhom

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List of Abbreviations

l	=	Length of wetland unit, m
W	=	Width of wetland unit, m
D	=	Depth of submergence, m
n	=	Porosity of the bed, as a decimal fraction
Q	=	Average flow through the wetland unit, m^3/d
AAS	=	Atomic adsorption spectrometry
FWS	=	Free water surface system
SF	=	Subsurface flow systems
ppm	=	Part per million
COD	=	Chemical oxygen demand
TSS	=	Total suspended solid
VSS	=	Volatile suspended solid
TKN	=	Total kjeldahl nitrogen
TP	=	Total phosphorus
DO	=	Dissolved oxygen
mg	=	Milligram
mL	=	Milliliter
mg/L	=	Milligram/Liter
Cd	=	Cadmium
d	=	Dispersion number
HRT	=	Hydraulic retention time
h	=	hour

Chapter I
Introduction

1.1 Introduction

Through mining, industrial activities and fossil fuels combustion, people each year, spew thousands of tons of metallic pollutants in to air and water. Toxic metal pollution is not only a problem for exposed workers, but is one of the global problems that concern us (Delgado et al., 1993). Many industries including electroplating, foundries, electronics, mining, smelting, tanning, photo processing, pulp and paper and metal finishing can be a significant source of wastewater containing heavy metal pollutants such as nickel (Ni), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu), iron (Fe), and mercury (Hg), etc. Heavy metals are ubiquitous environmental pollutants that arise from a variety of industrial, commercial, and domestic activities. Furthermore, studies show that heavy metals can be found in municipal sewage treatment plants receiving little or no industrial discharge (Gersberg et al., 1984). Heavy metals constitute a serious form of pollution since they do not degrade as organic pollutants do. (Delgado et al., 1993). Heavy metals concentrate in the food chains and they can accumulate poison to plants, animals and human. Especially, cadmium is an environmental pollutant that accumulates in the body and has biological half-life of greater than 10 years in humans (Khosraviani et al., 1998). Therefore, these pollutants must be removed in the effective way before the effluents are discharged from the wastewater treatment plants to the receiving water bodies.

Rivers of Asia are among the most polluted in the world and contain 10 times as many bacteria from human wastes as compared to the developed countries. It is clear that the course of action taken by the industrialized nations is not a variable alternative for developing countries. The high cost of infrastructure investment, continual replacement and ongoing operation costs of conventional wastewater management facilities, take these technologies beyond the financial grasp of most developing countries. Thus, there is a critical need for cost-effective, long-term, wastewater treatment technologies to deliver public health and environmental protection in both the developed and developing countries. Conventionally, wastewater treatment is accomplished by physical, chemical, and biological processes.

There are many techniques available for the removal of heavy metals from wastewater such as chemical precipitation, reverse osmosis, electrolysis, and ion exchange. Typically, these processes are supported by natural components such as a microbial organisms, but in a complex array of energy-intensive mechanical equipment. Conventional treatment systems, therefore, contribute to (1) depletion of nonrenewable fossil fuel sources, and (2) environmental degradation that occur due to extraction of nonrenewable resources, and also due to the byproducts/final products of these technologies, such as biosolids and sludge. Therefore, attempts for developing cost-effective treatment approach always revolved around using only the natural components devoid of any mechanical requirements that use up energy. Using plants to purify wastewater has always fascinated researchers and holds intuitive appeal to the general public as well. Consequently, many natural systems that use the ability of plant species in uptaking or degrading the pollutants were developed. The natural treatment systems that have been developed so far can be categorized into three major categorized:

1. Aquatic or pond/lagoon systems
2. Terrestrial or land application systems, and
3. Wetland systems

Wetland treatment systems use either the natural wetlands or constructed wetlands for treatment of wastewater. Wetlands have been used as convenient wastewater discharge sites for more 100 years in some regions. When monitoring was initiated at some of the existing wetland discharges, an awareness of the water purification potential of wetlands began to emerge. Significant advances have since been made in the engineering knowledge of creating constructed wetlands that can closely imitate the specialized treatment functions that occur in the natural wetland ecosystems. Among the natural treatment systems, the many advantages such as simplicity of design, and lower costs of installation, operation, and maintenance offered by constructed wetlands make them an appropriate alternative for both developed and developing countries.

Many varieties of wetland plant species are tolerant of high concentrations of heavy metals, perhaps because of the protective effect of the iron plaque, which can develop around the roots. Hence, wetlands can be designed and built for heavy metals removals. In fact, many constructed wetlands specifically built for heavy metal removal are in operation in Australia (Sundaravadivel and Vigneswaran, 2001).

1.2 Research objectives

The main objectives of this study were:

1.2.1 To investigate the fate of cadmium in wastewater effluents in constructed wetland systems under different environmental conditions.

1.2.2 To compare the efficiency of cadmium removal through laboratory scale experiments in free water surface (FWS) and subsurface flow (SF) wetland systems.

1.3 Scope and limitations of study

1.3.1 Two simultaneous experiments were carried out in four laboratory scale units for the two wetland systems during the four runs.

1.3.2 Cattail plants (*Typha angustifolia.*) were used in the constructed wetland units.

1.3.3 A synthetic wastewater was prepared in the laboratory. Cadmium concentrations of 1, 5, 10, and 20mg/L, mixed with the synthetic wastewater, were fed to the wetland units during four experimental runs.

1.3.4 Concentrations of some monitored parameters, chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP), total suspended solid (TSS), volatile suspended solid (VSS), as well as Cd were determined in the influent and effluent at frequent intervals during the four runs. The cadmium content in the soil were determined at the end of each run, while in plants, it was only measured at the end of the fourth run.

1.3.5 Performance of free water surface (FWS) and subsurface flow (SF) wetland systems were evaluated and compared for different influent cadmium concentrations.

Chapter II
Literature Review

2.1 Characteristics of cadmium (Cd) and its compounds

Cadmium is a rare element and is derived exclusively from zinc ores. It is most often found in combination with other elements, such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfer (cadmium sulfide). The mineral greenokite, CdS, is widely dispersed but is of no chemical value. Pure cadmium (Cd), a soft, silver-white metal, is quite ductile. It is not attacked in dry air but is slowly oxidized forming protective film of oxide and carbonate in moist air. The main physical properties of cadmium are reported in Table 2.1 (Townshend, 1995).

Table 2.1 Some physical properties of cadmium

Atomic Weight	112.41
Atomic Number	48
Oxidation State	2
Melting Point (S.T.P)	320.9 °C
Boiling Point (S.T.P)	765 ± 2 °C
Density (20°C)	8.65 g/cm^3

Cadmium and its compounds are stable, with high melting points and volatility (National Safety Council, 2000). The properties of numerous cadmium compounds are described below (Upadhyaya, 1994; Heinz et al., 1998; and King, 1994).

Cadmium oxide, CdO, is formed by heating the metal, its hydroxide, or carbonate in air. The amorphous oxide is insoluble in water and bases but is readily soluble in dilute acids, ammonia, ammonia salt solutions, and sodium cyanide solutions. CdO volatilizes at 700°C and may be used as pigment. Further uses include: in resistant enamels, in metal coating for plastics, and as a component of batteries. It is temperature resistant, and together with silver, is useful in heavy-duty electrical contacts. Cadmium oxide improves the behavior of some high-temperature plastics. It is also used in ceramic glazes.

Cadmium hydroxide, $Cd(OH)_2$, is formed as white precipitate on the addition of an alkali hydroxide to a solution of cadmium salt, preferably nitrate. It is insoluble in excess of alkali but dissolves in ammonia to form the complex ion, $[Cd(NH_3)_4]^{2+}$. Being a strong base, it absorbs carbon dioxide from the air. Cadmium hydroxide is a component of cadmium-nickel accumulators and silver-cadmium batteries.

Cadmium chloride, $CdCl_2$, is slightly soluble in water. The species are $CdCl_2.H_2O$, $CdCl_2.2^1/_2H_2O$ and $CdCl_2.4H_2O$. The hydrated chloride is obtained by dissolving the metal, its oxide or carbonate in dilute hydrochloric acid and concentrating the solution to the crystallization point. The anhydrous salt can be obtained by heating the hydrated chloride in dry hydrogen chloride. Cadmium chloride is a colorless crystalline solid very soluble in water 110.6 g $CdCl_2$ in 100 g of water at 18°C). It is also somewhat soluble in organic solvents such as acetone and ethyl acetate. Cadmium chloride is efflorescent and is used in photography, dyeing printing, radio valve manufacture, galvanoplasty, and mirror manufacture.

Other halides are similar in general characteristics. Cadmium fluoride, however, differs from others in being non-volatile and only slightly soluble in water. The solubility of these halides increases from the fluoride to the iodine. Cadmium bromide and iodine find use in photography.

Cadmium carbonate, $CdCO_3$ is obtained as the white precipitate on adding excess of ammonium carbonate to a solution of cadmium chloride. The precipitate dissolves in excess of ammonia solution from which cadmium carbonate is reprecipitated on heating. The alkali carbonate gives only a basic carbonate. Cadmium carbonate is starting material for the production of cadmium pigments and other cadmium salts.

Cadmium nitrate tetrahydrate, $Cd(NO_3)_2.4H_2O$ has a density of 2.46 g/cm^3. It small colorless deliquescing crystals readily dissolve in water. They have a melting point of 59.9 °C, and the liquid has a boiling point of 132 °C. It is used for the production of red lusters in glass and porcelain and in cadmium-nickel sinter plates of storage batteries.

Cadmium sulfide, CdS is obtained as a yellow precipitate by passing hydrogen sulfide into dilutes acid solution of a cadmium salt. It is soluble in dilute nitric acid and in concentrated mineral acids and insoluble in yellow ammonium sulfide. Mixed with barium sulfate, it is used as pigment under the name cadmiophone. CdS is an important yellow pigment, used in the paint, glass, rubber, paper, textile, and pyrotechnics industries.

Cadmium sulfate, $CdSO_4$ has a density of 4.7 g/cm^3. The melting point of the anhydrous salt is 1000 °C. Anhydrous cadmium sulfate is produced by melting cadmium with ammonium or sodium peroxodisulfate. Cadmium sulfate is soluble in water and on heating decomposes into the oxide. It forms double salts, e.g, $K_2SO_4.CdSO_4.6H_2O$, and is used in Western cells and also as a medicine in eye diseases (Upadhyaya, 1994). Cadmium sulfate is used in electroplating and as a starting material for pigments, stabilizers, and other cadmium compounds that can be precipitated from aqueous solution. It is used to produce fluorescent materials.

Cadmium Cyanide, $Cd(CN)_2$ has a density of 2.226 g/cm^3. The solubility in water is 17 g per liter at 15 °C. The solubility in sodium cyanide solution is greater because tricyanocdmium ions, $Cd(CN)_3^-$, form. Cadmium cyanide and its mixtures with an alkali-metal cyanide are used in electroplating (Upadhyaya,1994, Heinz et al.,1998, King, 1994).

2.2 Sources of cadmium (Cd)

Cadmium (Cd) can be found in electrodeposited and dipped coatings on metals, bearing and low-melting alloys, brazing alloys, fire protection systems, nickel-cadmium storage batteries, power transmission wire, and TV phosphorescence. Cadmium is also used as the basis of pigments in ceramic glazes, machinery enamels, fungicide photography and lithography, selenium rectifiers, electrodes for cadmium-vapor lamps, and photoelectric cell. Cadmium may enter water as a result of industrial discharges or the deterioration of galvanized pipe. Mining industries provide precious and semiprecious minerals including iron, gold, silver, tin, cadmium and nickel to the wastewater discharges. Electroplating is the electrochemical process of applying metal coatings to metallic objects for corrosion protection and for decorative finishing. Cadmium is one of heavy metals that are the pollutants from this process (Metcalf & Eddy, 1991). Cadmium is also used in the manufacture of photovoltaic devices such as photometers and solar cells and for the automatic control of camera apertures (Mcketta, 1993).

2.3 Harmful effects of cadmium (Cd) and its compounds

The harmful effects of cadmium to humans and environment include: it is flammable in powder form, toxic by inhalation of dust or fume, and is a carcinogen. Soluble compounds of cadmium are highly toxic. Long term-concentrates in the liver, kidneys, pancreas, and thyroid cause hypertension (Metcalf & Eddy, 1991). Short-term health effects include a flu-like illness with chills, headache, aching and/or fever. High exposures can cause rapid and serve lung damage, with shortness of breath, chest pain, cough and a buildup of fluid in the lungs. High exposure to cadmium may cause nausea, salivation, vomiting cramps, and diarrhea. (National Safety Council, 2000). The famous "itai-itai" or "ouch-ouch" bone disease of the Japanese in Toyama Inlet was the result of chronic exposure to Cd waste. The disease furthers progress to borne weakness that results in multiple stress fractures in the back and legs (Buzzi, 1992). For this result, the World Health Organization has recommended a maximum intake of 0.4-0.5 mg/week (Wase, 1997). The main target organs for cadmium are the kidney and liver, with critical effects occurring when a content of 200 μg Cd/g (wet weight) is reached in the kidney cortex (O'Neill, 1993).

2.4 Wetlands

Wetlands are areas that are inundated or saturated soil by surface or groundwater at a frequency or duration sufficient to maintain saturated conditions and growth of related vegetation (Polprasert, 1996). Wetlands occur in a wide range of physical settings at the interface of terrestrial and aquatic ecosystems. The natural wetlands are referred to as marshes, swamps, bogs, cypress domes and strands, etc.

Wetlands that are dominated by water tolerant woody plants are generally called as swamps; those with soft-stemmed plants species as marshes; and those with mosses as bogs. Swamps and marshes can be of either salt water or freshwater type. Saltwater swamps are popularly known as mangroves.

Wetlands have high rate of biological activity and hence high rate of vegetative growth as well as zooplanktons. They can transform of the common pollutants into harmless byproducts or essential nutrients that can be used for additional biological productivity. These transformations are accomplished by virtue of the wetland's land area, with its inherent natural environment energies of sun, wind, soil, plants, and animals. These pollutant transformations can be obtained for the relatively low cost of earthwork, piping, pumping, and a few concentrate structures (Kadlec and Knight, 1996). Wetlands along the shores of seas, lakes and reverbanks play a valuable role in their stabilization and protection from erosive tides, waves, storms, floods and wides. They also function as groundwater recharge areas and sometimes as discharge areas where the water table touches the surface level. Because of their ability to transform and store organic matter and nutrients, wetlands are often described as the "kidneys of the landscape".

Constructed wetlands, as the term suggests, are man-made wetlands artificially developed in areas where they do not occur naturally. Although constructed wetlands are being developed in many parts of the world for various functions, their wastewater capabilities have attracted research efforts for a wide range of treatment applications including domestic wastewater, urban stormwater, industrial/agricultural flows, landfill leachates, acid mine drainage, etc. (Sundaravadivel and Vigneswaran, 2001).

Constructed wetlands are planned systems designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands. The many advantages of constructed wetlands include site location flexibility, optimal size for anticipated waste load, potential to treat more wastewater in smaller areas than with in natural wetlands, less rigorous preapplication treatment (Bastian et al., 1989).

Originally, the basis for employing constructed wetlands for wastewater treatment is the ability of water plants to translocate oxygen to their roots, and the surrounding water (wastewater, in case of treatment wetlands) environment. Although a number of other pollutant removal processes have been identified, the wetland plants play a major role in the occurrence of most of these processes (Sundaravadivel and Vigneswaran, 2001).

2.4.1 Components of constructed wetlands

There are four main components of constructed wetlands.

- Wetland vegetation
- Soil or substrate (media) supporting vegetation
- Water column (in and above the substrate)
- Living organisms

Aquatic plants that are used in wetlands may be divided into several categories. Three types of aquatic plants are the major and typical component of the wetlands system.

1. <u>Floating type</u>: There are two subtypes of floating aquatic plants.

- Floating unattached plants: the roots hang in the water and are not attached to the soil. The leaves and stems are above the water for receiving sunlight directly. The submerged roots and stems are good habitat for bacteria responsible for waste stabilization. Examples of such plants are water hyacinth, duckweed, and water lettuce.
- Floating attached plants: they have their leaves floating on the water surface, but their roots are anchored in the sediment such as water lilies (Polprasert, 1996).

2. <u>Submerged type</u>: Plants that grow below the water surface are called submerged. These species can only grow where there is sufficient light and may be adversely affected by turbidity and excessive populations of planktonic algae, which decrease the penetration of light into the water. Many submerged plants are known, such as hydrilla and water milfoil (Polprasert et al., 1986).
3. <u>Emergent type</u>: They produce aerial stems and leaves, and an extensive root and rhizome system. They have the capability to grow in a wide range of substrate and in rapid or extensive fluctuations in water level occur. Emergent types in wetlands system include cattails, bulrushes and reeds.

2.4.2 Types of constructed wetland systems

Two types of constructed wetland systems have been developed for wastewater treatment:

1. Free Water Surface System (FWS) consists of parallel basins or channels with relatively impermeable bottom. Soil or suitable media and rock layers to support the emergent vegetation, and water flowing velocity over the top of the soil media and through wetland vegetation in shallow basins or channels. The water depth is maintained at 0.1-0.6 m above the soil surface (Polprasert, 1996). The configuration of the system is usually in the form of long narrow channel with length-to-width ratio of 10:1 or greater to minimize short-circuiting. The low velocity and presence of the plant stalks, as well as litter provide the necessary conditions for near plug-flow hydraulic pattern (Phanuwan, 1999). Cattails, bulrushes, and various sedges are the emergent plants used commonly in free water surface wetlands (Figure 2.1).
2. Subsurface Flow Systems (SF), also called 'root zone', 'rock bed filter' or 'reed beds', consist of channels or trenches with impermeable bottom and soil and rock layers to support the emergent vegetation. The water depth is maintained at or below the soil surface (Polprasert, 1996). When the wastewater flows through the media, it is being purified through contact with the surfaces of the media and the root zone of plants. The subsurface zone is generally anoxic but the plants can transfer excess oxygen to the root system thus creating aerobic microsites adjacent to the roots and rhizomes. There is also a thin oxic zone in the substratum adjacent to the air-soil interface (Figure 2.2) (Lim and polprasert, 1996).

2.5 Pollutant removal mechanisms

Many studies and monitoring for constructed wetlands have shown the significant removal of organic matter (BOD), suspended solids (SS), nutrients (N and

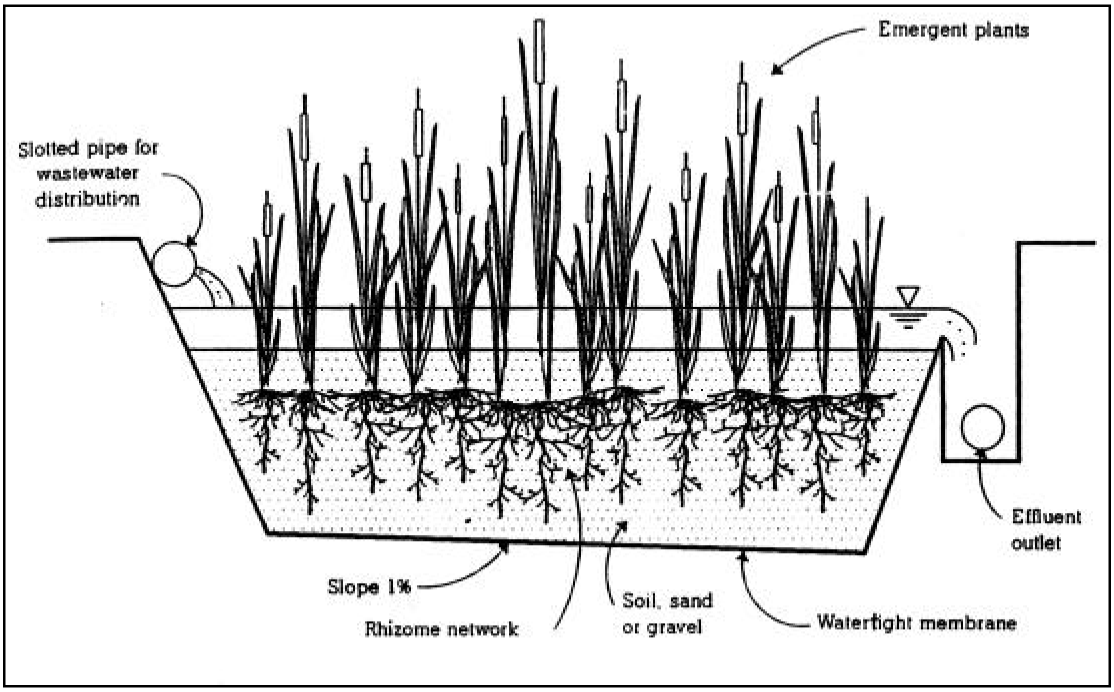


Figure 2.1 Free water surface wetland system (FWS)

(Source Lim and Polprasert, 1996)

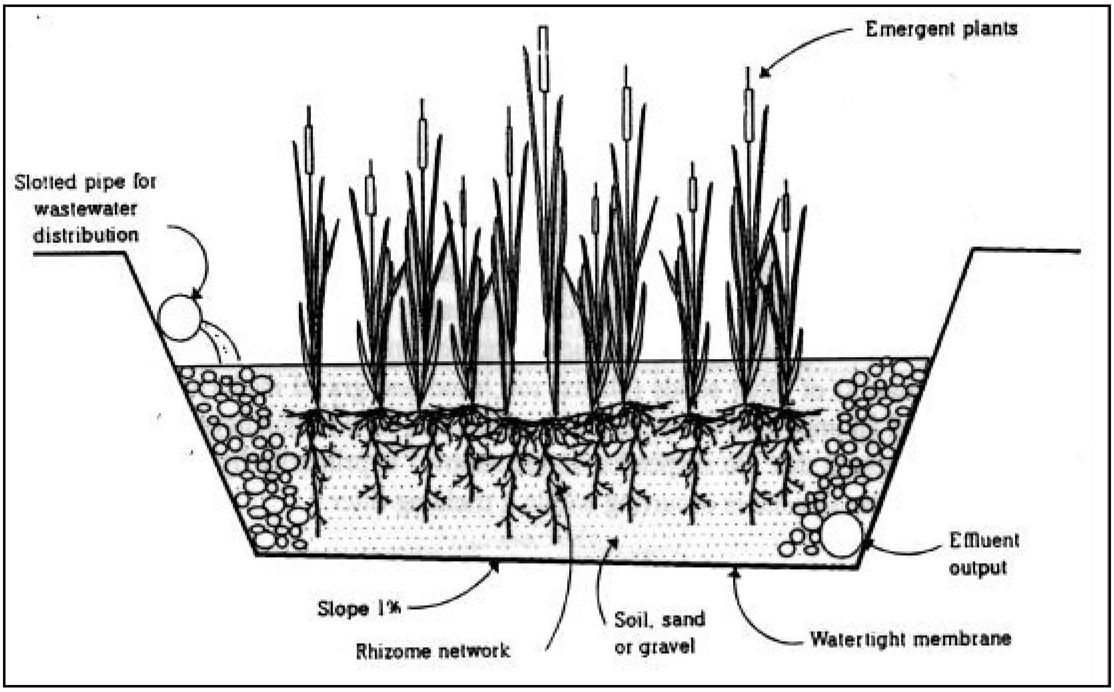


Figure 2.2 Subsurface flow wetland system (SF)

(Source Lim and Polprasert, 1996)

P), and pathogens. In wetlands treatment processes, the pollutants are removed from wastewater through a combination of physical, chemical, and biological processes including sedimentation, precipitation, adsorption to soil particles, assimilation by the plant tissue, and microbial transformations. The principal pollutant removal mechanisms operative in wetland systems, are listed in Table 2.2 (Lim and polprasert, 1996).

2.5.1 Organic matter removal

BOD removal is due to microbial growth attached to plant roots, stems, and leaves that are submerged in the wastewater and the quiescent condition is attributed for the removal in free water surface wetland system. In subsurface wetlands system, the major BOD removal mechanism is deposition and filtration. The major oxygen source is the transmission by the emergent plants from atmosphere through the root zone and to leakage of some oxygen to the surrounding sediment. In surface flow wetlands, the major oxygen source for these reactions is reaeration at the water surface.

2.5.2 Solids removal

Suspended soils removal is very effective in both types of constructed wetlands due to the long HRT, shallow depth, and quiescent condition. Colloids are removed by attachment of bacteria, and by collisions (inertial and Brownian) with an adsorption to other solids such as plants, pond bottom, and suspended solids.

For surface wetlands, after the suspended material reaches the wetland, it joins large amounts of internally generated suspendable material, and both are transported across the wetland. Sedimentation and trapping and resuspension, occur en route, as does “generation” of suspended material by activities both above and below the water surface (Figure 2.3).

For subsurface wetlands, it is different than surface wetlands. Macrophyte leaves and seed litter are mostly contained on the surface of the bed and so do not interact with the water flowing in the interstices below. Most vertebrates and invertebrates do not interact with the water. Resuspension is not caused by wind or vertebrate activities (Figure 2.4) (Kadlec and Knight, 1996).

Table 2.2 The principal pollutant removal mechanisms operative in wetland systems

Mechanism	Pollutant affected[a]								Description
	Settleable solids	Colloidal solids	BOD	N	P	Heavy metals	Refractory organics	Bacteria& virus	
Physical sedimentation	P	S	I	I	I	I	I	I	Gravitational settling of solids (and constituent pollutants) in wetland settings.
filtration	S	S							Pariculates filtered mechanically as water passes through substrate, and root masses.
adsorption volatilization		S		S					Interparticle attractive forces(Van der waals force) Volatilization of NH_3 from the wastewater.
Chemical precipitation					P	P			Formation of or coprecipitaton with insoluble compounds.
adsorption					P	P	S		Adsorption on substrate and plant surfaces.
decomposition							P	P	Decomposition or alteration of less stable compounds by phenomena such as UV irradation, oxidation and reduction.
Biological bacterial - metabolisms[b]		P	P	P			P		Removal of colloidal solids and soluble organics by suspended and plant-supported bacteria. Nitrifiation/denitrification.
plant metabolisms							S	S	Uptake and metabolism of organics by plants.Root excretion may be toxic to organisms of enteric origin.
plant adsorption				S	S	S	S		Under proper conditions, siginificant quantities of these pollutants will be taken up by plants.
natural die-off								P	Natural decay of organisms in an unfovorable environment.

Notes:[a] P=primary effectes, S=secondary effects, I=incidental effect (effect occurring incidental to removal of another pollutant)

[b] The term metabolism includes both biosynthesis and catabolic reactions

(Source: Lim and Polprasert, 1996)

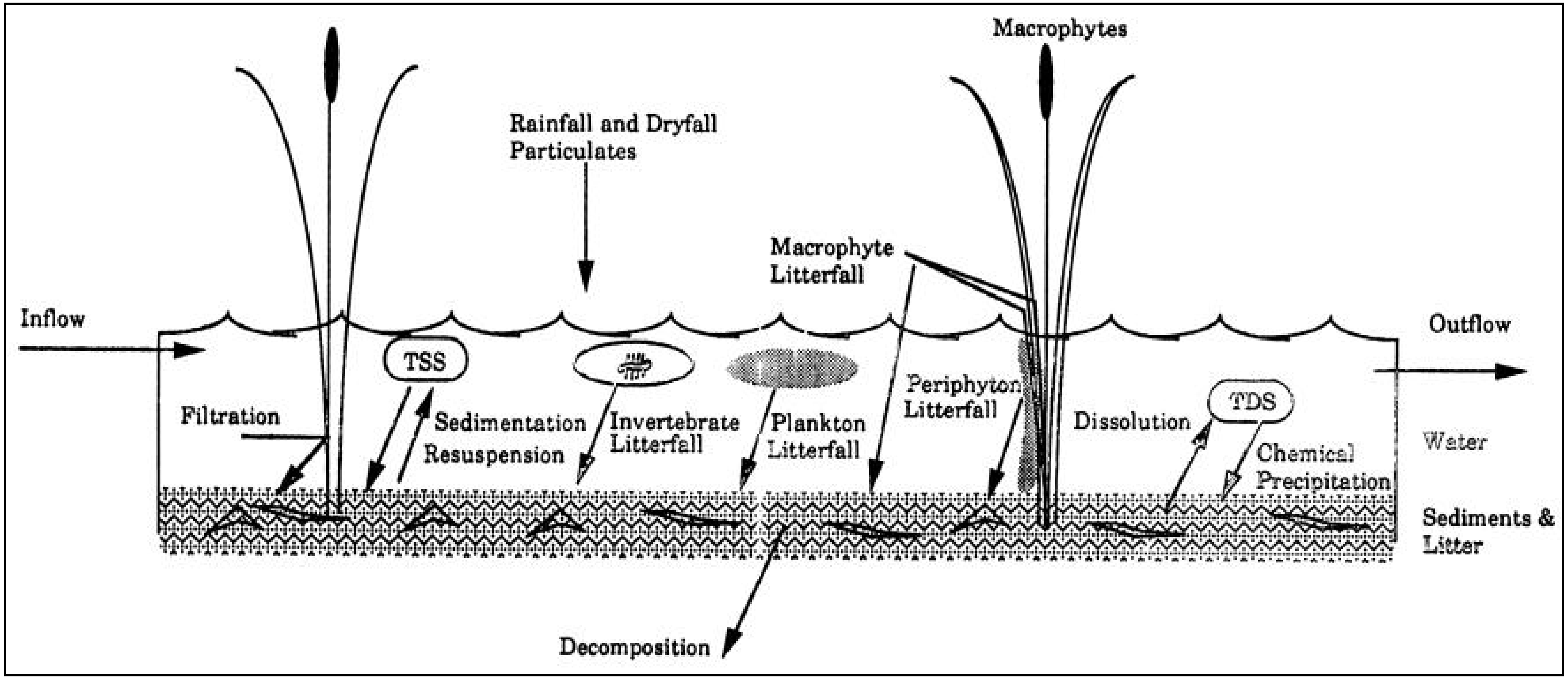


Figure 2.3 Suspended solids storages and transfers in the wetland environment.
(Source Kadlec and Knight, 1996).

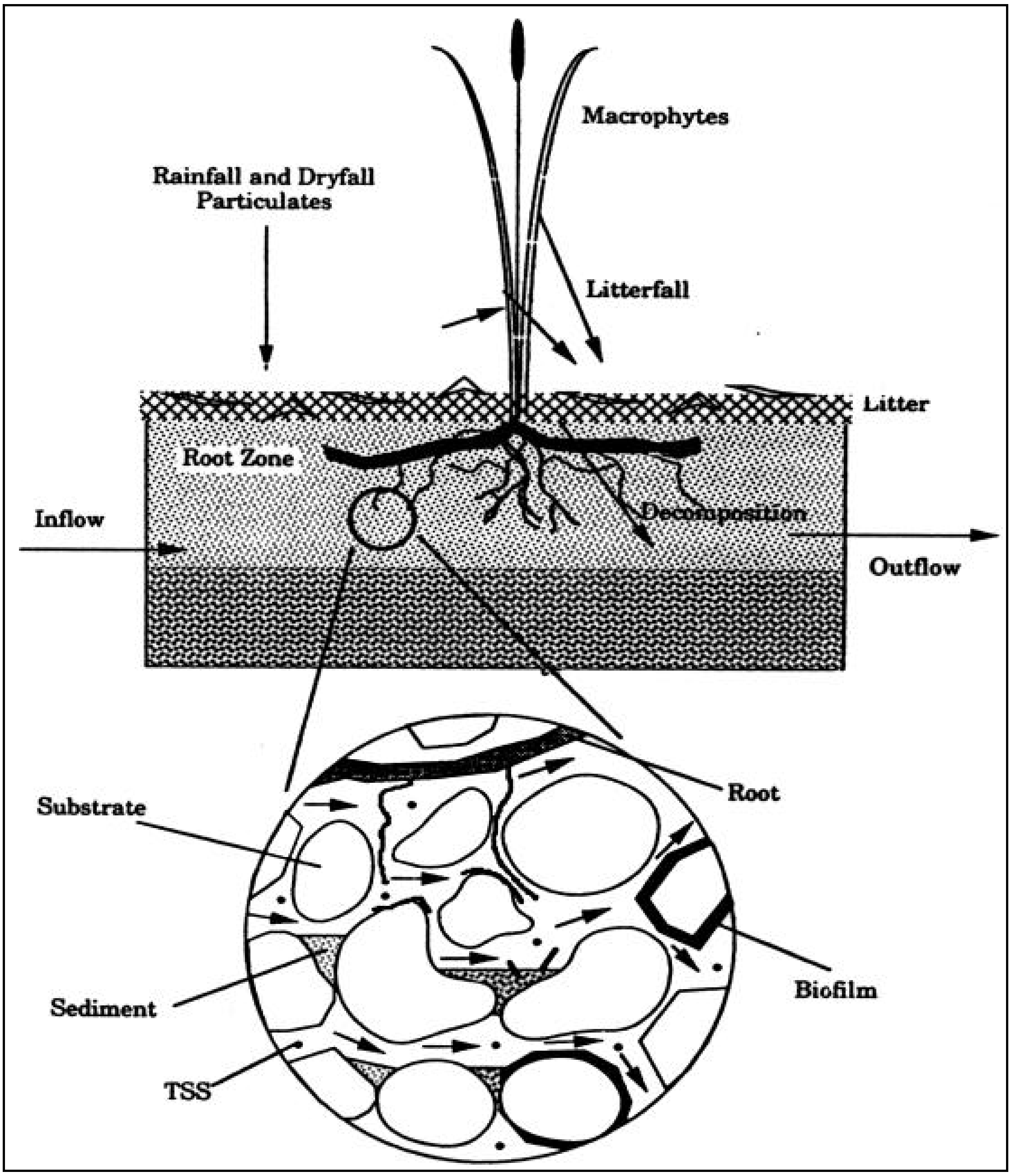


Figure 2.4 Particulates in the subsurface flow wetland environment. Generation is via chemical precipitation, biofilm decomposition, and root litterfall. Settling is in crevices; resuspension can be form pockets or biofilm sloughing. (<u>Source</u> Kadlec and Knight, 1996).

2.5.3 Nitrogen removal

Nitrogen is removed by a number of mechanisms such as plant uptake, ammonia volatilization, nitrification, and denitrification (Figure 2.5).

Although plant uptake of nitrogen occurs, only a minor fraction can be removed by plants. Nitrification/denitrification are the most effective removal of nitrogen. Ammonia is oxidized to nitrate by nitrifying bacteria in aerobic zones, and nitrates are converted to free nitrogen in anoxic zones by denitrifying bacteria. In subsurface flow systems, oxygen required by the nitrifiers is supplied by leakage from plant roots. Oxygen mass transfer limits nitrification in attached growth systems. The factors important to the nitrification process are (1) minimizing carbonaceous oxygen demand, so slower growing nitrifiers can compete with the heterotrophic organisms; (2) maintaining pH within the optimum range of 7 to 8; (3) establishing adequate retention time (at least 5 days based on available data) ; and (4) limiting toxics (certain heavy metals and organic compounds inhibit nitrifiers) (Watson et al., 1989).

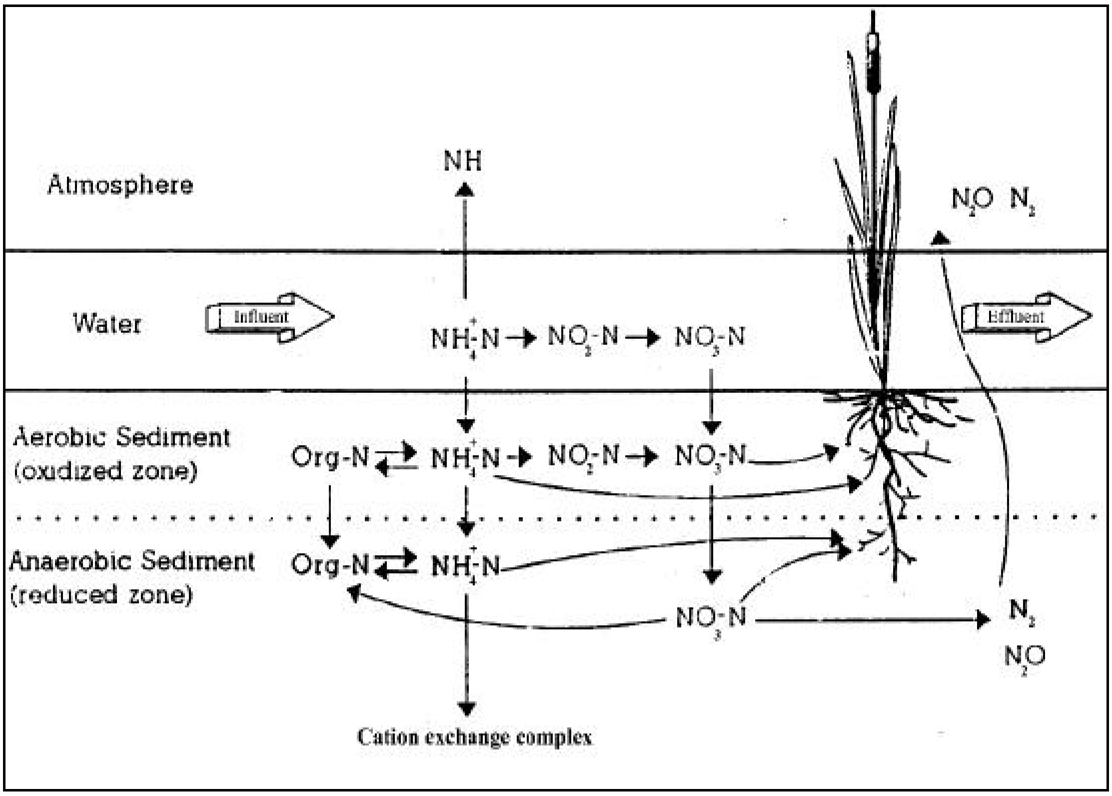


Figure 2.5 Nitrogen transformation in wetland system.

(Source Lim and Polprasert, 1996)

2.5.4 Phosphorus removal

The mechanisms of phosphorus removal are plant uptake, and several chemical adsorption and precipitation reactions (occurring primarily at the sediment/water column interface). A significant clay content and iron, aluminum, and calcium will enhance phosphorus removal (Lim and Polprasert, 1996).

2.5.5 Heavy metals removal

Heavy metals can be removed from wastewater in wetlands system by plant uptake, precipitation as oxides, hydroxides, carbonates, phosphates, and sulfides; and also remove by ion exchange with and adsorption to sedimented clay and organic compounds (Polprasert et al., 1986, Sintumongkolchai, 1996).

The three main wetland processes, which remove heavy metals are:

- Binding to soils, sediments and particulate matter
- Precipitation as insoluble salts; and
- Uptake by bacteria, algae, and plants

Major proportion of heavy metal removal is accounted to binding processes within wetlands. Because of their positive charge, the heavy metals are readily adsorbed, complexed and bound with suspended particles, which subsequently settle on the substrate. Precipitation of heavy metals as insoluble salts such as carbonates, bicarbonates, sulfides and hydroxides is another process that leads to their long-term removal. These salts forms by the reaction of heavy metals with other chemicals present in water column are insoluble, and hence precipitate to the bottom to become fixed within the wetland substrate.

During the initial period of establishment of treatment wetlands, the binding processes are limited and the uptake by the biota is dominant. Algae and microorganisms take up heavy metals available in the dissolved form, whereas macrophytes can take up also from the sediments. However, the uptake by plants, bacteria, and algae accounts for less than 1% of the total heavy metals removal in constructed wetlands (Sundaravadivel and Vigneswaran, 2001).

2.5.6 Pathogens removal

Bacteria and viruses are removed from the waste stream by: (1) physical processes such as aggregate formation, followed by sedimentation, filtration and adsorption; and (2) actual die-off as a result of prolonged exposure to hostile environmental conditions such as temperature, and unfavorable water chemistry (Phanuwan, 1999, Kadlec et al., 1996).

2.6 Removal mechanisms and pathways of heavy metals transformation in constructed wetlands

The mobility of heavy metal pollutants in wetland plants and medium depends on a more or less complex network of interactions between aqueous and heterogeneous chemical reactions as well as particle coagulation and flocculation phenomena. Hydrolysis and dissolved complexation tend to increase the solubility of heavy metals while precipitation and adsorption will delay heavy metals availability and transport as shown in Figure 2.6 (Bourg, 1995).

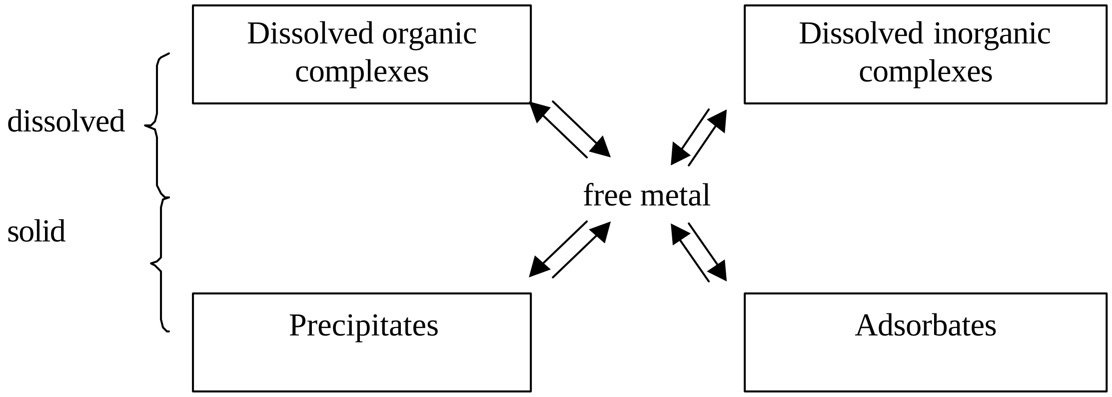


Figure 2.6 Geochemical speciation of heavy metals (all of theses processes are prone to concurrent reactions with other cations, including H^+) (Source Bourg, 1995)

The most mobile fractions of ions occur at a lower range of pH, which is illustrated in Figure 2.7.

Cd is most mobile in acidic soils within the range of pH 4.5 to 5.5, whereas in alkaline soil Cd is rather immobile. It can be anticipated that with increasing pH of the soil substrate, the solubility of most cations will decrease. The solubility of Cd appears to be highly dependent on the pH; however, the nature of sorbent surfaces and of organic ligands are also of importance (Pendis and Pendias, 1992).

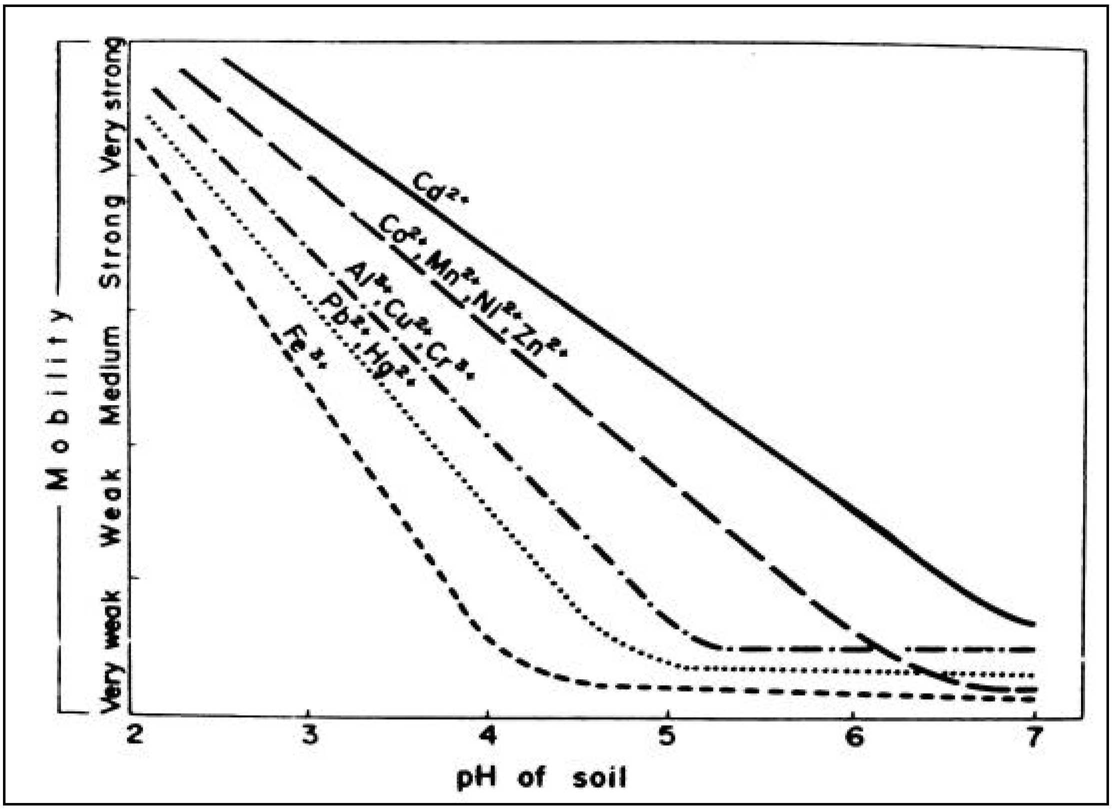


Figure 2.7 Schematic trends in the mobility of some metals as influenced by soil pH (Source Pendis and Pendias, 1992)

The major mechanisms of heavy metals removal in constructed wetlands are:

2.6.1 Plant uptake

Plants can accumulate heavy metals, in or on their tissues due to their great ability to adapt to variable chemical properties of the environment. Thus plants are intermediate reservoirs of heavy metals from soils, and waters. The uptake by roots is the main pathway of heavy metals to plants.

Nonmetabolic uptake is the diffusion of ions from the external solution into the root endodermis. Metalbolic uptake requires energy and takes place against a chemical gradient. Several data support the suggestion that, at the concentration generally present in soil solutions, the adsorption of heavy metals by plant roots is controlled by metabolic processes within roots.

Roots and associated microorganisms are known to produce various organic compounds which are very effective in releasing the heavy metals from firmly fixed species in soils. The heavy metals most readily available to plants are, in general, those that are adsorbed on clay minerals, while those fixed by oxides and bound onto microorganisms have much less readily available rate of their uptake by roots than mass-flow and diffusion mechanisms in certain soils. The mechanisms of heavy metals uptake by roots involve several processes:

1. Cation exchange by roots
2. Transport inside cells by chelating agents or other carriers
3. Rhizosphere effects

Cation oxidation states around roots are believed to be of great importance in these processes. Changes in the pH of the root ambient solution may play and especially significant role in the rate of availability of certain heavy metals.

Heavy metals entering plant tissues are reactive in metabolic processes, but also can be stored as inactive compounds in cells and on the membranes. In each case, however, they may affect the chemical composition of plants without causing easily visible injury. The most common symptoms of phytotoxicity of cadmium is described in detail in Table 2.3 (Pendis and Pendias, 1992).

Table 2.3 Symptoms of phytotoxicity of cadmium

Element	Symptoms	Sensitive crop
Cadmium	Brown margin of leaves, chlorosis, reddish veins and petioles, curled leaves, and brown stunted roots. Severe reduction in growth of roots, tops, and number of tillers (in rice). Reduced conductivity of stem, caused by deterioration of xylem tissues.	Legumes(bean, soybean), spinach, radish, carrots, and oats.

2.6.2 Adsorption

The term "adsorption" is commonly used for the process of sorption of chemical elements from solutions by soil particles. Adsorption is thus the kinetic reaction based on thermodynamic equilibrium rules. The forces involved in the adsorption of ionic species at charged surfaces are electrostatic and can be explained by coulomb's law of attraction between unlike charges and repulsion between like charges.

Soils are considered as heavy metals' sinks, and for that reason, they play an important role in environmental cycles of these elements. They also have a great ability to fix many species of heavy metals.

When a wastewater effluent with moderate concentration of heavy metals passes through a wetland, the bed media can adsorb metal ions. There are the major factors involved in adsorption: pH and type of media. Adsorption can occur in the pH range of 4-7.7 (Sintumongkolchai, 1996). Soil components involved in adsorption of heavy metals are:

1. Oxides mainly of iron, manganese, aluminum and silicon
2. Organic matter and biota
3. Carbonates, phosphate, sulfides, and basic salts
4. Clays

Of all these components, clay minerals, hydrated metal oxides, and organic matter are considered to be the most important group in contributing to and competing for adsorption of heavy metals (Pendis and Pendias, 1992).

2.6.3 Precipitation

Every soil component is active and affects the ion concentration in its solution either by precipitation-dissolution reaction or by ionic interactions with phase surfaces. In the aqueous phase of soil, organic compounds and water are the most abundant ligands. Therefore, hydrolysis and organic complexing are the most common reactions in soil solutions. These reactions are pH sensitive and can be corrected with the size and charge of the cations. Higher ionic potentials usually indicate higher degree of hydration in the solution, resulting an easier precipitation (Pendis and Pendias, 1992).

From the basic physical chemistry, it is known that heavy metals precipitate as the result of changes in pH, oxidation state, and other changes of their chemical composition (Novotny, 1995). Precipitation of cadmium can occurr with carbonates ($CdCO_3$) in the pH range of 8-12, hydroxides ($Cd(OH)_2$) at pH >12, and (CdS) under reducing condition (Sintumongkolchai, 1996).

The organic sediments are good cation exchange sites for cadmium, and hence these are found bound to sediments in preference to the dissolved forms. Furthermore, the anaerobic zones of the wetland-soils can generate sulfide ions which precipitate the insoluble sulfides of heavy metals (Kadlec and Knight, 1996).

The precipitation /dissolution reactions and adsorption of cadmium is shown in equation below.

$$Cd^{2+} + CO_3^{2-} \longrightarrow CdCO_3$$

The sand is very rich in CO_3^{2-} concentration. Hence, as the wastewater enters into the system, cadmium carbonate is supersaturated and precipitates.

2.6.4 Complexation

When heavy metals are added to soils and water (sediments), they undergo complexation with ligands. Ligands are chemical constituents, both organic and inorganic, that combine with the heavy metals in a chemical complex (Novotny, 1995).

Organic matter of soils consists of a mixture of plant and animal products in various stages of decomposition and of substances that are synthesized chemically and biological. This complex material, greatly simplified, can be divided into humic and nonhumic substances. The major portion of the organic matter in most soils results from biological decay of the biota residues. The end products of this degradation are humic substances, organic acids of low molecular and high molecular weights, carbohydrates, proteins, peptides, amino acids, lipids, axes, polycyclic aromatic hydrocarbons, and lignin fragments. In addition, the excretion products of roots, composed of a wide variety of simple organic acids, are present in soils.

Complex formations with such substance as fluvic or humic acids is known as organic complexation. These organic matters are from decaying plant materials. The most stable compounds in soils are humic substances partitioned into fractions of humic acid and fluvic acid, which are similar in structure but differ in their reactions. Humic substances are also easily adsorbed by clay and oxide particles in soil and water environments. Fluvic acid can form complexes with heavy metals over a wide pH range thus increasing their solubility and mobility. Humic acids are insoluble in acid medium but dissolve gradually as pH increases. Hence at high pH values, humic complexes are formed (Sintumongkolchai, 1996). Metal-fluvic acid complexes with lower stability constants usually are more readily soluble and thus more available to plant roots. Heavy metals complexed by fluvic acid presumably are more available to plant roots and soil biota than are those accumulated by humic acid which can form both water-soluble and water-insoluble complexes with heavy metal ions and hydrous oxides. The complexing of Cd with humic substances lead to the solubilization at high pH (range 3 to 9.5) and precipitation at low pH (range, 1 to 3). The adsorption of Cd on humic acid is 77% when pH is 5.8 (Pendis and Pendias, 1992).

The presence of compounds that will react with the heavy metals' ions and cause their precipitation or adsorption on solids, will reduce their toxicity and makes them less bio-available for organisms. The colloidal and ionic compounds which combine within a complex with the heavy metal ion, are called ligands which include organic acid and humic substances, dissolved sulfides, chloride and OH^- ions.

Hence, the adsorbing and complexing compounds for toxic metals include.

- particulates: sulfates, particulate organic matter, and clays
- dissolved: sulfides, humic compounds, organic acids, chloride ion, hydroxyl ion (Novotny, 1995).

The possible equations for adsorption, precipitation, and complexation mechanisms of a heavy metal include the following:

$$SO^- + M^{2+} \longrightarrow SOM^+$$

$$SO^- + MOH \longrightarrow SOMOH$$

$$SOH + M^{2+} \longrightarrow SOM^+ + H^+$$

$$SOH + MOH^+ \longrightarrow SOMOH + H^+$$

Where SO^- denotes negatively charged surface, SOH denotes neutral surface and M denotes heavy metal. (Namasivayam and Ranganathan, 1995)

2.7 Previous research work

The heavy metals removal in constructed wetlands has been studied for a long time. The uptake of metals by the plants from soils and solutions has been investigated for a variety of species. Most of these studies involved the phytotoxic effects of heavy metals on crop species over a relatively long-term exposure period (30 days) (Delgado et al., 1993). Many researchers have used cattail plants to remove heavy metals in wetland systems.

David et al. (1984) studied about cadmium uptake by the water hyacinths, which were grown in a glasshouse or laboratory using a combination of candescent (60 W bulbs) and fluorescent (40 W sylvania Gro-Lux) lighting (14h light cycle). Their results clearly demonstrated that the water hyacinth was able to remove cadmium effectively from solutions over a wide concentration range within 24 hr. This ability to remove cadmium and, in fact, to survive high exposure concentrations (up to 100 ppm), showed that the water hyacinth could be a reasonable alternative to conventional wastewater treatment systems for heavy metals' removal. Concentrations above 100 ppm were acutely toxic to the plants. A biphasic rate of uptake was observed with a fast phase of about 4 hours and a slow phase of at least 72 hours. Stirring the solution enhanced uptake in the fast phase, suggesting that uptake was in part diffusion limited. Increasing the pH from 2 to 5 enhanced the uptake rate.

Based on a study, Gersberg et al. (1984) reported that at the hydraulic application rate of 4.7 cm per day (residence time equal to about 5.5 days), Cu, Zn and Cd removal efficiencies in the subsurface flow wetland units were 99%, 97% and 99% respectively. In their experimental investigations, the predominant removal mechanisms in the artificial wetlands were attributed to precipitation-adsorption phenomena. Precipitation was enhanced by wetland metabolism which increased the pH of inflowing acidic waters to near neutrality.

Blake et al. (1987) studied the incorporation of cadmium by water hyacinth. Water hyacinth was grown in plastic tanks for continuous flow system, in a green house of the Center of Nuclear Studies in Grenoble, France. Different concentrations of cadmium (0.25, 0.50, 1.00 and 2.00 ppm) were used, and toxic effects were obvious at 1.00 ppm concentration. The distribution of metals was followed in the medium and different parts of the plants. As expected, the roots accumulated the major part

(73-86%) of the incorporated cadmium. The removal of cadmium from the solution by the water hyacinth could be predicted by the empirical equation:

$$C_t = C_o (1+ t/a)^n$$

Where, C_t is the cadmium concentration at time t, C_o is the cadmium concentration in solution at time zero, t is the time (hour) and a, n are the constants. From the results, the constants a and n for different cadmium concentrations (0.25, 0.50, 1.00 and 2.00 ppm) were determined to be 2.956, 2.213, 6.972, 4.044, and –0.698, -0.514, -0.543, -0.281, respectively.

Sinha and Chanda (1990) conducted a study to show that copper and cadmium could be removed from water by coastal waterhyssop (*Bacopa monnieri*) , a common aquatic plant found all over India. Plants showed a capability to accumulate both metals in single and mixed metal treatments. Copper accumulation was stimulated by the presence of Cd, whereas Cu inhibited uptake of Cd. The preferential accumulation of Cu indicates the ion selective nature of this plant. The results suggested the possibility of using this plant for mitigating Cu and Cd pollution in the aquatic environments (Sinha and Chanda, 1990).

Delgado et al. (1993) conducted a study in a green house (at 28-30°C) to determine the phytotoxic effects and uptake capacity of water hyacinth for Zn, Cr and Cd. Results showed that among the three elements tested, Cd was most phytotoxic, showing up some necrosis in the plants when the concentration was greater than 2.5 ppm. In case of Cr and Zn, the phytotoxicity produced the apperance of chlorosis in the aerial parts of the plants. Cr (maximum 9 ppm) caused no reduction of productivity, whereas in case of Zn, the concentration of 9 ppm in solution caused a 30% reduction in the plant weight. It was proved that after 24 days of growth, the heavy metals were totally depleted from the nutritive solution suggesting complete absorption of these metals by the plants.

Shutes et al. (1993) carried out a research on the use of cattail plants (*Typha latifolia*) for heavy metals pollution control in urban subsurface wetlands system. Cd, Cu, Pb and Zn were the heavy metals'studied in their experiments. The heavy metals' uptake patterns of *Typha* plants were more in the roots than leaves. They suggested that the use of a gravel, which would not only allow adequate root growth but also support high hydraulic loading, might provide a more suitable substrate for emergent macrophytes with in urban retention basins. Additionally, the subsurface introduction of wastewater effluent into the basin through submerged inlets would also maximize the purification potential.

Thayalakumaran (1994) reported the removal efficiencies of some heavy metals (Cr and Ni) in subsurface flow systems (SFS) by cattail plants to be more than 99%. The removal mechanisms were mainly precipitation and adsorption. About 15% of these heavy metals were found to be removed by soil adsorption; the extents of heavy metals adsorption decreased along the bed length of the wetland units. Heavy metals' accumulation was more in the roots than in the leaves and stems of the cattail plants. The removal efficiency for COD, TSS and TKN were 64, 89 and 85%, respectively. The mechanisms for removing COD, TSS and TKN are filtration, flocculation, sedimentation, biological processes, as well as nitri-denitrification reactions.

Sintumongkolchai (1996) investigated the removal of cadmium in free water surface system (FWS) by cattail plants. About 73-98% of Cd were found to be removed by sorption to the sand media, while plant uptake of Cd accounted for only 1-6% of Cd removal. The results showed that pH is an important factor. At pH of 4.26-5.35, plant uptake of Cd was 58.83% of total Cd in sand layer, while at pH of 7.42-8.03, the plant uptake of Cd was found to be 35.24%. The removal efficiencies of COD, TSS, TKN and TP were approximately 61.84, 74.18, 85.09 and 77.83% respectively. The main mechanism of COD removal was biodegradation by the attached and suspended microorganisms. TSS was effectively removed by sedimentation to the wetland beds, and some could be attached to the stems and roots of cattail plants. TKN removal efficiency was high at longer hydraulic retention time. The effect of TP removal was related to the snails present in wetland units because they could uptake P and also released P when they died.

Mungur et al. (1997) investigated the removal of some metals by a wetland system. This study complemented the research on the performance of a subsurface flow system treating runoff being carried out by the Urban Pollution Research Centre, Bounds Green Road, London. The system was planted with cattail (*Typha latifolia*), common reed (*Phragmites australis*), common club-rush (*Schoenoplectus lacustris*), and yellow iris (*Iris pseudacorus*), dosed with various concentrations (1, 5 and 10 mg/L) of Cu, Pb and Zn, respectively. Finally, a shock load of metals (concentration 20 mg/L) was introduced to simulate a storm event. In each experiment water samples were collected from outlet at timed intervals and were analyzed. Loadings were calculated in order to assess the metal removal efficiency of the system. The removal efficiencies and rates for these different doses ranged from 81.7% to 91.8 % and 36.6 to 372.7 mg/m^2/d for Cu, 75.8% to 95.3% and 30.8 to 387 mg/m^2/d for Pb and 82.8% to 90.4% and 33.6 to 362.1 mg/m^2/d for Zn, respectively.

Hansen et al. (1998) conducted a study on Selenium (Se) removal by constructed wetlands, located adjacent to San Francisco Bay. One environmental friendly way of cleaning up Se from oil refinery effluents was by uptake by plants, and microbial volatilization of Se using constructed wetlands. The results showed that 89% of Se was removed in constructed wetlands. Inflow Se concentration of 20-30 μg/L decreased to<5 μg/L in the outflow. Most of the Se was removed by immobilization into sediments and plant tissues where its concentration reached 5 and 15 mg/kg, respectively. Biological volatilization may have accounted for as much as 10-30% of Se removed. The highest rates of Se volatilization for vegetated sites were 190, 180 and 150 μg of Se/m^2-d for rabbitfoot grass, cattail, and saltmarsh bulrush plants, respectively.

Chapter III
Material and Methodology

3.1 Experimental site

Laboratory scale experimental set-up was located at a site near the Center for Scientific and Technological Equipment (F5) at the Suranaree University of Technology (SUT) as shown in Figure 3.1.

3.2 Experimental set-up

Experimental set-up consisted of:

a) four wetland units
b) head tank unit

3.2.1 Wetland units

Four units of constructed wetland were made of zinc plate with dimension of LxWxD = 2m x0.5m x1m, designated as R1, R2, R3, and R4.

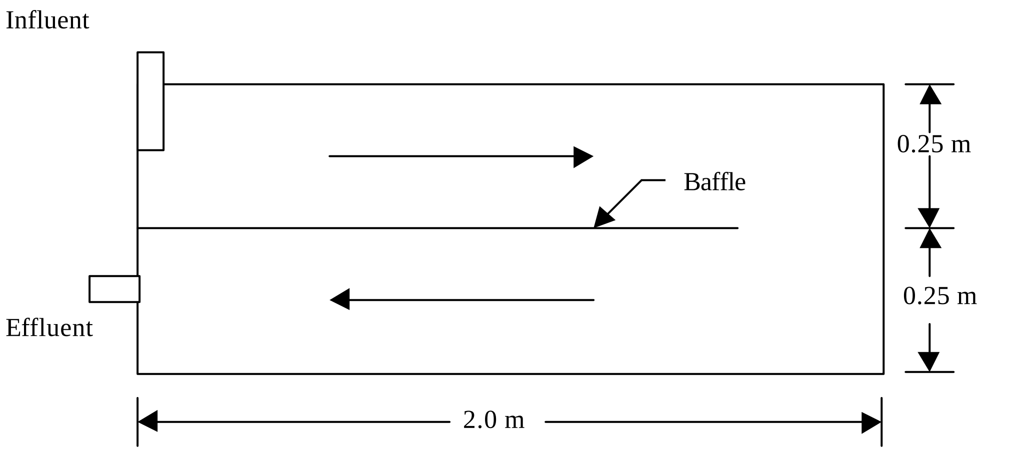
Details of these units are given as follows:

- Reactors R1 and R2 were used for the free water surface wetland system (R1 as control unit).
- Reactors R3 and R4 were used for the subsurface flow wetland system (R3 as control unit).

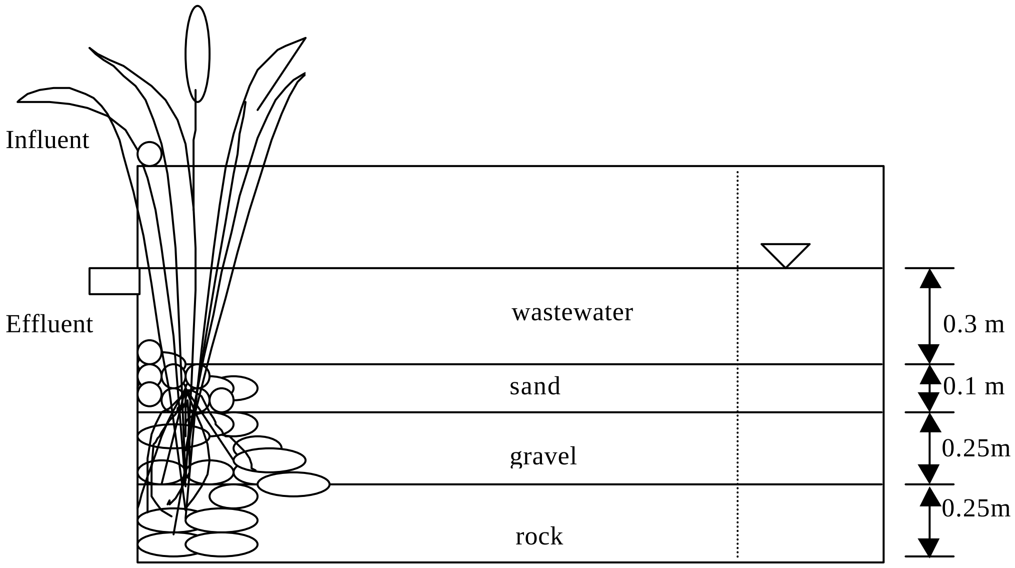
All four reactors consisted of:

a) sand (0.1 cm diameter) of 10-cm depth at the top.
b) the medium layer of 25 cm depth with small gravels(1.2-2.5 cm diameter).
c) large gravels(2.5-5.0 cm diameter) of 25 cm depth at the bottom.

A depth of 30 cm of water was maintained in reactors R1 and R2 as shown in Figure 3.2. For reactors R3 and R4, the flow of wastewater was maintained approximately 15-30 cm below the bed surface as illustrated in Figure 3.3. Cattail plants were cultured in the constructed wetland beds at approximately 0.15m intervals.

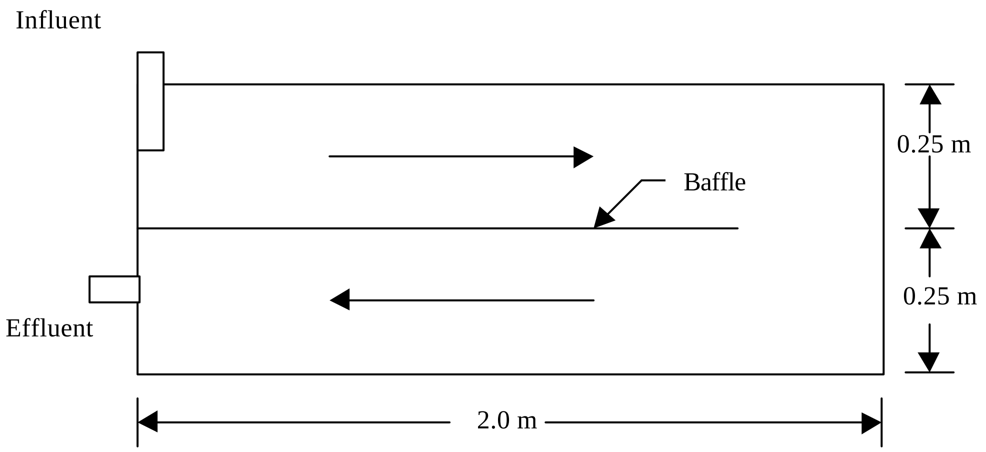


Top View of Reactors R1 and R2

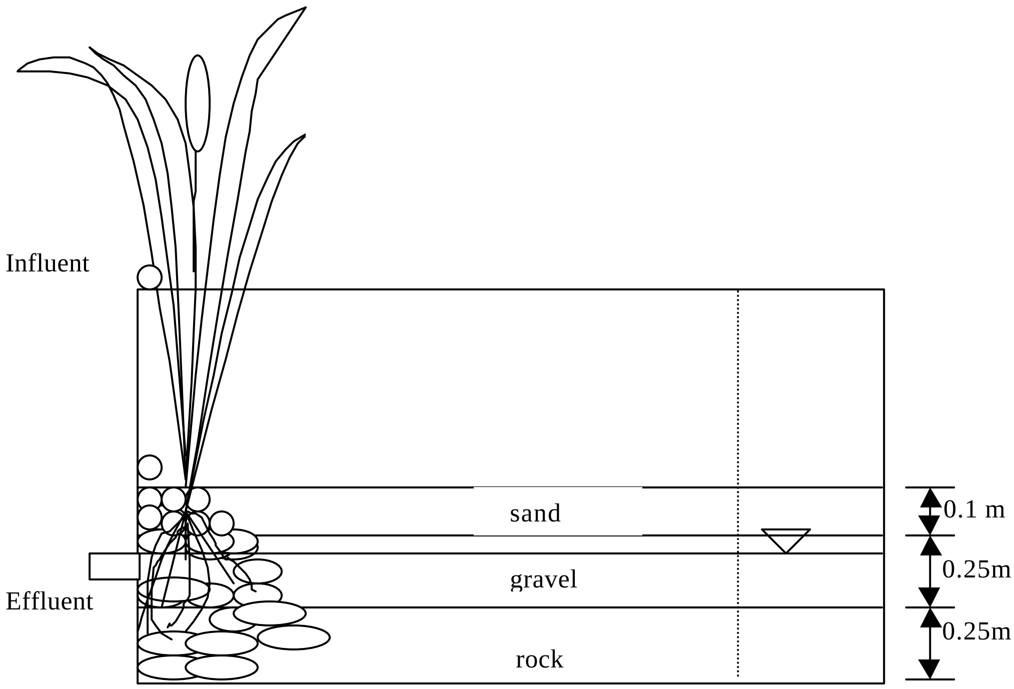


Side View of Reactors R1 and R2

Figure 3.2 Reactors R1 and R2 (Free water surface wetland system)



Top View of Reactors R3 and R4



Side View of Reactors R3 and R4

Figure 3.3 Reactors R3 and R4 (Subsurface flow wetland system)

The four constructed wetland units are shown in Figure 3.4.

Figure 3.4 The four reactors of constructed wetlands

3.2.2 Head tank unit

Two storage tanks were used to store the tap water for making the synthetic wastewater. Four head tanks (200 L each) were used for feeding the wastewater to the four constructed wetland units. Head tank no.1 and 2 were used for control reactors R1 and R3. Head tank no.3 and 4 were used for feeding the synthetic wastewater mixed with known concentration of cadmium to reactors R2 and R4. From the head tank, the synthetic wastewater was fed in to the reactors by peristaltic pumps. The schematic layout of head tanks units is illustrated in Figure 3.5.

3.3 Characteristics of synthetic wastewater

The synthetic wastewater was prepared for this study by mixing of the constituents shown below in the laboratory (Asian Institute of Technology, 2001):

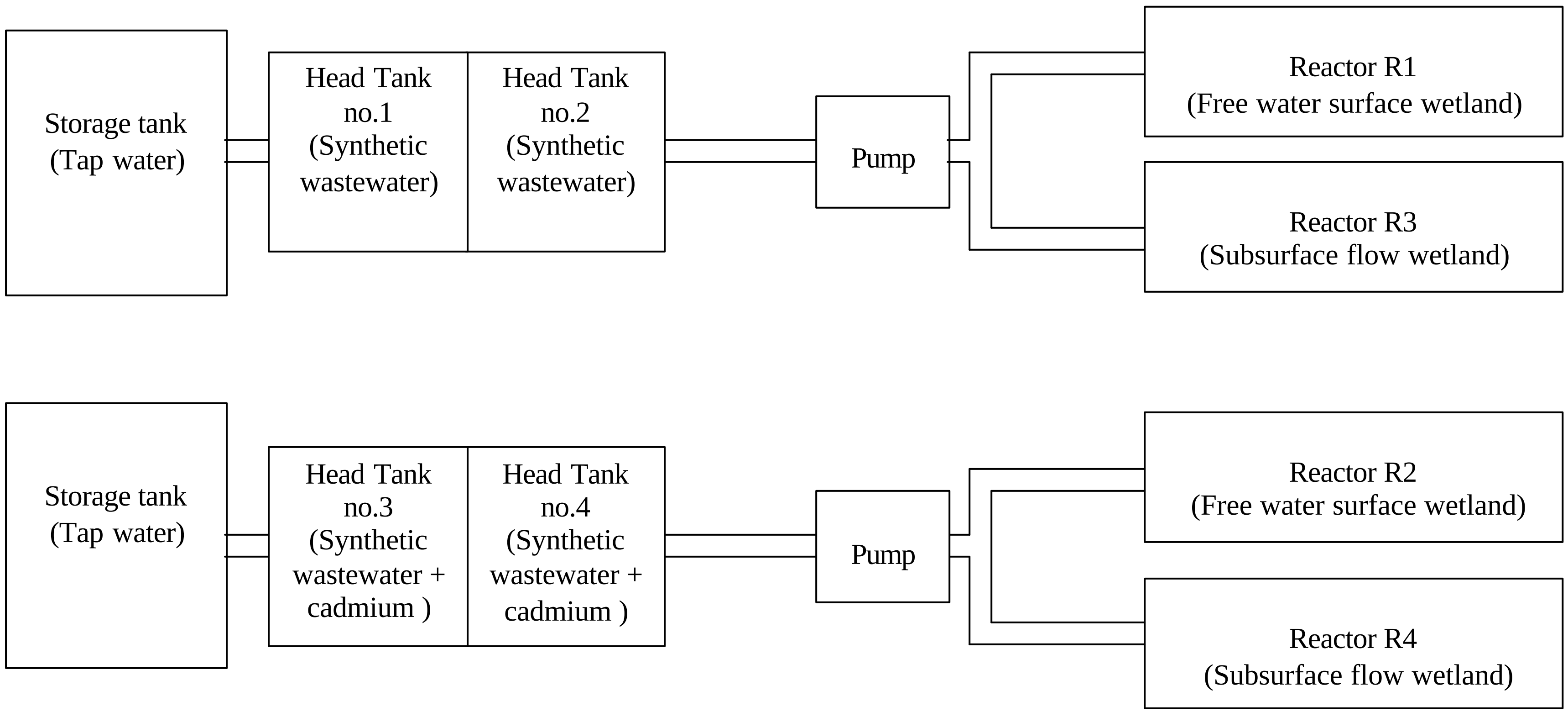


Figure 3.5 Schematic layout of head tank unit and constructed wetland unit

Glucose - 131.58 mg/L

NH_4Cl - 73.68 mg/L

KH_2PO_4 - 13.15 mg/L

Solution A - 10 ml/L

Where, solution A was 2 litters of $MgSO_4.7H_2O$ - 15.0 mg/L

$FeSO_4.7H_2O$ - 0.5 mg/L

$ZnSO_4$ - 0.5 mg/L

$MnSO_4$ - 0.5 mg/L

$CaCl_2$ - 2.0 mg/L

Influent for various runs were obtained by mixing the prepared synthetic wastewater with various $CdCl_2.H_2O$ with concentration of 1, 5, 10, and 20 mg/L, respectively. The synthetic wastewater was prepared every two days and stored in a head tank before feeding into the constructed wetlands by the peristaltic pumps. The characteristics of the prepared synthetic wastewater are shown in Table 3.1.

Table 3.1 The characteristics of the synthetic wastewater

Parameters	Range (mg/L)	Average (mg/L)
COD	90-130	113
TKN	4.48-6.72	5.39
TP	0.91-1.77	1.42
TSS	50-150	94
VSS	78-164	114
DO	0.00-0.66	0.19
pH	6.12-7.17	6.56

The synthetic wastewater were mixed with cadmium concentrations of 1, 5, 10 and 20 mg/L, respectively in a head tank unit and fed to constructed wetland units during four experimental runs designated by Runs I-IV. The flow rate Q for the free water surface (FWS) and subsurface flow (SF) wetland units were calculated by the following equation.

Subsurface flow wetland system

From $$HRT = \frac{LWnD}{Q} \qquad (1) \quad \text{(Metcalf \& Eddy,1991)}$$

Where; HRT = hydraulic retention time, d

L = basin length, m

W = basin width, m

D = depth of basin, m

n = porosity of the bed

Q = average flow through the unit, m^3/d

L/W ratio = 16 :1

W = 0.25 m

L = 4 m

D = 0.45 m

n = 0.33

HRT = 5.5 d (Gersberg et al., 1984)

From (1) $$5.5\ d = \frac{4 \times 0.25 \times 0.33 \times 0.45\ m^3}{Q}$$

$$Q = 0.027\ m^3 / d$$

$$= 27\ L / d$$

Free water surface wetland system

From $$HRT = \frac{LW(d_m n + d_w)}{Q} \qquad (2) \quad \text{(Lim and polprasert,1996)}$$

Where; HRT = hydraulic retention time, d

L = basin length, m

W = basin width, m

d_m = media depth, m

d_w = water depth from media surface, m

n = void fraction in the media(as a decimal fraction)

Q = average flow through the unit, m^3/d

L/W ratio = 16 :1

W = 0.25 m

L = 4 m

d_m = 0.6 m

d_w = 0.3 m

n = 0.33

HRT = 5.5 d (Gersberg et al., 1984)

From (2)

$$5.5\ d = \frac{4 \times 0.25 \times (0.6 \times 0.33 + 0.3)\ m^3}{Q}$$

$$Q = 0.0905\ m^3 / d$$

$$= 90.5\ L / d$$

The plan of experimental runs and plan of operating conditions are summarized in Table 3.2 and 3.3, respectively.

Table 3.2 Plan of experimental runs

Run	Free Water Surface System		Subsurface Flow System	
	Reactor R1	Reactor R2	Reactor R3	Reactor R4
	Cd concentration (mg/L)	Cd concentration (mg/L)	Cd concentration (mg/L)	Cd concentration (mg/L)
Run I	-	1	-	1
Run II	-	5	-	5
Run III	-	10	-	10
Run IV	-	20	-	20

Table 3.3 Plan of operating conditions

Run	Hydraulic Retention Time (HRT) (d)	Flowrate (Q) (L / d)	
		Free Water Surface System	Subsurface Flow System
Run I	5.5	90.5	27
Run II	5.5	90.5	27
Run III	5.5	90.5	27
Run IV	5.5	90.5	27

3.4 Sampling and analysis

Daily wastewater samples were collected from the influent and effluent points, and analyzed for COD concentration until the steady-state conditions reached. After the steady-state conditions, the parameters to be analyzed in influent and effluent wastewater samples included: COD, TSS, VSS, TKN, TP, pH, DO, and cadmium. Samples from soil and plants were also analyzed for cadmium accumulations. Cadmium concentrations in the influent-effluent, soil, and plants were analyzed according to the procedures mentioned in the Standard Methods (APHA, AWWA, and WFE.,1995), Chemical Analysis of Ecological Materials(Allen,1974), and Soil Testing Sorbed Metals(Westerman, 1990), respectively. The details of analyses are given in Table 3.4 below.

Table 3.4 Plan of individual experiments

Parameters	Frequency	Method of Analysis
COD	3/week	Open Reflux
TSS	3/week	Filtration/Evaporation (103-105°C)
TKN	3/week	Digestion/Distillation
TP	3/week	Digestion with Nitric Acid-Sulfuric Acid
pH	3/week	pH Meter
DO	3/week	Azide Modification of Iodometric method
Cadmium in wastewater	3/week	Digestion with HNO_3 and use Atomic Adsorption Spectrometry (AAS) as an instrument for measuring cadmium
Cadmium in soil	End of each run	Digestion with HNO_3 and use Atomic Adsorption Spectrometry (AAS) as an instrument for measuring cadmium
Cadmium in plants	end of the experiments	Digestion with HNO_3, $HClO_4$, H_2SO_4 and use Atomic Adsorption Spectrometry (AAS) as an instrument for measuring cadmium

Chapter IV

Results and Discussion

4.1 Tracer Study

If the researcher knows precisely what is happening within the vessel, then the behavior of a vessel as a reactor can be predicted. For example, how long the individual molecules stay in the vessel, or more precisely, the distribution of residence times of the flowing fluid. This information can be determined easily and directly by a widely used method of inquiry, the stimulus-response experiment. This method of experimentation is widely used in science. The stimulus is a tracer input into the fluid entering the vessel, whereas the response is a time record of the tracer leaving the vessel. The normalized response is then called the C curve. It is frequently desirable to characterize a distribution by a few numerical values. For this purpose the most important measure is the location of the distribution. Thus for a C versus t curve the mean is given by equation (4.1) (Levenspiel, 1972).

At the onset of this research, a tracer study was carried out to evaluate the flow pattern in the four experimental wetland units. The NaCl solution was mixed with tap water and fed into the constructed wetlands. The effluents were observed of chloride concentration. The two flowrates were used as 83.0 and 24.75 L/h for free water surface and subsurface flow wetland system, respectively. With equations 4.1-4.5 given below, data of tracer study were used to find out the dispersion number and actual HRT (Mattaraj, 1995). Raw data of tracer study are given in Tables A.1-A.4 in Appendix A. Figures 4.1-4.4 show the results of tracer experiments.

Mean HRT (actual), $$t = \frac{\sum t_i C_i}{\sum C_i} \qquad (4.1)$$

Standard Deviation, $$\sigma^2 = \frac{\sum t_i^2 C_i}{\sum C_i} - t^2 \qquad (4.2)$$

Then $$\sigma_\theta^2 = \frac{\sigma^2}{t^2} = 2d + 8d^2 \qquad (4.3)$$

The dispersion number of flow, d, can be expressed as:

$$d = \frac{D}{uL_1} \tag{4.4}$$

Where, D = the longitudinal or axial dispersion coefficient characterizing the degree of back mixing during flow

u = the flow velocity

L_1= the length of fluid travel path from influent to effluent

The condition of dispersion number (D/uL_1) can be characterized as follows:

D/uL_1 = 0, is plug flow condition (negligible dispersion)

D/uL_1 = 0.002, is small amount of dispersion

D/uL_1 = 0.025, is intermediate amount of dispersion

D/uL_1 = 0.2, is large amount of dispersion

D/uL_1 = $\propto$ is mixed flow condition (large dispersion)

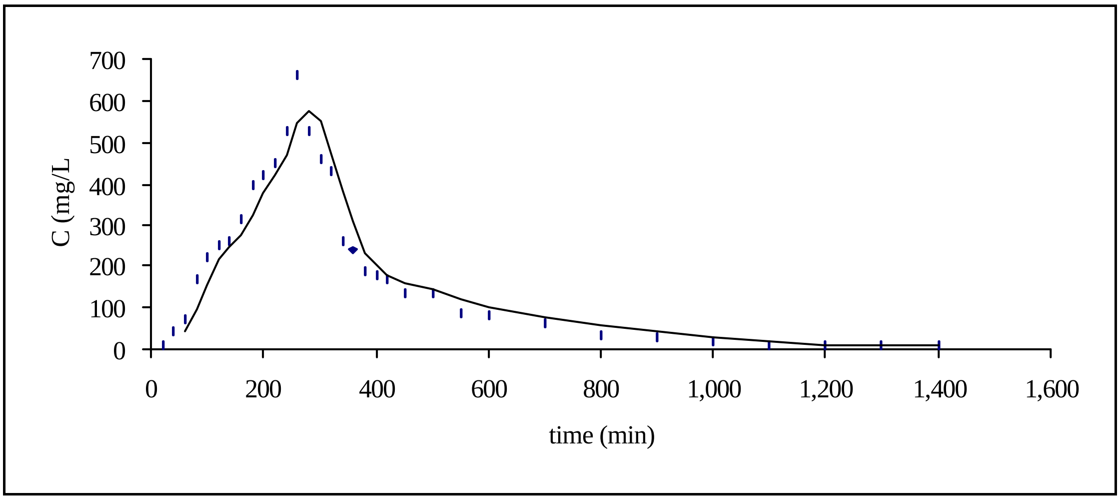


Figure 4.1 The variation curve of chlorine concentration in effluent of reactor R1

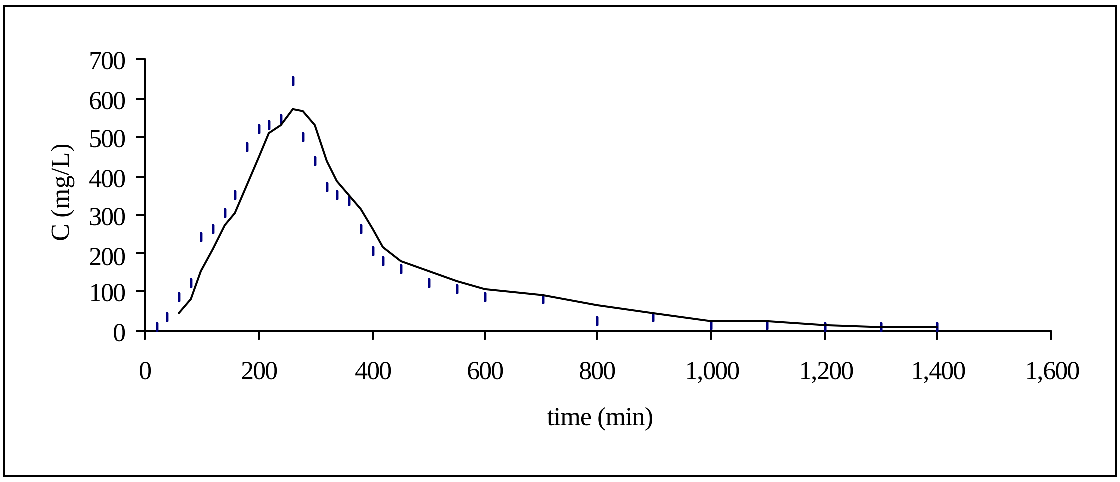


Figure 4.2 The variation curve of chlorine concentration in effluent of reactor R2

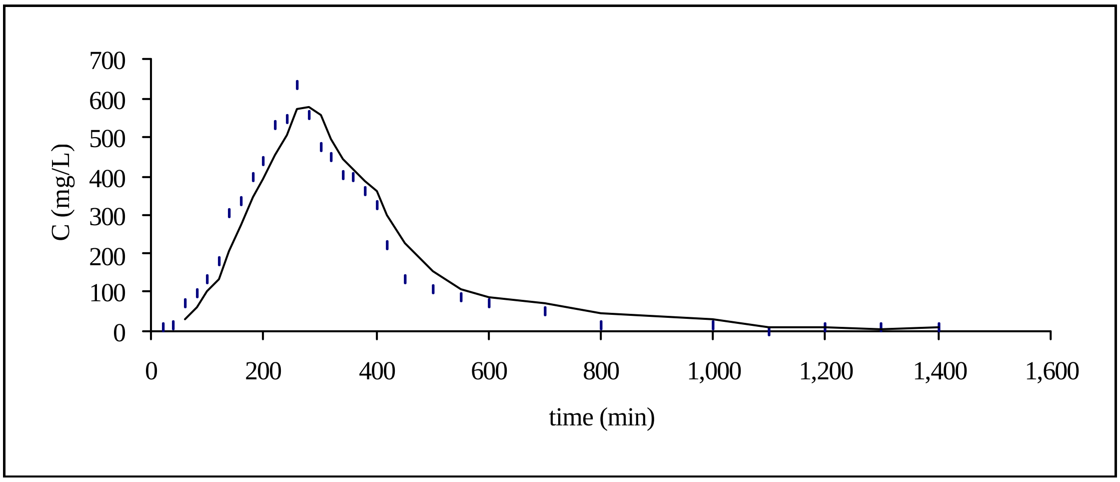


Figure 4.3 The variation curve of chlorine concentration in effluent of reactor R3

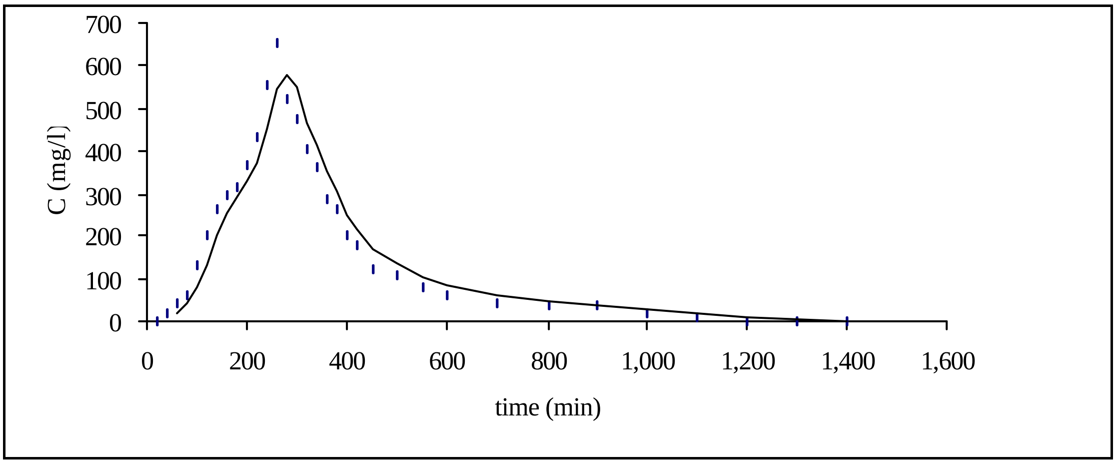


Figure 4.4 The variation curve of chlorine concentration in effluent of reactor R4

From Figures 4.1-4.4, it can be seen that the effluent chloride concentrations increased with the time to reach the peak values. After reaching the peak, chloride concentrations decreased with the time to very low concentration approaching zero. The values of actual HRT and dispersion number are shown in Table 4.1 below.

Table 4.1 Actual HRT and dispersion numbers of constructed wetlands by tracer Study

Reactors	HRT (hr)	Actual HRT (hr)	Dispersion Number (d)
R1	6.0	5.78	0.14
R2	6.0	5.86	0.14
R3	6.0	5.66	0.13
R4	6.0	5.67	0.12

The dispersion number, determined by equation 4.4 was in range of 0.12-0.14, which slightly difference in FWS and SF. These values showed small amount of flow dispersion in the constructed wetland units. In view of the low dispersion number (d), the flow characteristic of all of four reactors could be classified as approaching plug flow pattern.

4.2 Systems performance

The four simultaneous experiments in the wetland units during the four runs (Run I-Run IV) were designated by R11, R12, R13, R14; R21, R22, R23, R24; R31, R32, R33, R34, and R41, R42, R43, R44, respectively. Concentrations of some monitored parameters, dissolved oxygen (DO), pH, temperature, chemical oxygen demand (COD), total kjeldahl nitrogen (TKN), total phosphorus (TP), total suspended solid (TSS), volatile suspended solid (VSS), as well as Cd were determined in the influent and effluent at frequent intervals during the four runs.

4.2.1 DO

Oxygen, although abundant in the atmosphere, has a limited solubility in water. It is frequently a limiting factor for the growth of plants and animals in wetlands. Wetland plants have physiological adaptations that allow growth in low-oxygen soils (Kadlec and Knight, 1996). Cattails have free gas exchange with the atmosphere through leaves and stems extending above water and have large gas vessels which conduct gases to the roots, so the capacity of cattails for oxygen translocation to the root system is relatively high. The emergent plants can transfer 5 to 45 gO_2/m^2.day of wetland surface area depending on plant density and oxygen stress levels in the soil. Experimental data are shown in Appendix B. Figures 4.5-4.8 show the influent and effluent DO variations in the four reactors during the experimental runs (Run I-RunIV).

The DO of the influent was very low nearly approaching zero. The mean effluent DO concentrations during the four experimental runs varied from 4.43-4.96, 4.36-4.97, 5.39-5.99, and 5.39-5.81 mg/L for reactors R1, R2, R3, and R4, respectively, which were much higher than the influent DO. The high effluent DO could be due to release of oxygen via root hairs of the cattails and surface aeration by wind (Phanuwan, 1999). Oxygen is also produced by photosynthesis. When photosynthesis takes place below the water surface, as in the case of plankton or algae, O_2 is added to the water (Kedlec and Knight, 1996).

4.2.2 pH

Hydrogen ion concentration, measured as pH, influences many biochemical transformations. Hydrogen ions form part of the total cation content of wetland waters and are active in cation exchange processes with wetland sediments and soils (Kadlec and Knight, 1996). pH affects the solubility and the ionic form of heavy metals. Mechanisms by which ions are absorbed by roots are pH dependent. Activities of nitrogen fixing and nitrifying bacteria are also influenced by the pH. Details of the experimental data are showed in Appendix B. Figures 4.9-4.12 show the influent and effluent pH variations during the four experimental runs (RunI–RunIV).

During the experimental period, pH of the prepared synthetic wastewater were in the range of 6.50-6.66, while the pH of synthetic wastewater mixed with different cadmium concentrations varied between 6.46-6.57. The mean effluent pH of four experimental runs varied between 7.22-7.32, 7.20-7.35, 7.03-7.26, and 6.96-7.03 for reactors R1, R2, R3, and R4, respectively. They were favorable for the cattail growth, which suitable pH range of naturally occurring cattails is between

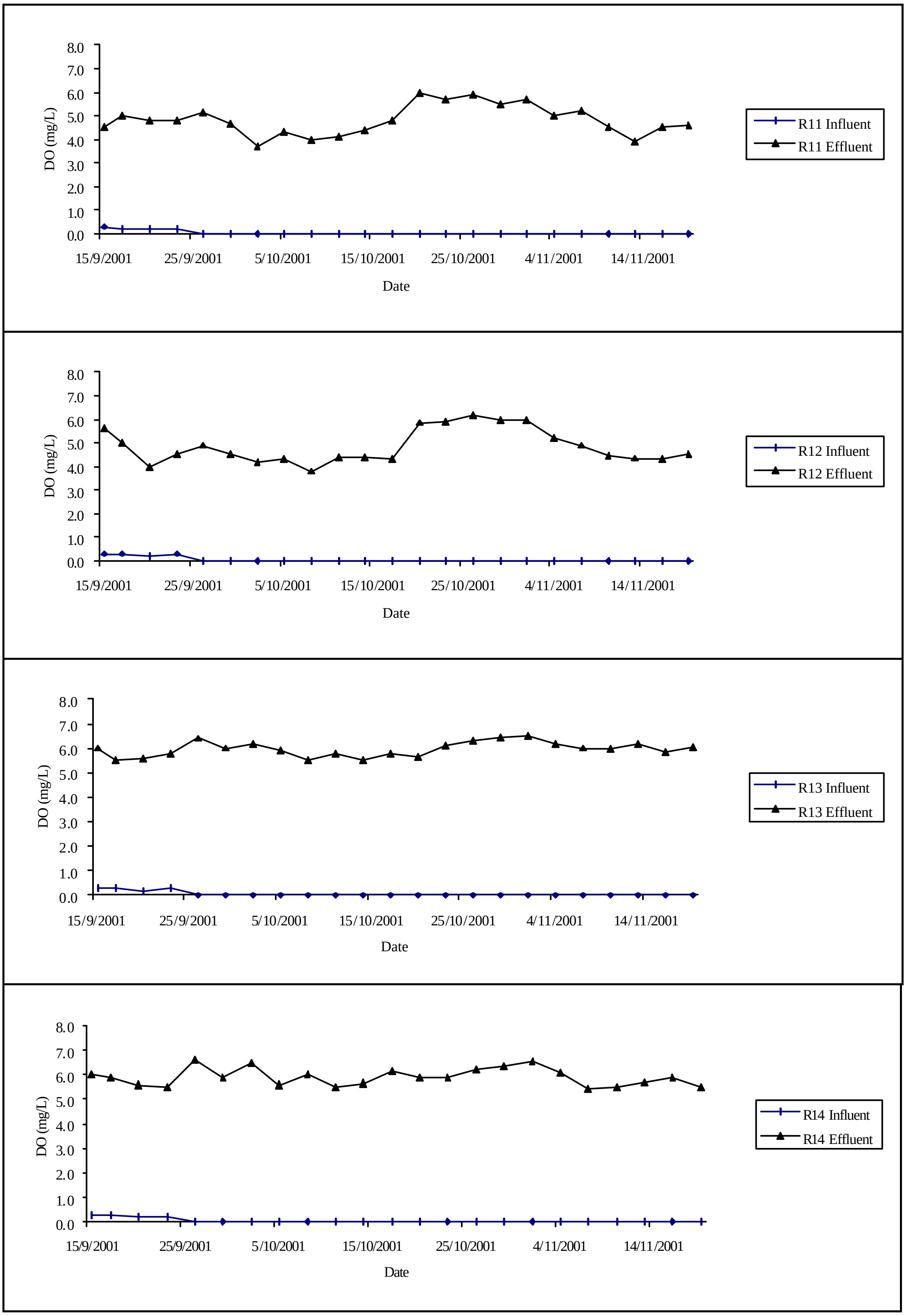


Figure 4.5 The influent and effluent DO concentrations in four reactors during Run I

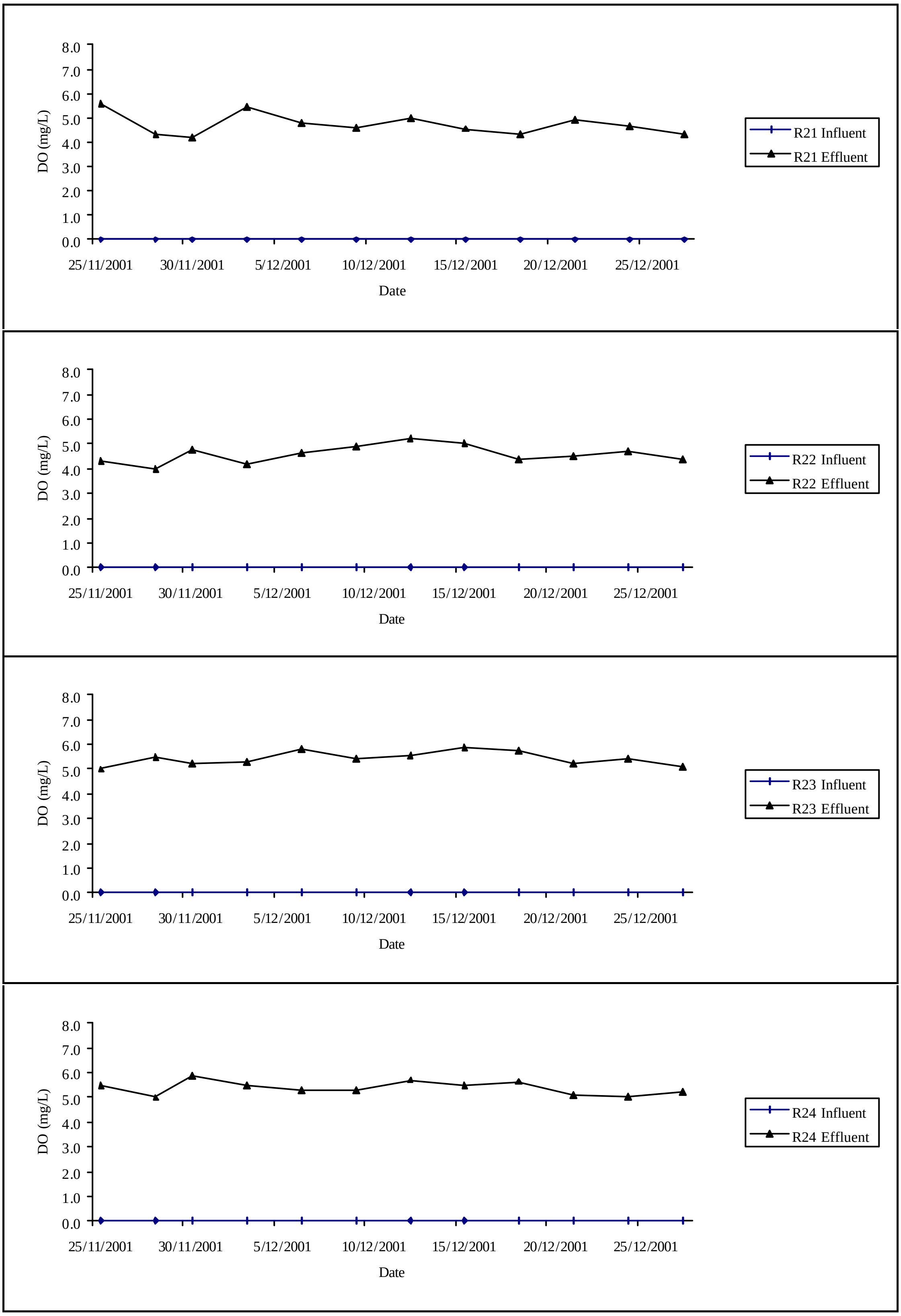


Figure 4.6 The influent and effluent DO concentrations in four reactors during Run II

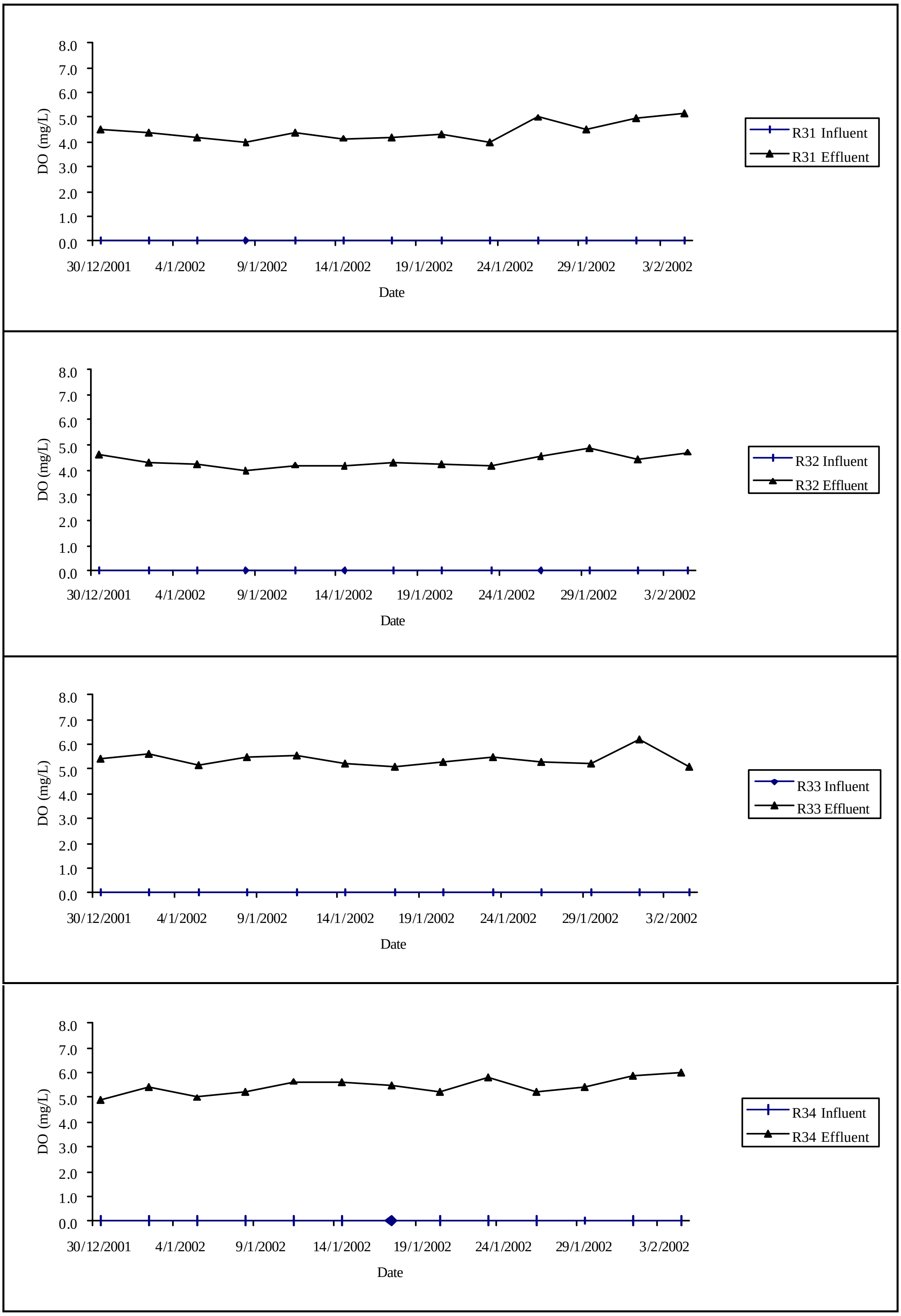


Figure 4.7 The influent and effluent DO concentrations in four reactors during RunIII

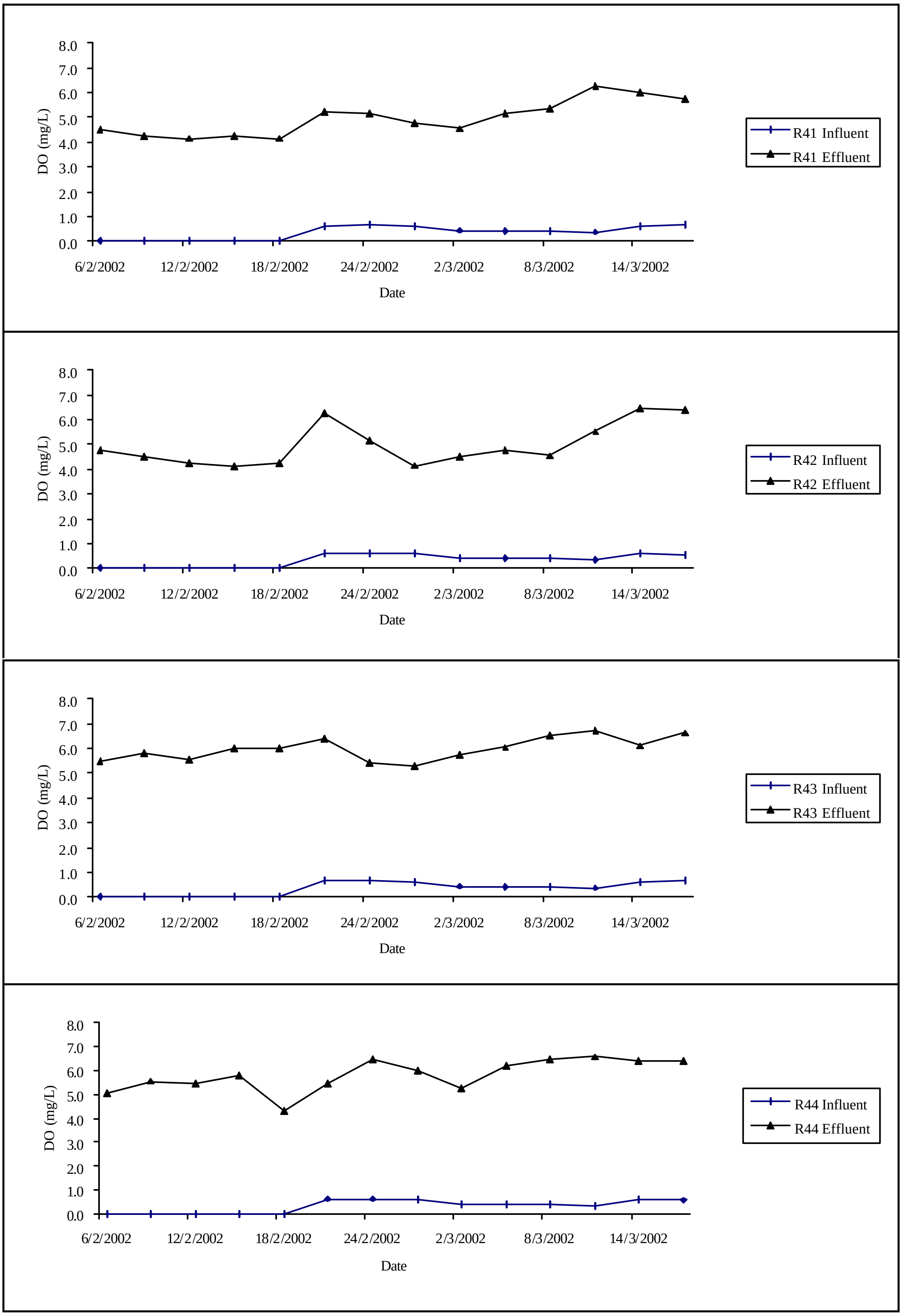


Figure 4.8 The influent and effluent DO concentrations in four reactors during RunIV

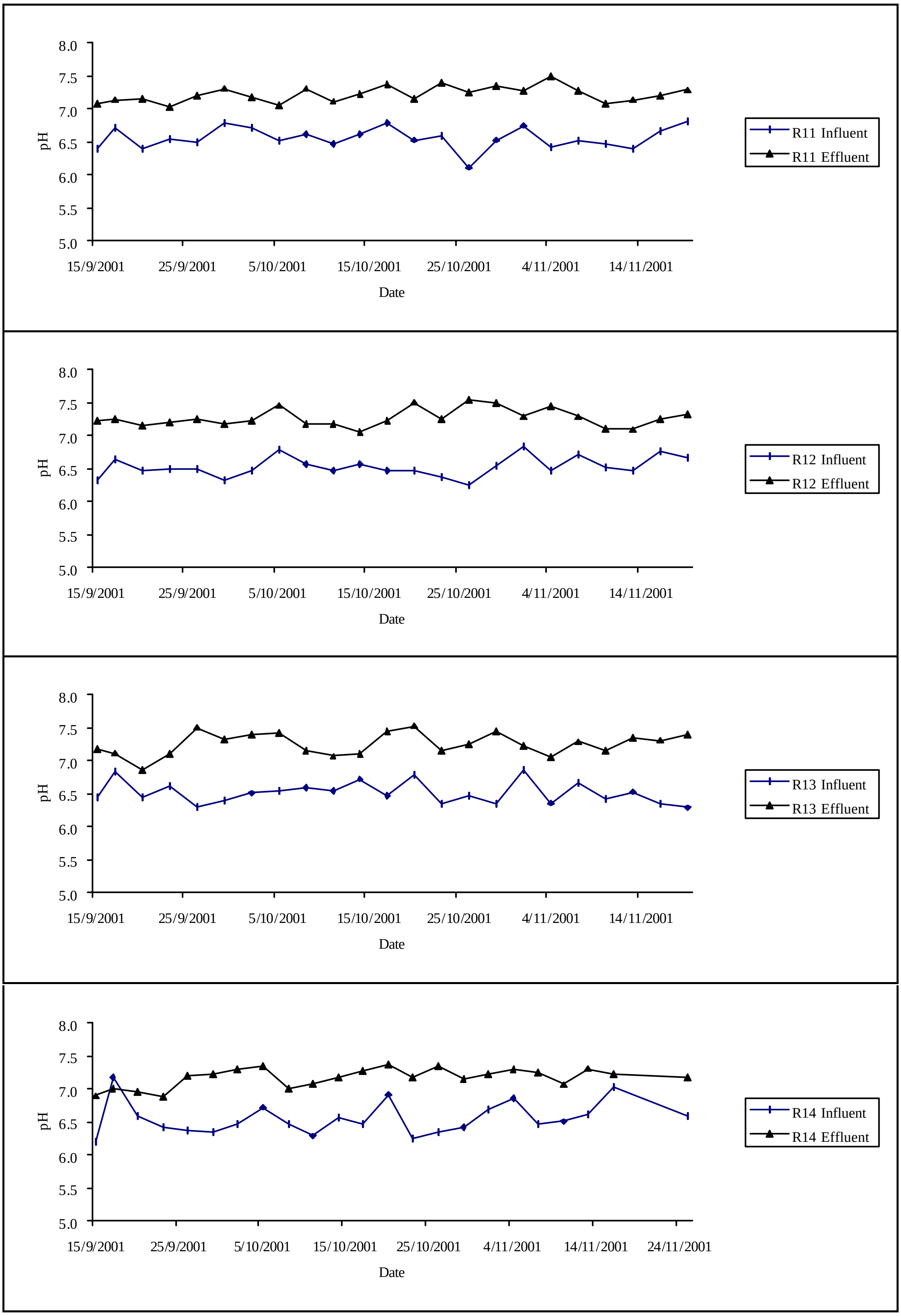


Figure 4.9 The influent and effluent pH values in four reactors during Run I

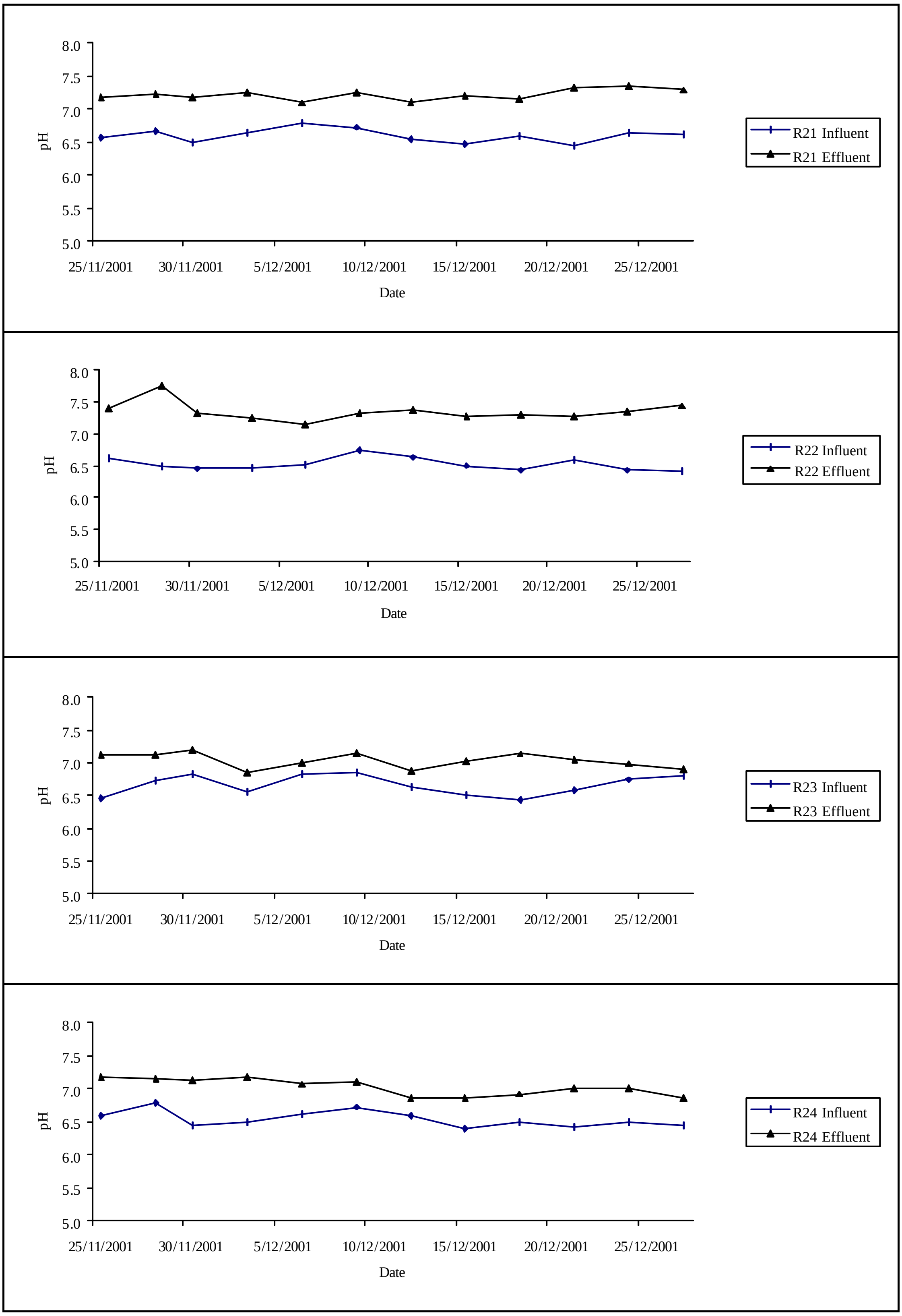


Figure 4.10 The influent and effluent pH values in four reactors during Run II

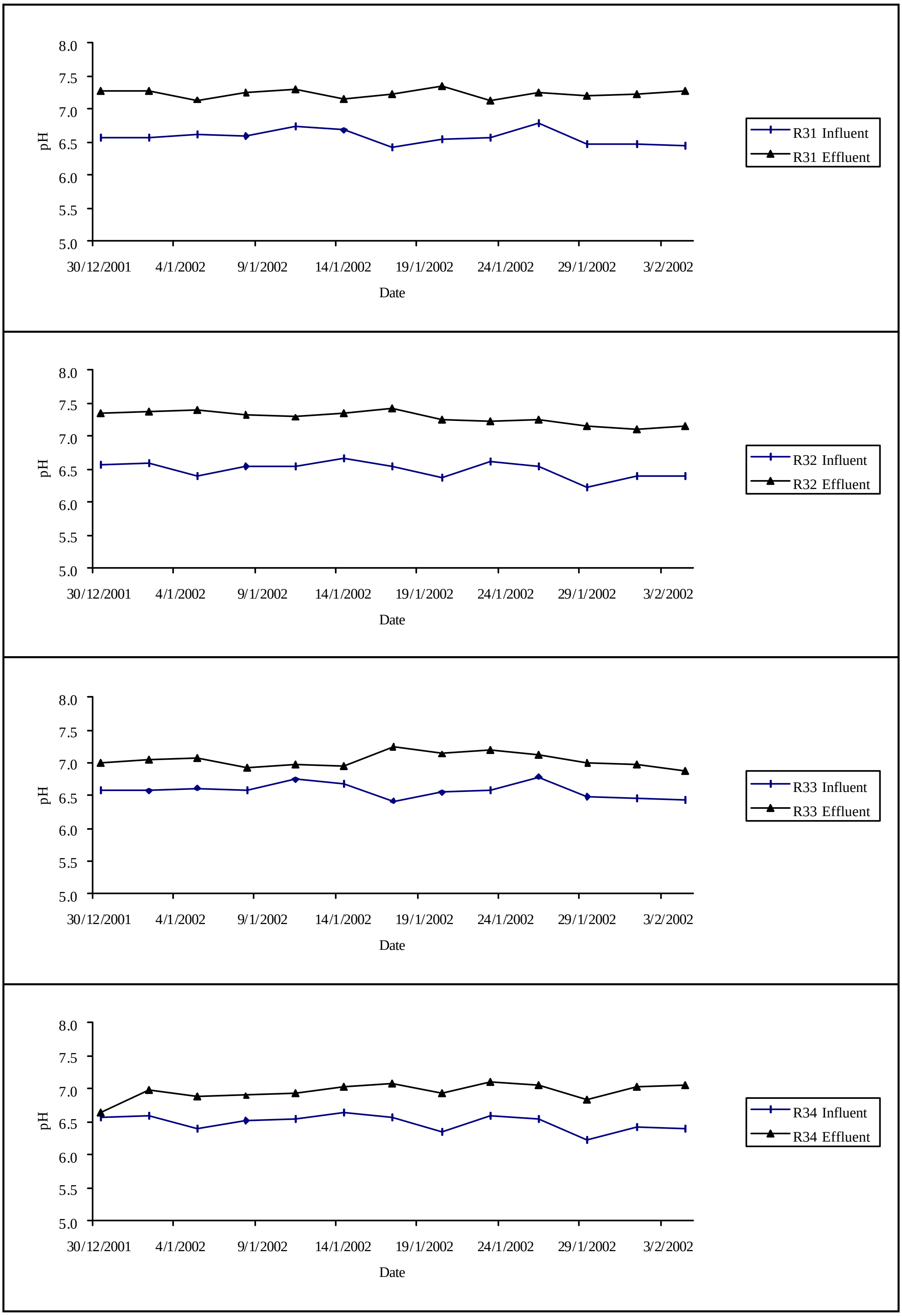


Figure 4.11 The influent and effluent pH values in four reactors during III

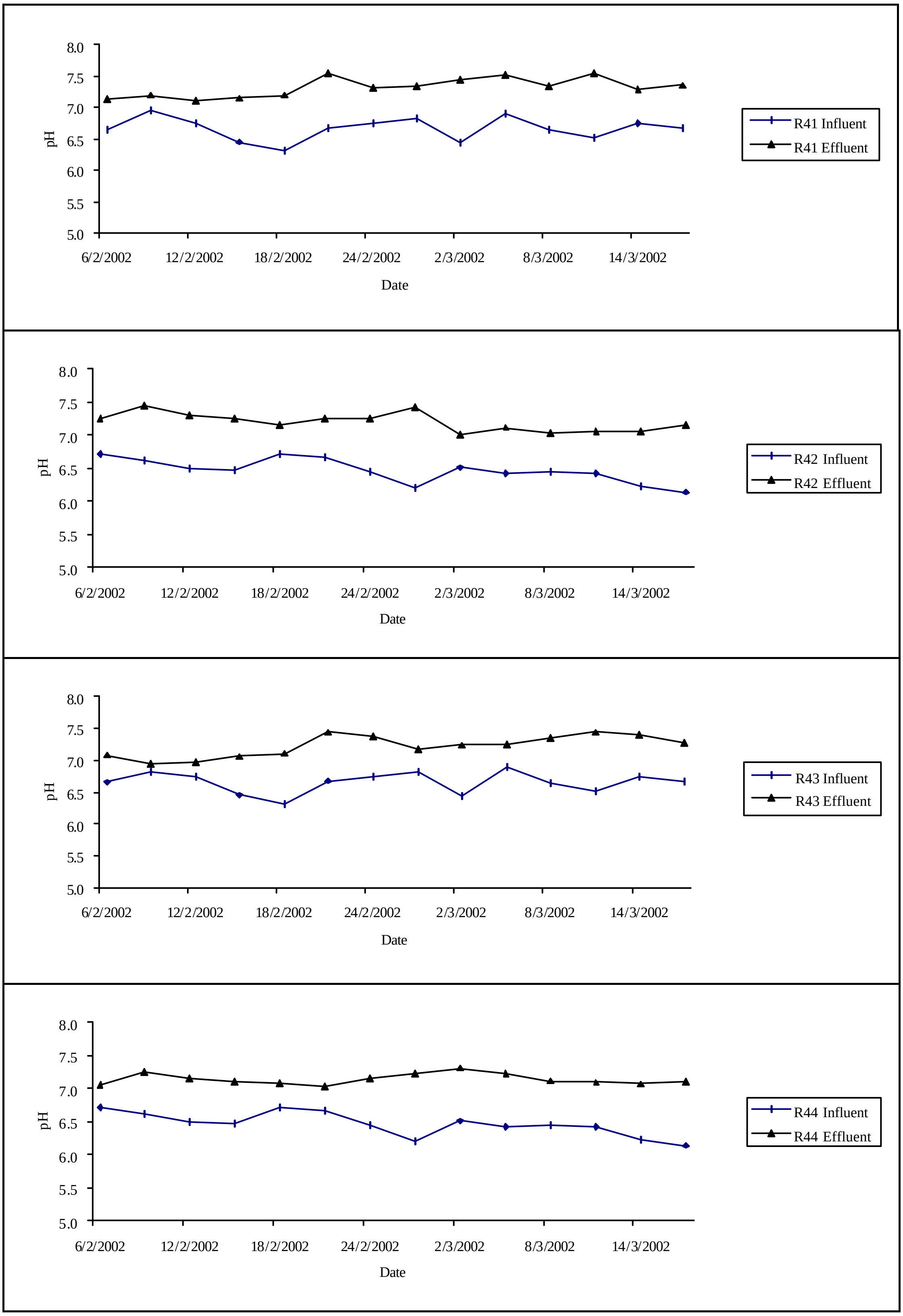


Figure 4.12 The influent and effluent pH values in four reactors during Run IV

4.7-10. At these ranges of pH, the precipitation was the predominant mechanism in the removal of cadmium in wetlands. The effluent pH was higher than the influent pH, which could be due to metabolism of the biotic components of the wetland system. Photosynthesis utilizes carbon dioxide and produces oxygen, therefore shifting the carbonate-bicarbonate-carbon dioxide equilibria to a higher pH. The organic substrates generated within a wetland via growth, death, and decomposition cycles could be the sources for increasing pH in wetlands.

4.2.3 Temperature

Temperature is highly variable over daily, seasonal, and latitudinal gradient; however, it is affected very little by biology. The optimum water temperature for growth of cattails is 30 °C. Details of the experimental data are showed in Appendix B. The results of influent and effluent temperature variation of wastewater during the four experimental runs are shown in Figures 4.13-4.16.

The mean ambient temperature during the experiment period varied between 25-31°C. The mean influent and effluent wastewater temperatures during the four runs were in the range of 25-30°C.

4.2.4 Chemical Oxygen Demand (COD) removal

In wetland systems, microbial degradation plays a dominant role in the removal of soluble/colloidal biodegradable organic matter (BOD or COD) present in wastewater (Lim and polprasert, 1996). Settable organics are rapidly removed in wetland systems by quiescent conditions, deposition, and filtration.

Appendix B shows the data of influent and effluent COD variations during the experimental period profiles. The influent and effluent COD during the four experimental runs are shown in Figures 4.17-4.20. Inflow and outflow rates of each experiment were used to obtain the COD removal efficiencies. Mean removal efficiencies in the two types of wetland systems during the four runs are shown in Figure 4.21.

The oxygen transfer rates for emergent plant range from 5 to 45 $g/m^2.d$. The major oxygen source for subsurface flow systems is via diffusion from the atmosphere to the root zone (rhizophere) (Watson et al., 1989). For SF in which roots are in contact with the flowing water column, the oxygen transferred to the roots will be available to attached organisms that degrade the soluble organic in the water

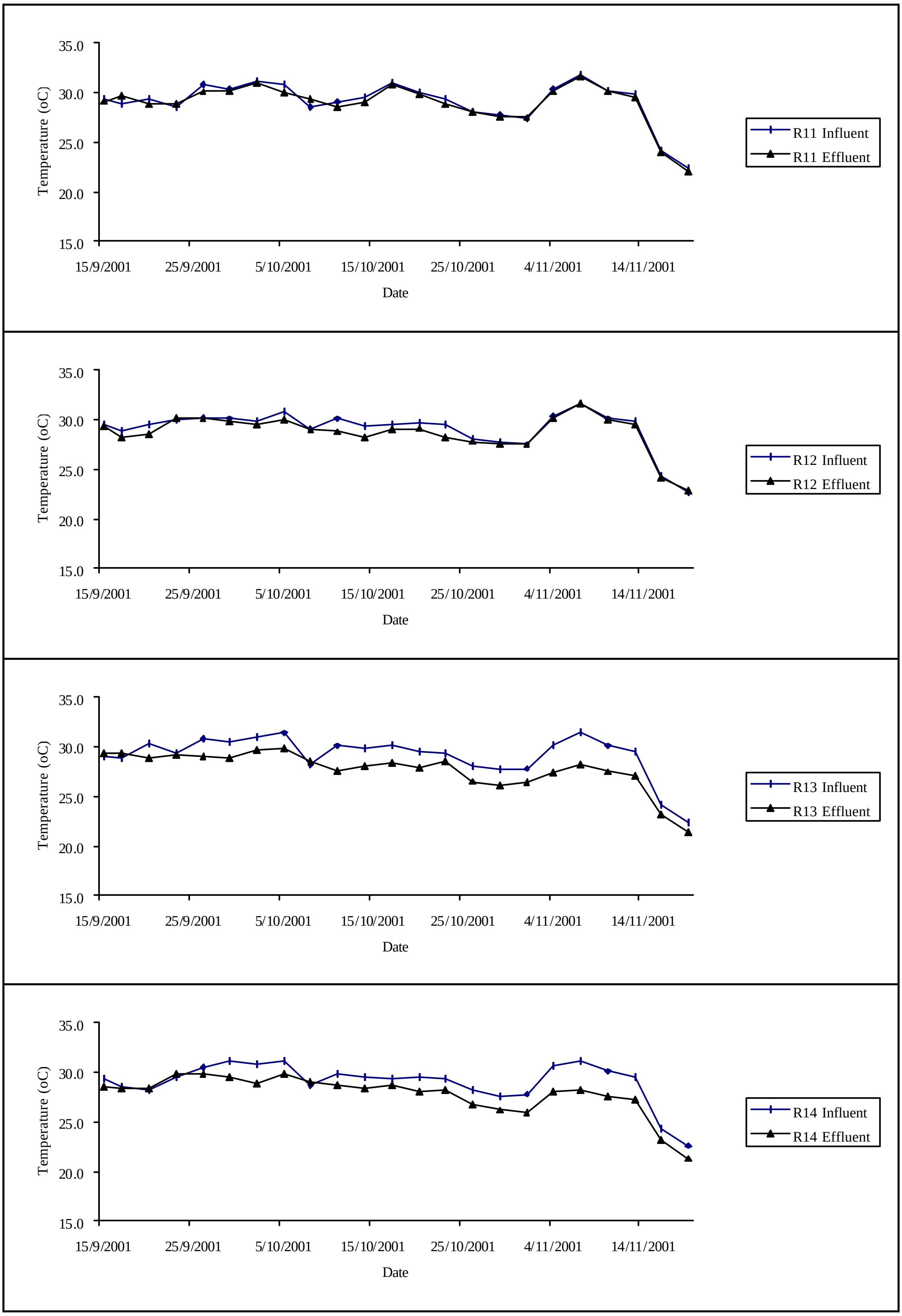


Figure 4.13 The influent and effluent temperature in four reactors during Run I

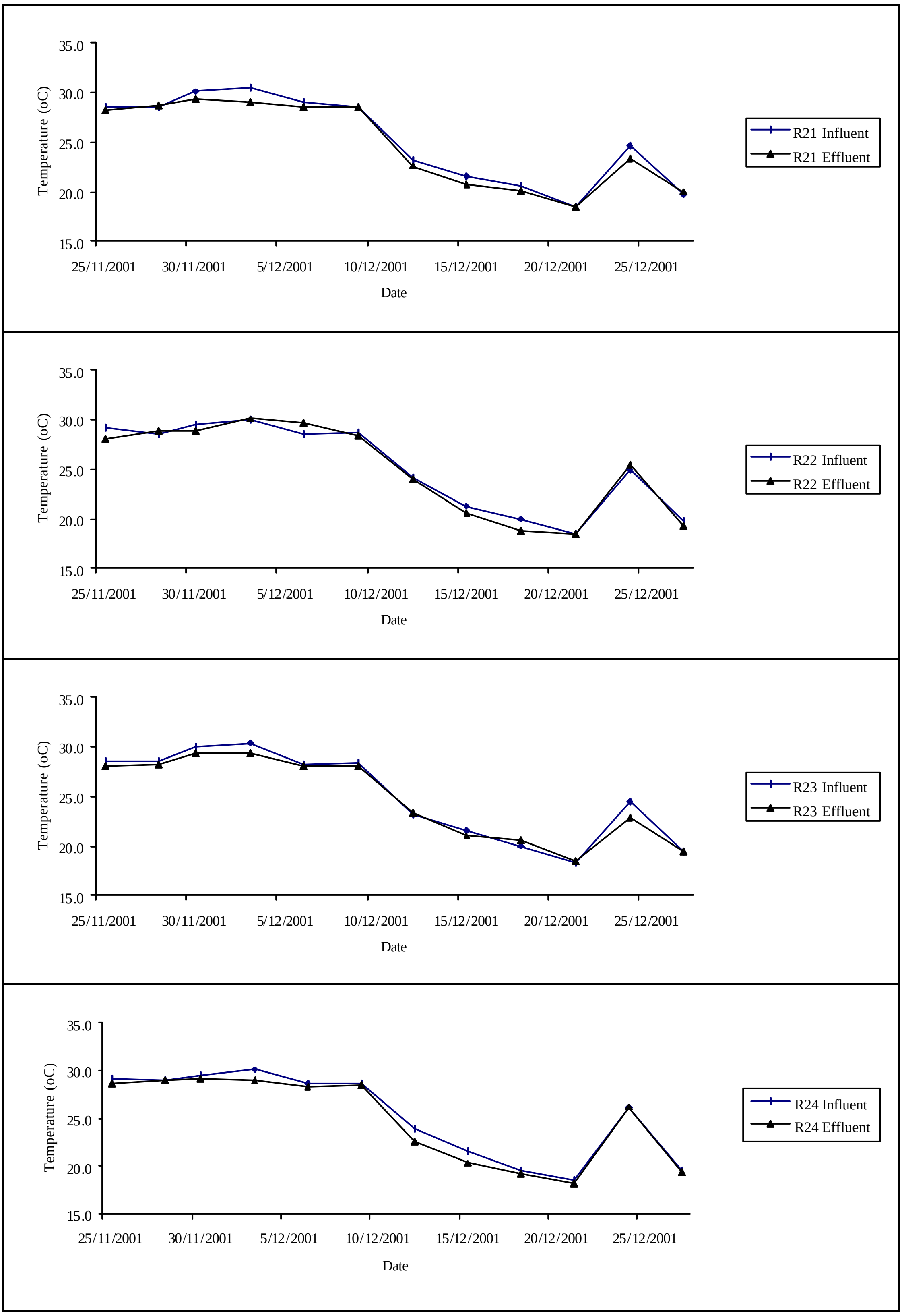


Figure 4.14 The influent and effluent temperature in four reactors during Run II

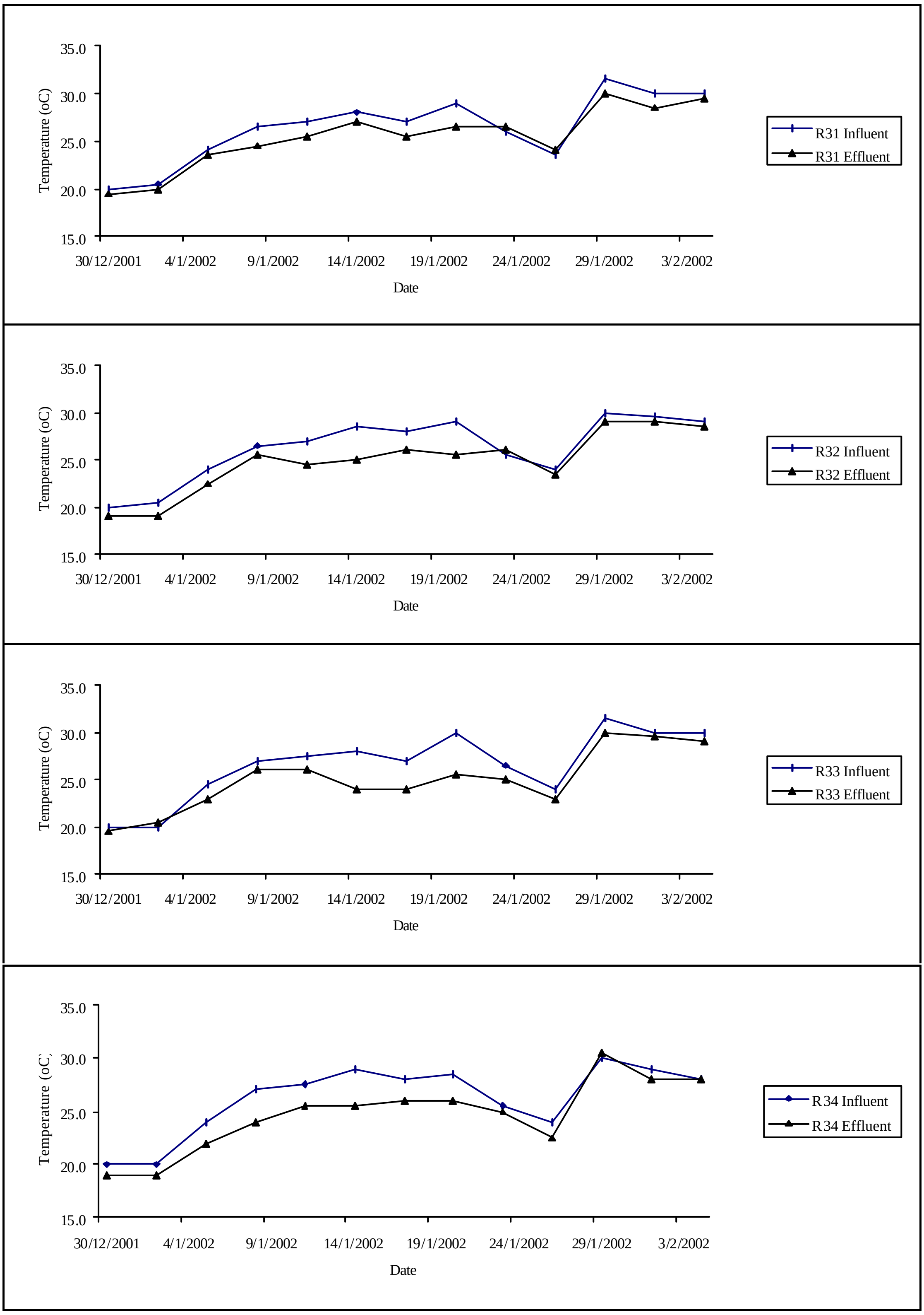


Figure 4.15 The influent and effluent temperature in four reactors during Run III

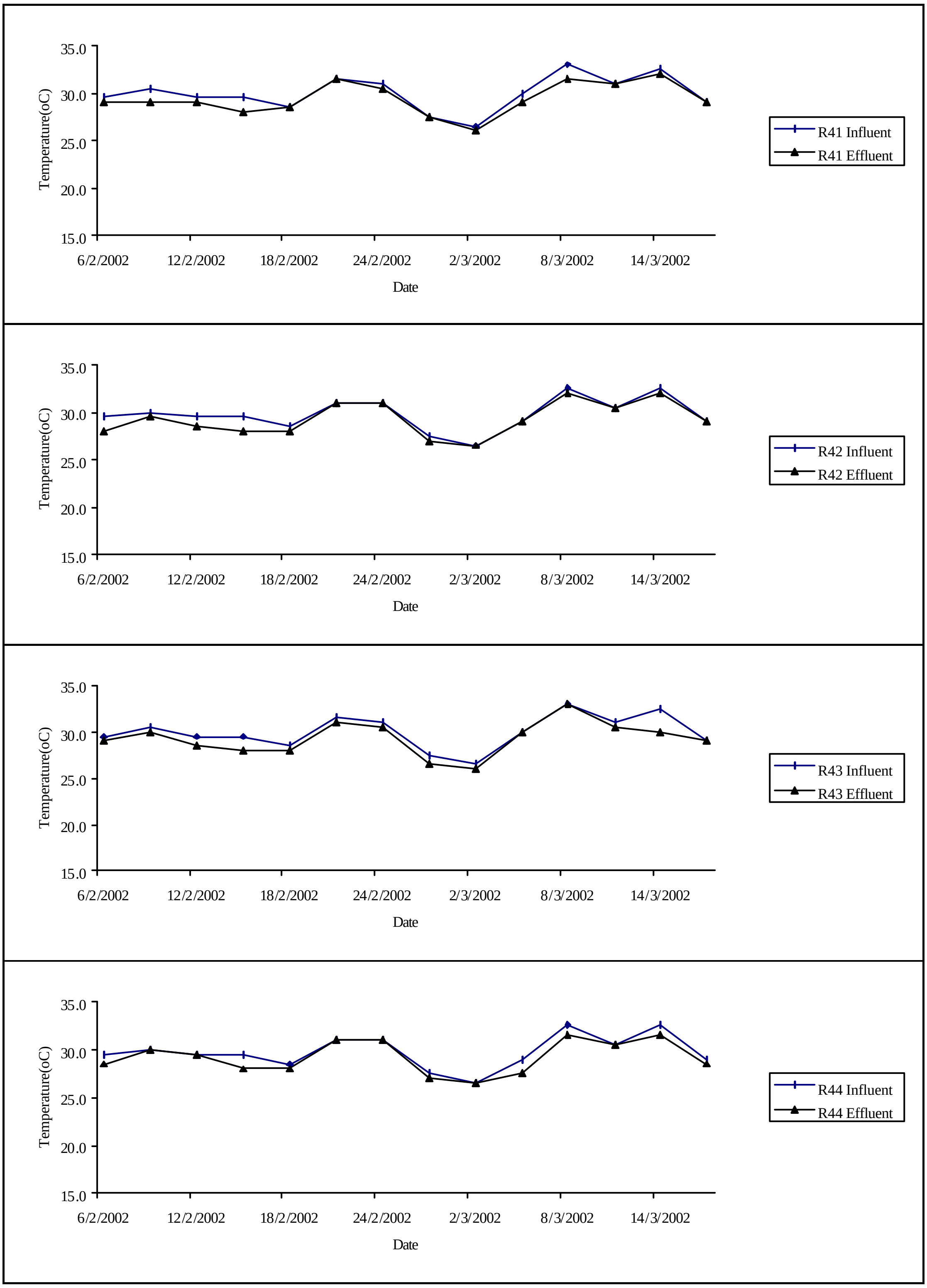


Figure 4.16 The influent and effluent temperature in four reactors during Run IV

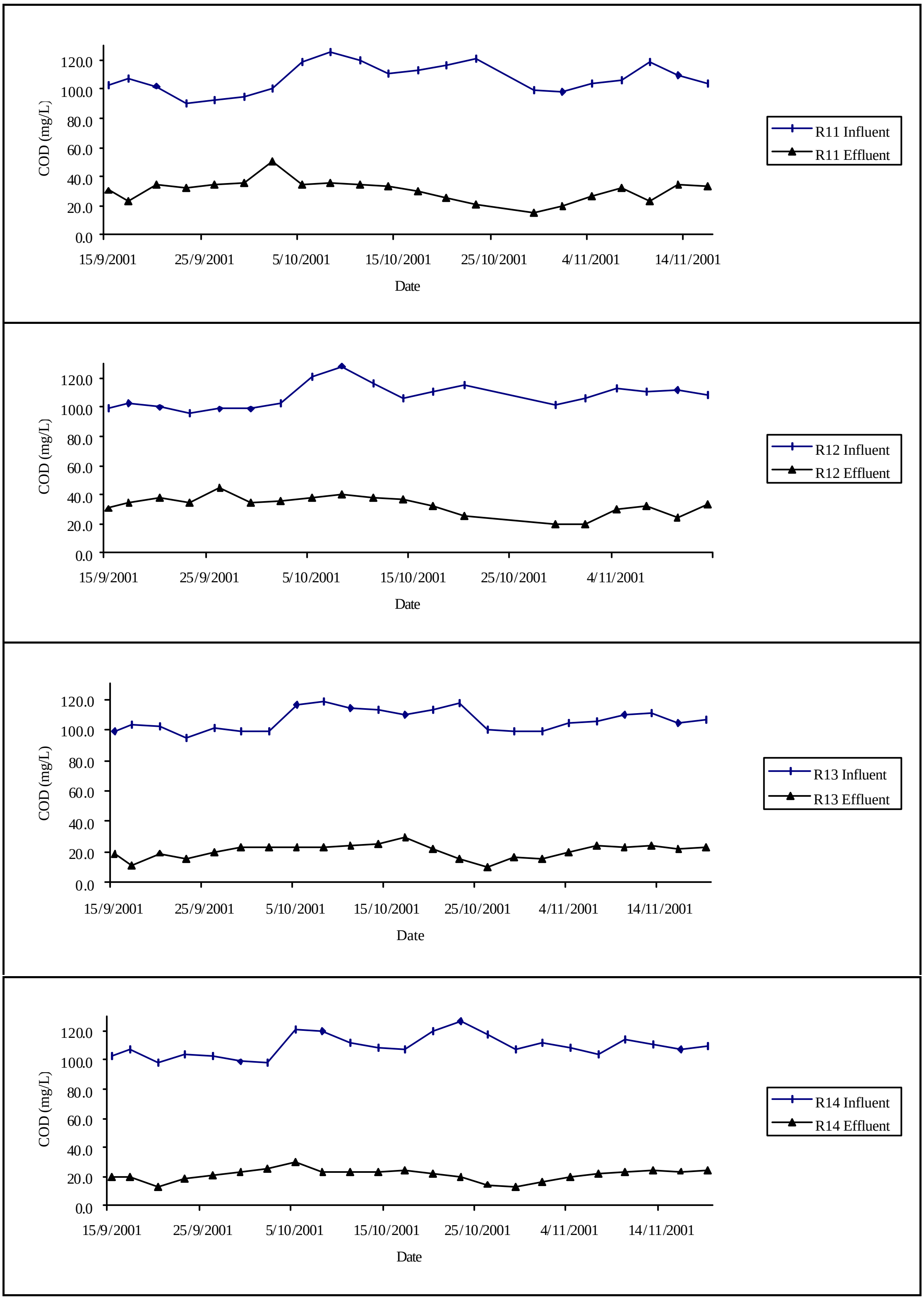


Figure 4.17 The influent and effluent COD concentrations in four reactors during Run I

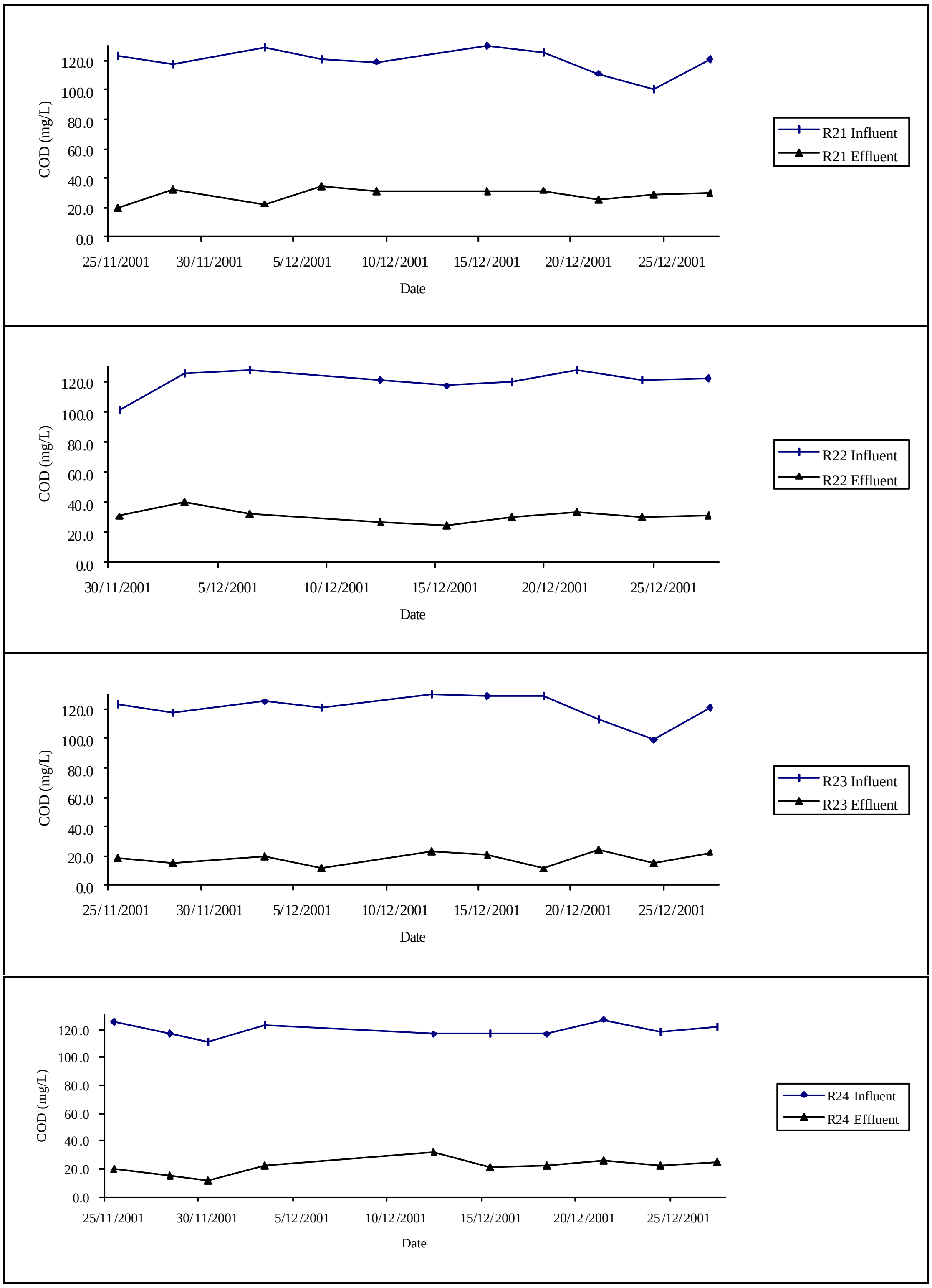


Figure 4.18 The influent and effluent COD concentrations in four reactors during Run II

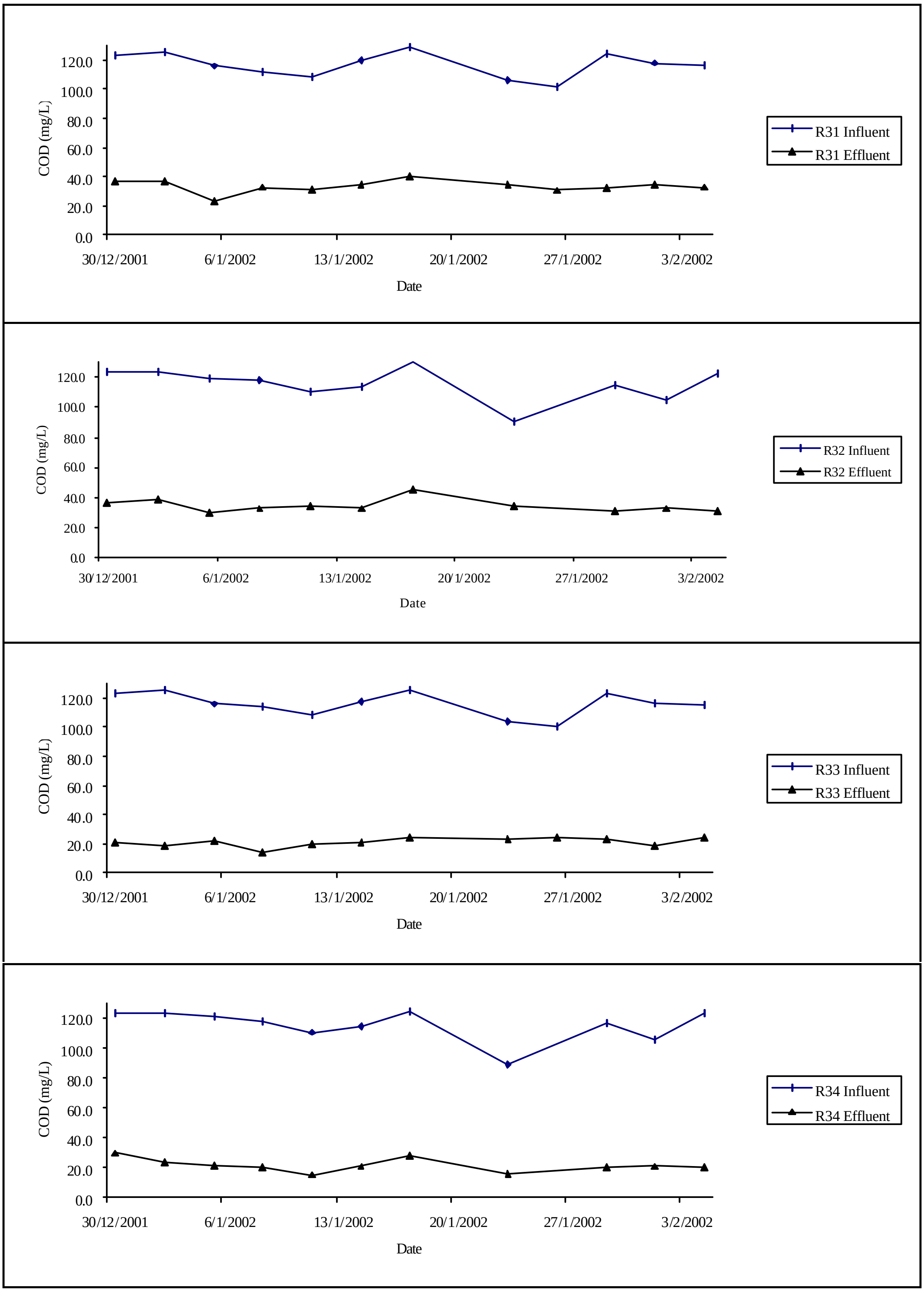


Figure 4.19 The influent and effluent COD concentrations in four reactors during Run III

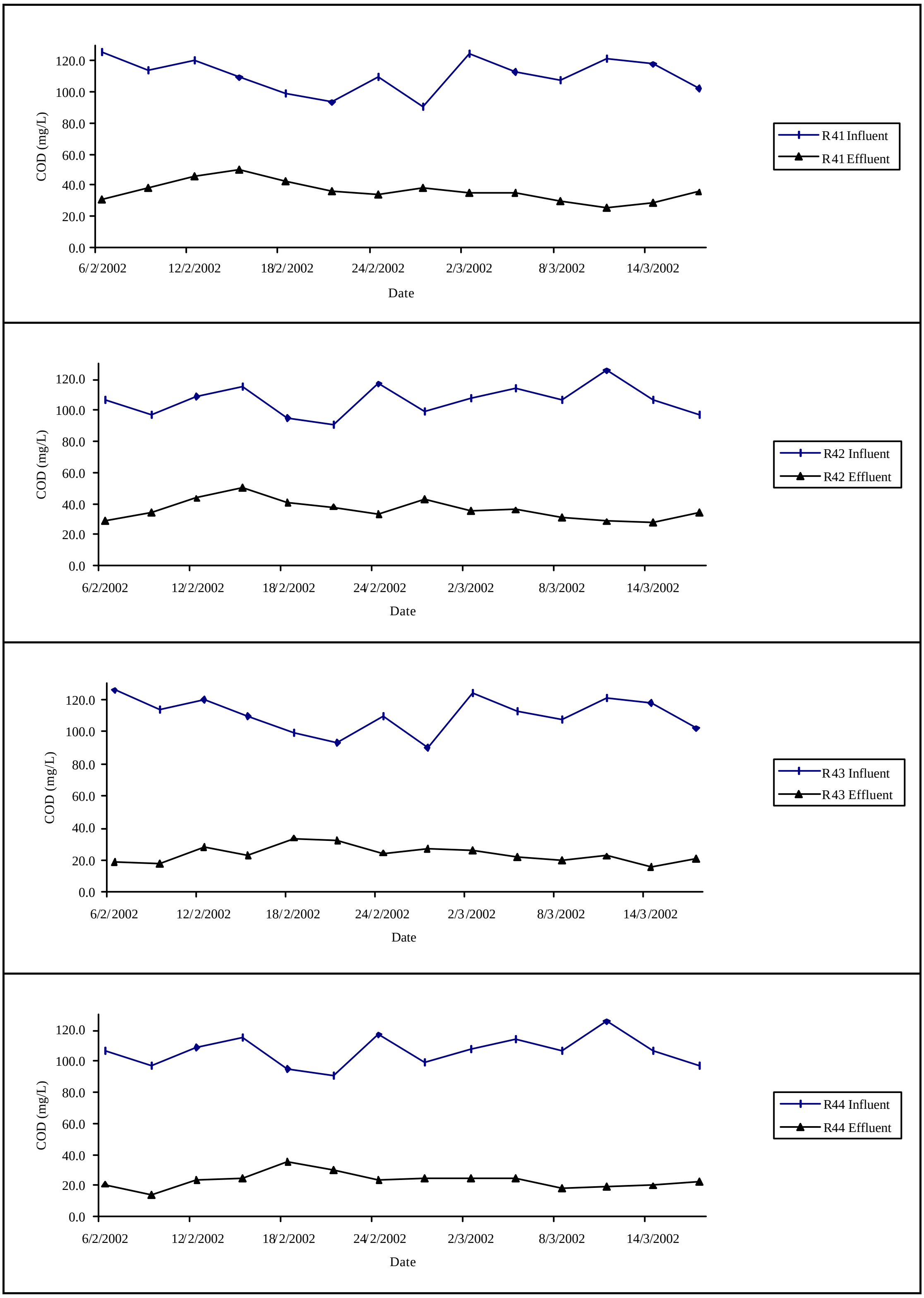


Figure 4.20 The influent and effluent COD concentrations in four reactors during Run IV

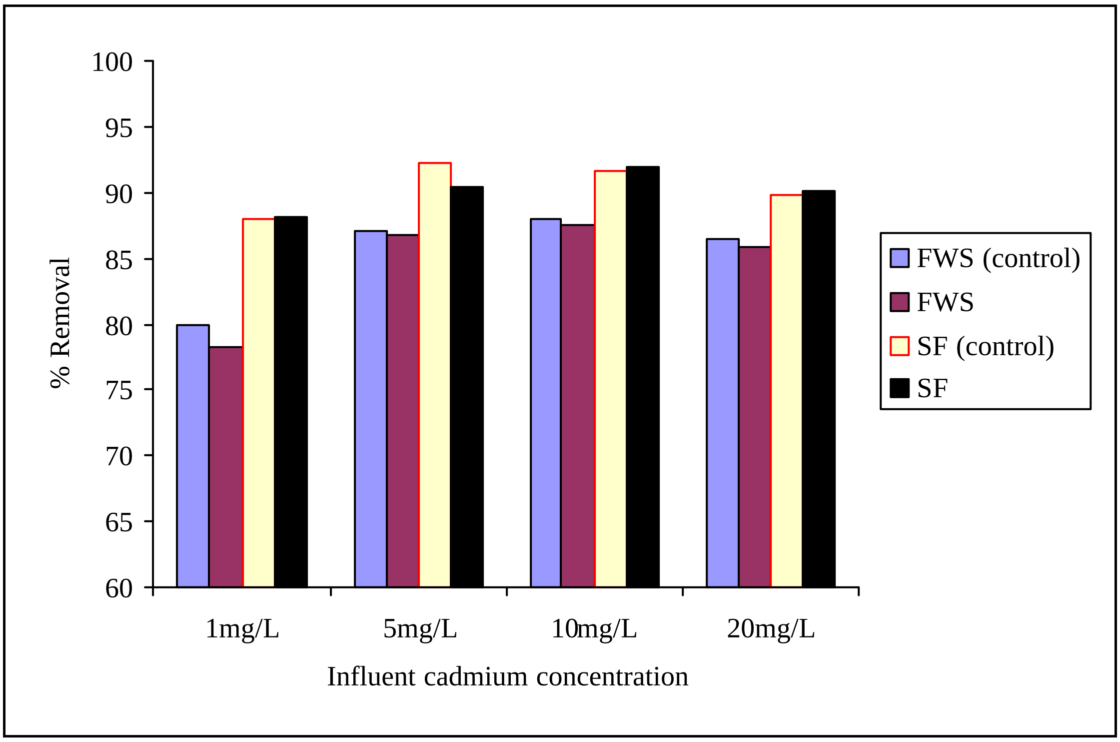


Figure 4.21 The mean COD removal efficiencies during the four runs

column. In free water surface wetlands, the major oxygen source for these reactions is reaeration at the water surface. For FWS, oxygen supply to the water column is limited, as compared to SF, because the root zone is in the soil below the water column and any oxygen transported to the root zone will likely be consumed by the large benthic oxygen demand that normally exists in wetland. Furthermore, oxygen transfer through the water surface by wind-induced reaeration and photosynthesis is minimized when dense vegetation is present (Metcalf&Eddy, 1991).

The average removal efficiencies of COD were in the range of 80.0-88.06%, 78.4-87.5%, 87.9-92.2%, and 88.2-91.9%, during the experimental period for reactors R1, R2, R3, and R4, respectively. The removal efficiencies increased in Run I-III, and slightly decreased in Run IV of both wetland systems. It may be because of the cattail plants becoming dense and consequently the growth rate being reduced, COD removal in the control units and experimental units of both wetland systems were not significantly different. Thus, different concentrations of cadmium (1, 5, 10 and 20 mg/L) were not affecting the mechanisms of microorganisms in the removal of organics from wastewater.

4.2.5 Total kjeldahl nitrogen (TKN) removal

Nitrogen is removed in free water surface and subsurface flow wetlands by similar mechanism. Removal of nitrogen in wetlands is achieved through three main mechanisms: such as nitrification/ denitrification, volatilization of ammonia, and uptake by plants. (Lim and polprasert, 1996).

Inflow and outflow rates were used to determine the removal efficiencies of total kjeldahl nitrogen (shown in Appendix B). The influent and effluent TKN concentrations during the four experimental runs are shown in Figures 4.22-4.25. Figure 4.26 shows the average TKN removal efficiencies during the four runs.

The average removal efficiencies of TKN during the four experimental runs were found to be in the range of 65.9-85.4%, 64.7-83.5%, 85.1-90.1%, and 85.4-91.3% for reactors R1, R2, R3, and R4, respectively.

The potential rate of nutrient uptake is limited by the growth rate of the plants and the concentration of nutrients in the plant tissues. In view of overall removal of nitrogen from wastewater, plants that have rapid growth rates and capability to attain a high standing crop (biomass per unit area) can influence the rate of removal (Sundaravadivel and Vigneswaran, 2001).

4.2.6 Total phosphorus (TP) removal

Phosphorus removal in wetlands systems occurs through absorption, complexation, and precipitation.

Orthophosphate is the predominant inorganic form of P in surface waters. This form of phosphorus readily accumulates in wetland vegetation and soils, as a result of biological uptake and chemical bonding. Formation of iron and aluminum phosphate minerals (low-pH wetlands) and calcium phosphate minerals (high-pH wetlands) is the major pathway for phosphorus removal in some wetlands. Organic forms of phosphorus are generally not biologically or chemically reactive in wetlands. Particulate organic phosphorus may be removed by settling from the water column. Both dissolved and particulate organic phosphorus may be biologically broken down to inorganic forms (mineralization), and subsequently removed through biological and chemical process.

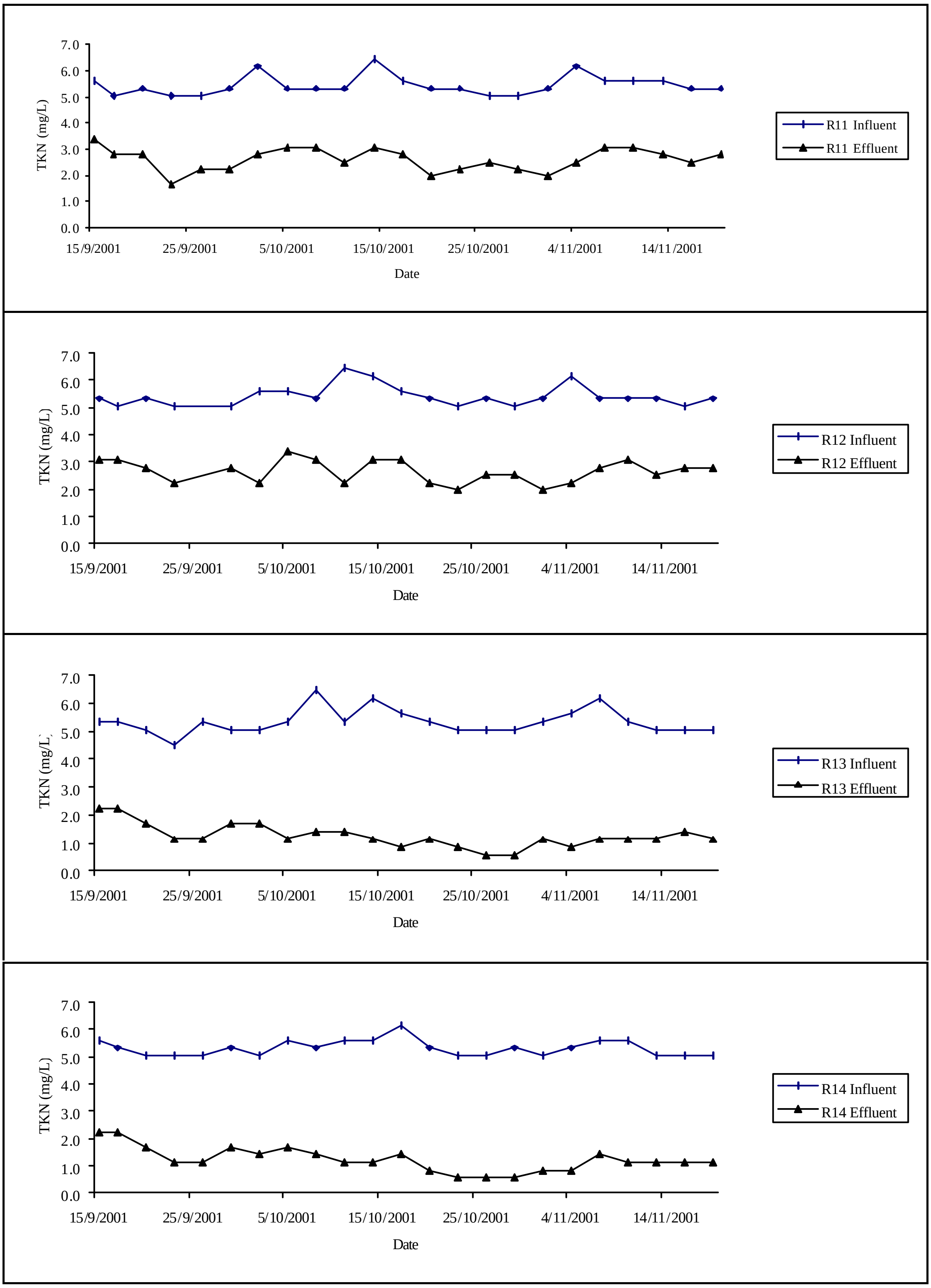


Figure 4.22 The influent and effluent TKN concentrations in four reactors during Run I

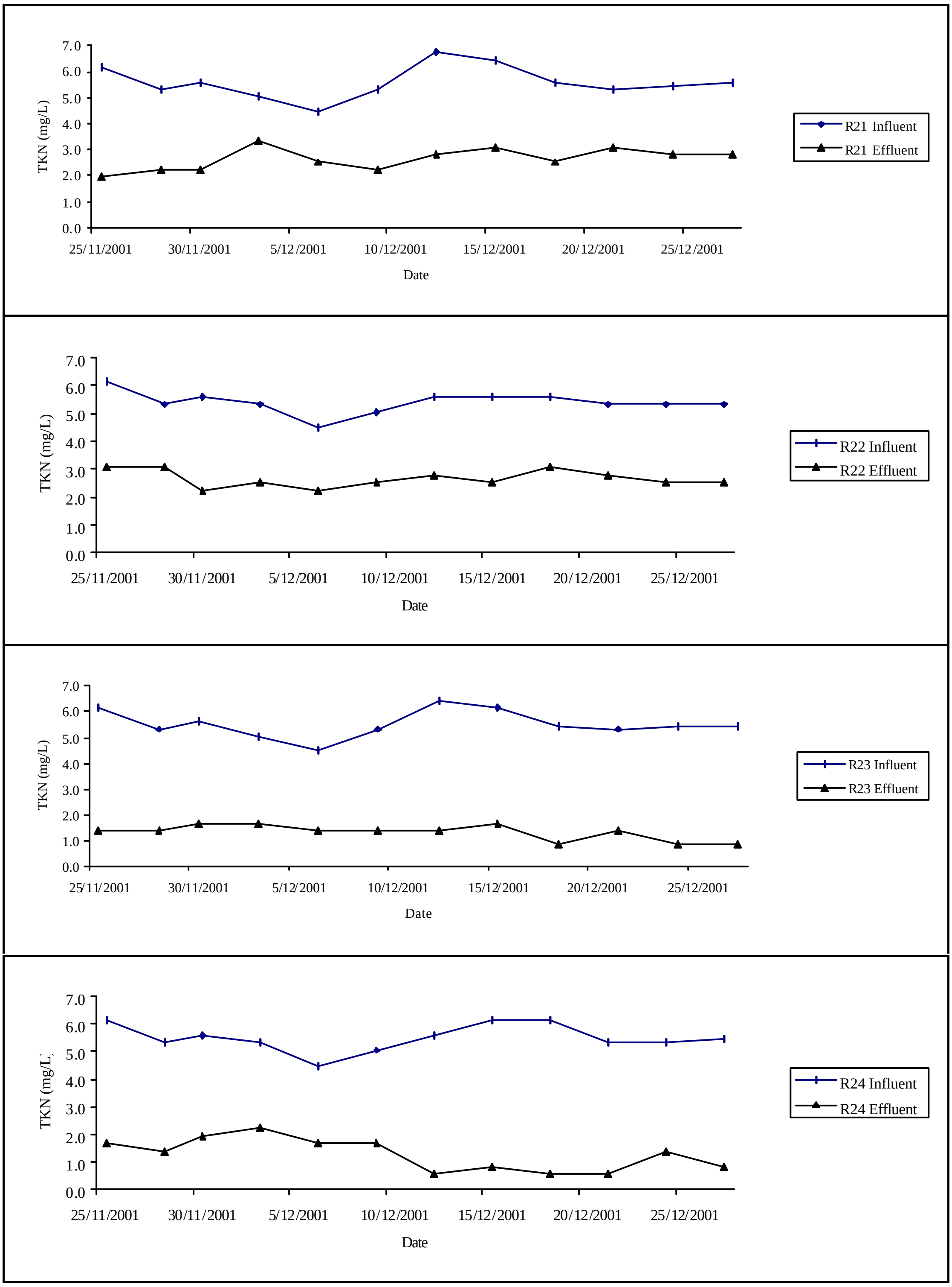


Figure 4.23 The influent and effluent TKN concentrations in four reactors during Run II

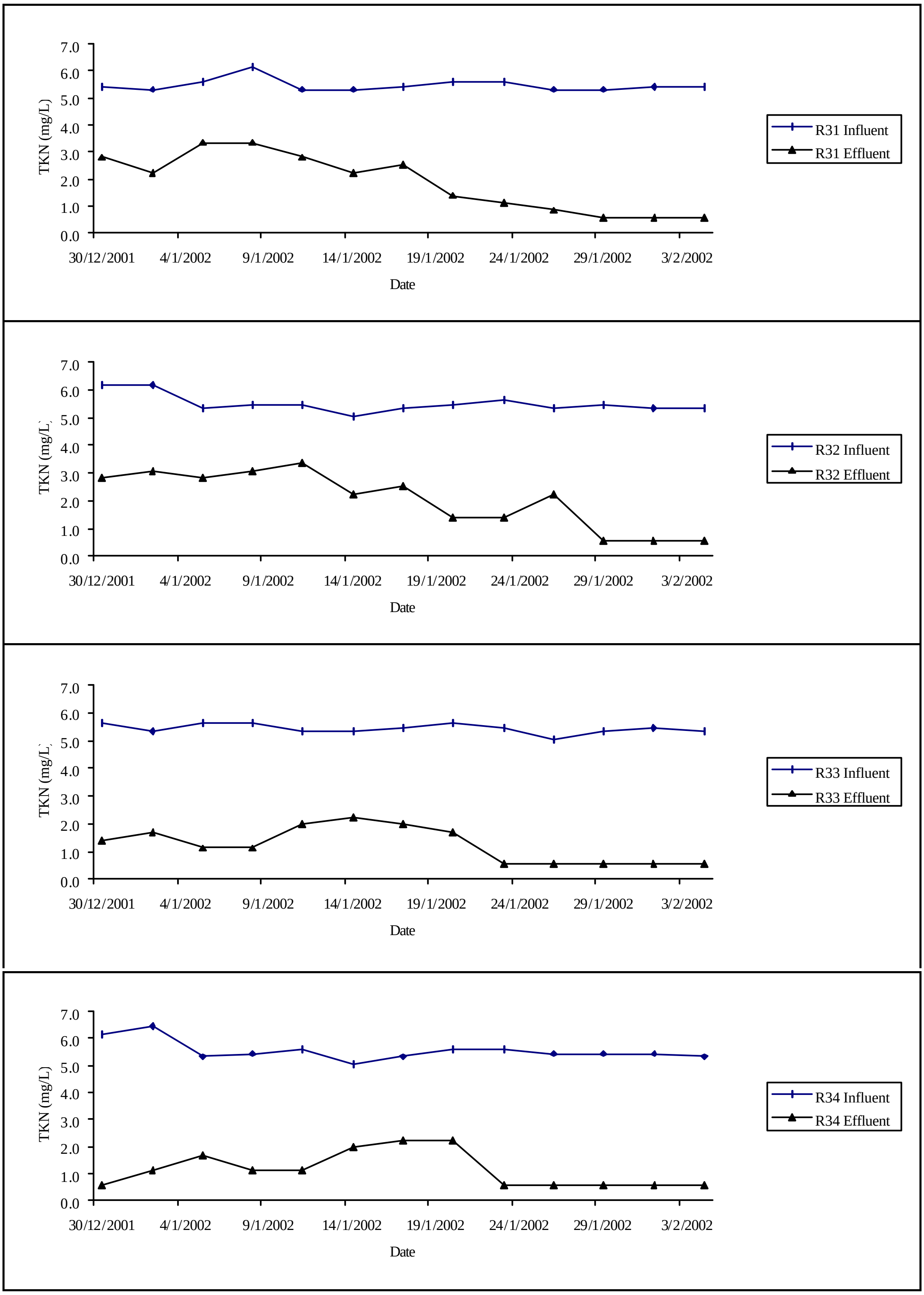


Figure 4.24 The influent and effluent TKN concentrations in four reactors during Run III

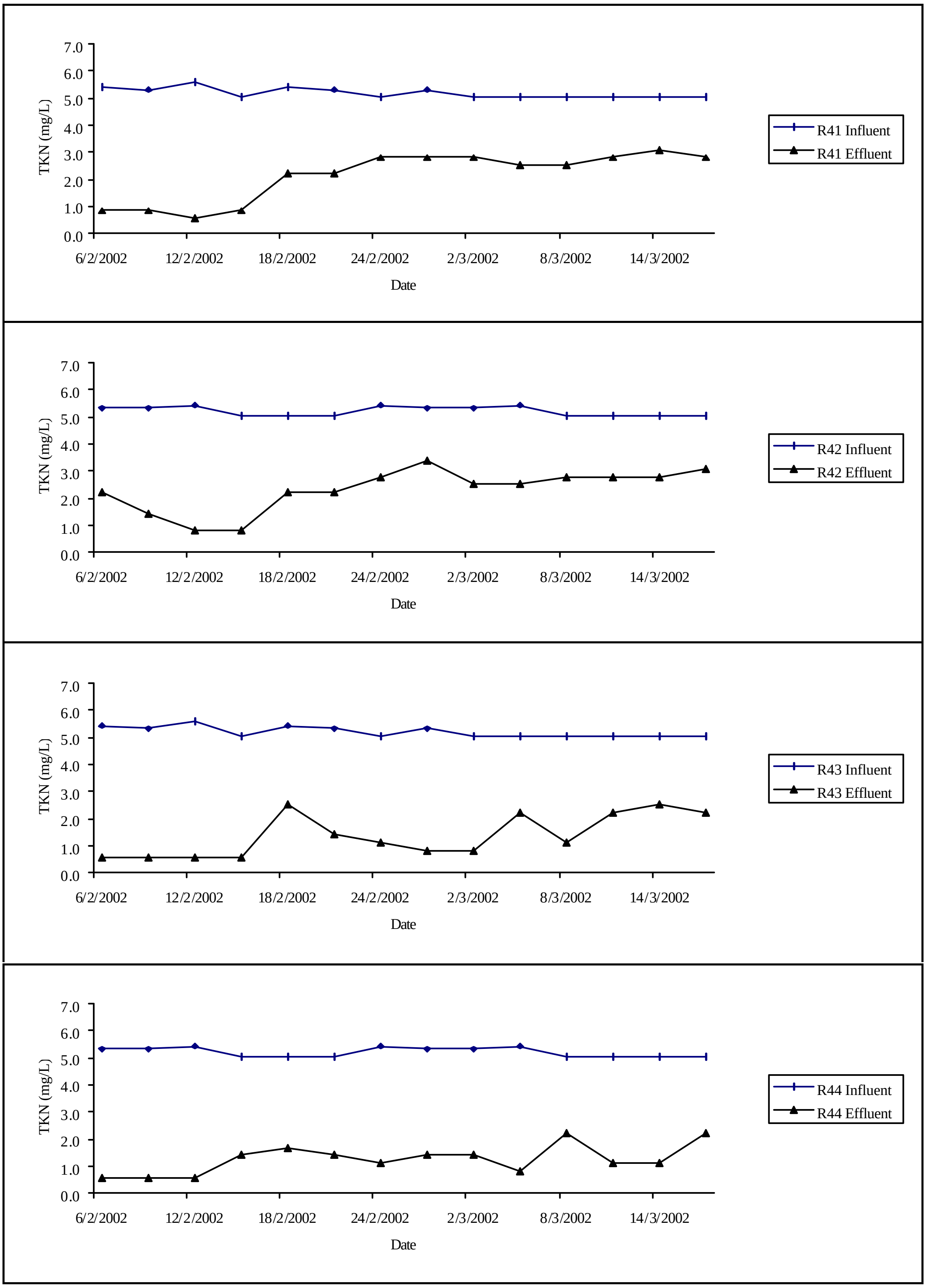


Figure 4.25 The influent and effluent TKN concentrations in four reactors during Run IV

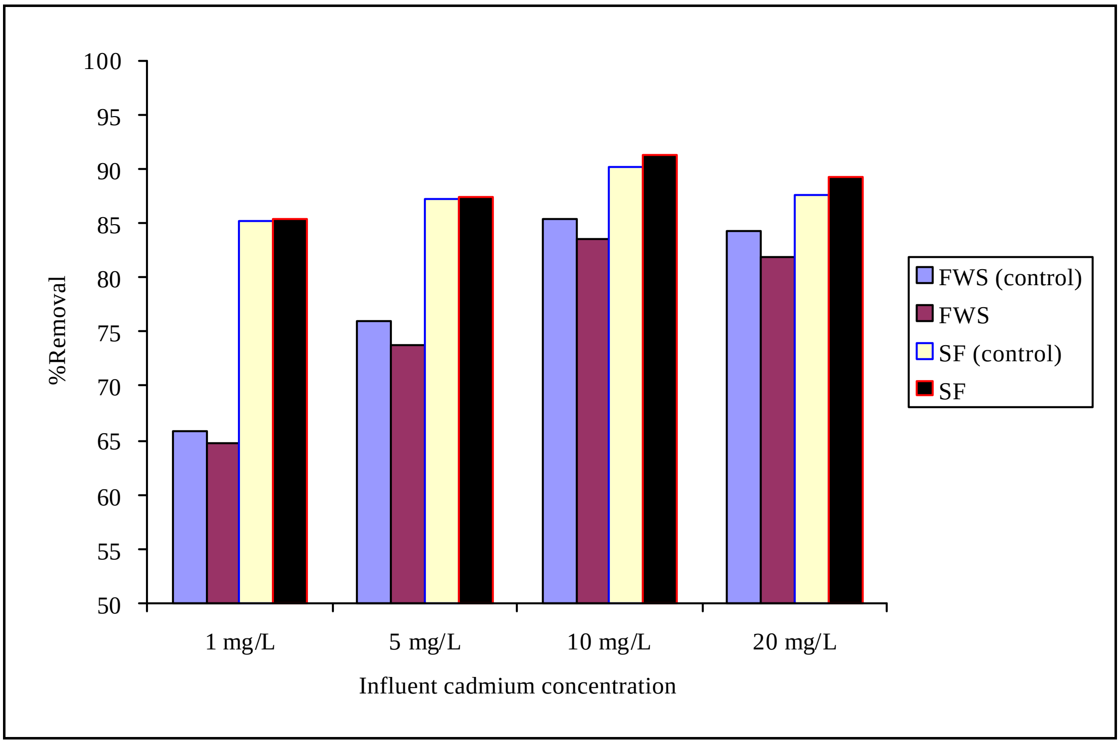


Figure 4.26 The average TKN removal efficiencies during four runs

Experimental results on phosphorus removal are shown in Figures 4.27-4.30 (also in Appendix B). The average removal efficiencies of TP during the four runs were determined by inflow and outflow rates as shown in Figure 4.31.

The average phosphorus removal efficiencies were in the range of 63.1-86.1%, 61.6-85.9%, 74.3-89.4%, and 74.9-90.5%, during the four runs for reactors R1, R2, R3, and R4, respectively. The removal efficiencies of TP were low in Run I and increased in Run II, III, and IV in both wetlands. The high removal efficiencies could be due to the increased absorption and precipitation in the longer operations.

It could also be seen from these results that phosphorus removal was lower in free water surface wetland because of limited contact with the soil and root zone. Sink may be important in free water surface flow system. Plants absorb phosphorus through their roots and transport it to growing tissues (Watson et al., 1989).

4.2.7 Total suspended solid (TSS) removal

Wetlands are capable of achieving a high efficiency of suspended solids removal from the water column. Settleable solids are removed easily via gravity

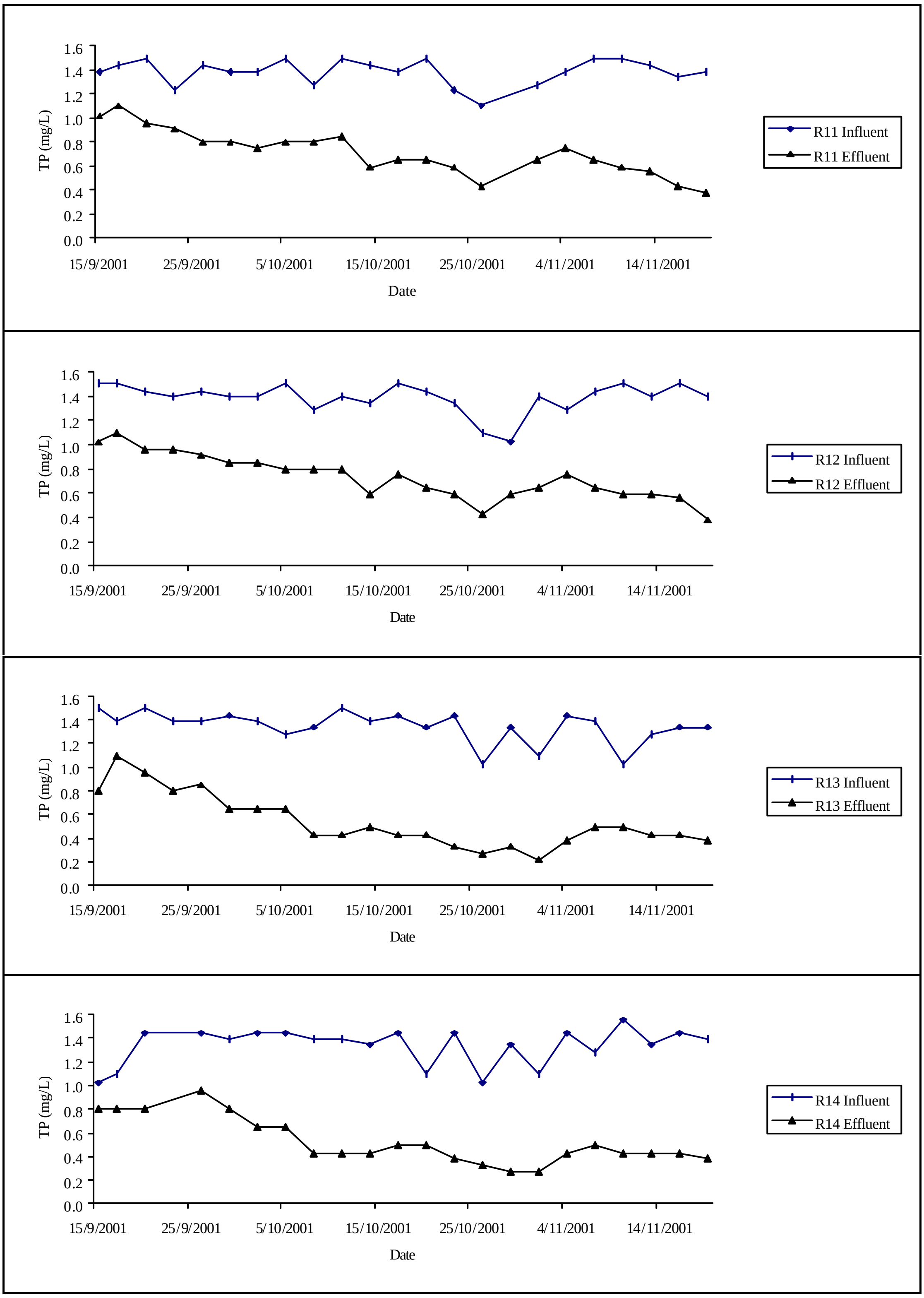


Figure 4.27 The influent and effluent TP concentrations in four reactors during Run I

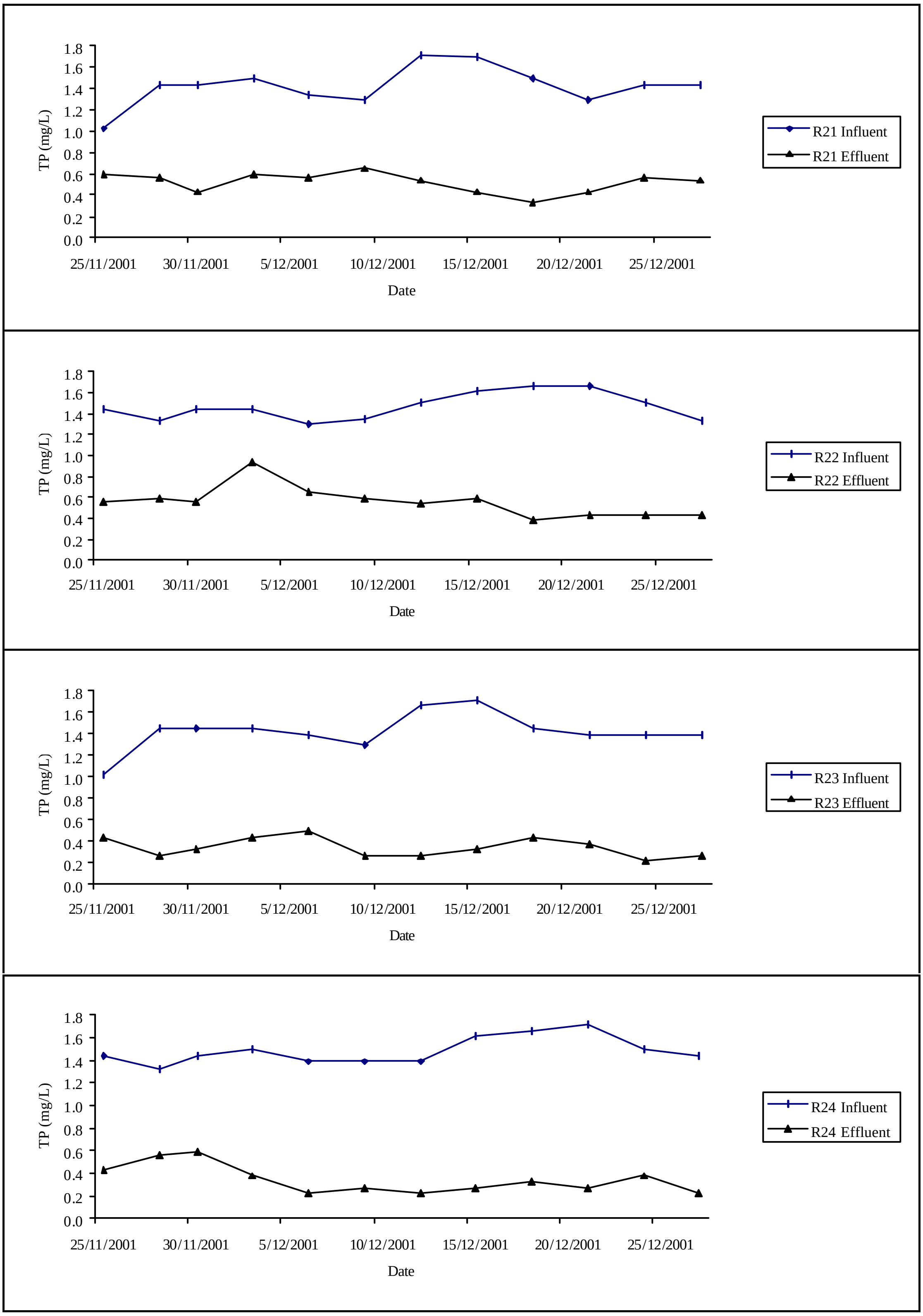


Figure 4.28 The Influent and effluent TP concentrations in four reactors during RunII

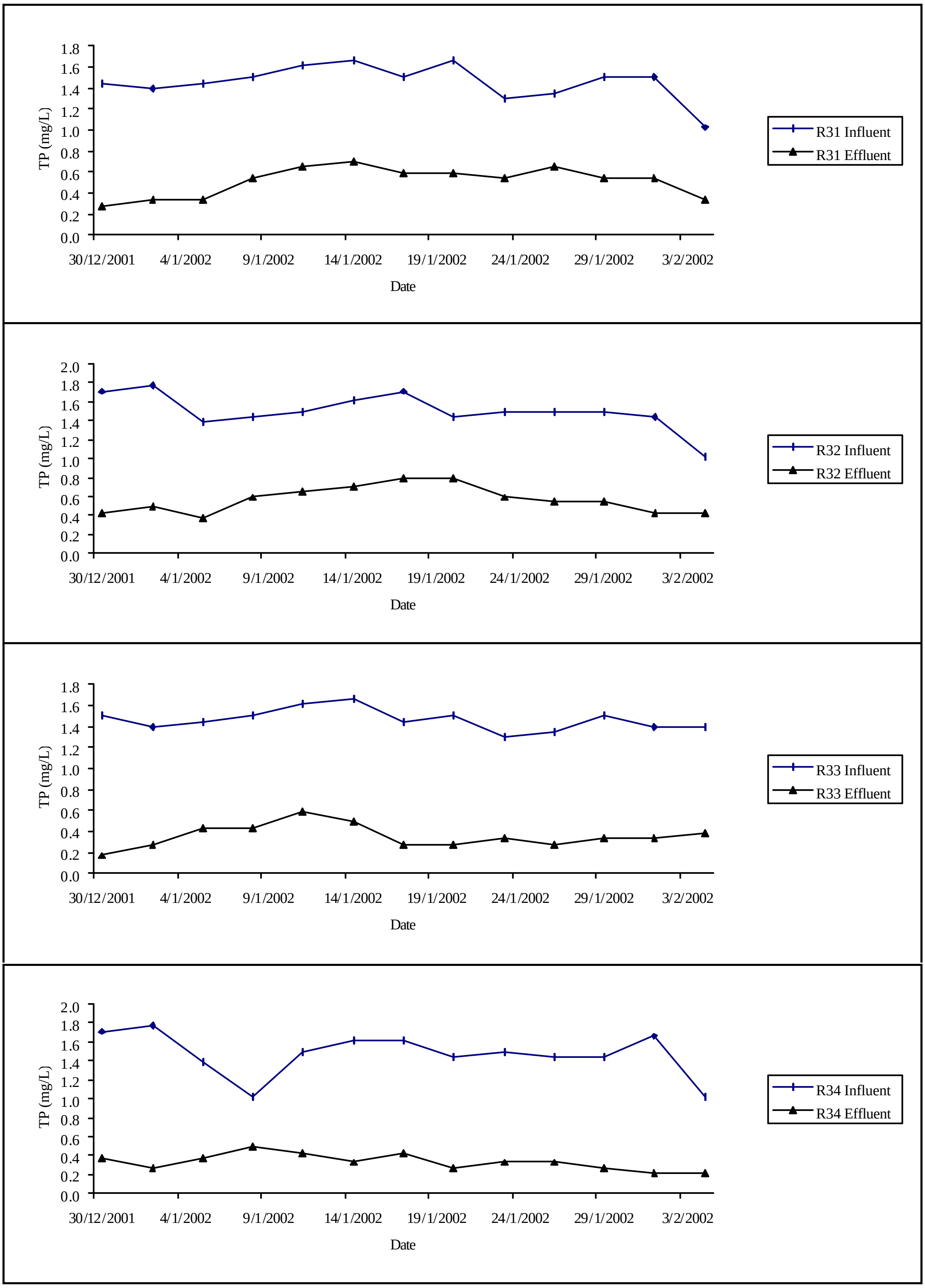


Figure 4.29 The influent and effluent TP concentrations in four reactors during Run III

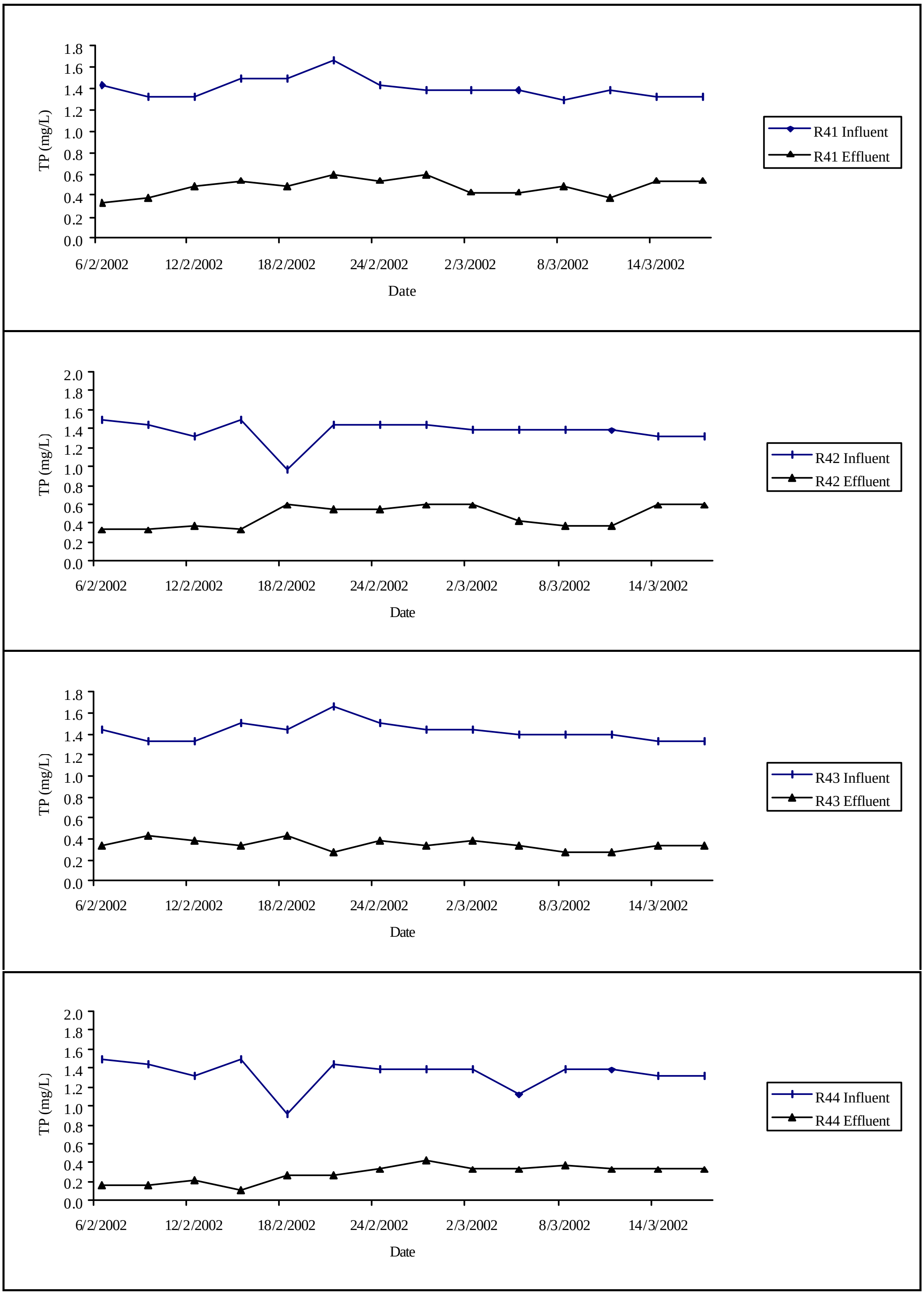


Figure 4.30 The influent and effluent TP concentrations in four reactors during Run IV

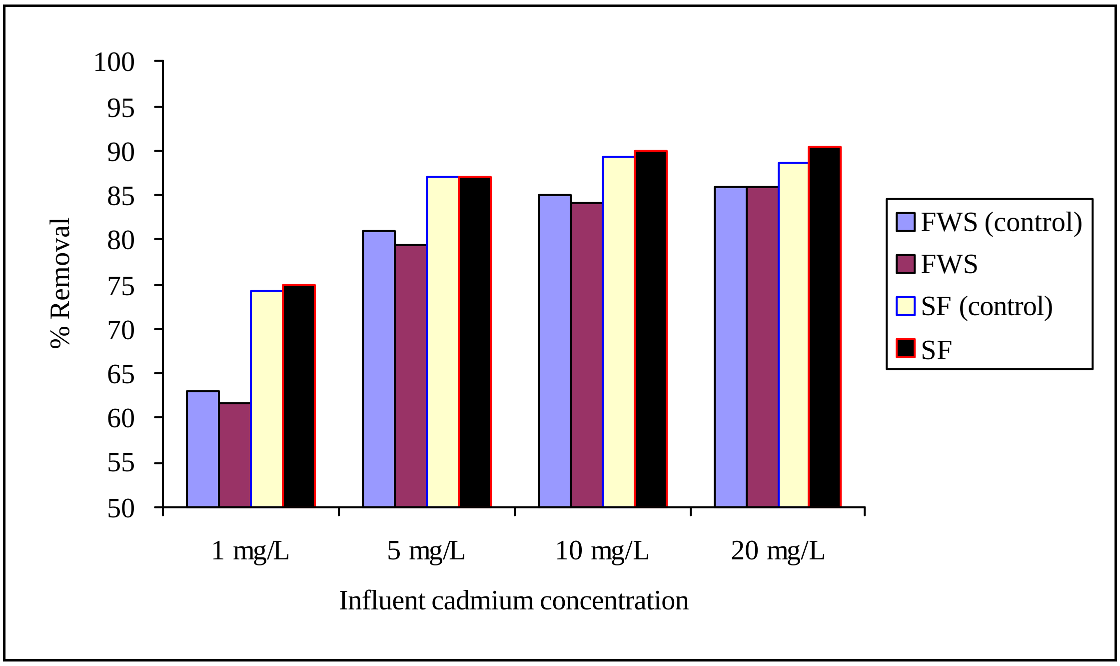


Figure 4.31 The mean removal efficiencies of TP during the four runs

sedimentation as wetland systems generally have long hydraulic retention tmes. nonsettling/colloidal solids are removed via various mechanisms that include: straining (if sand media is used); sedimentation and biodegradation (as a result of bacterial growth); and collisions (inertial and Brownian) with adsorption (van der waals forces) of other solids (plants, soil, sand and gravel media etc.). For SF, gravel media is an important component for the TSS removal (Lim and polprasert, 1996).

The influent and effluent TSS concentrations during the four experimental runs are shown in Figures 4.32-4.35. The overall mean removal efficiencies are shown in Figure 4.36.

Inflow and outflow rates were used to find the mass removal efficiencies of the wetland systems (shown in Appendix C). The average mass removal efficiencies during four experimental runs were in the range of 71.3-81.7%, 68.3-81.5%, 79.8-90.9%, and 77.8-89.5% for rectors R1, R2, R3, and R4, respectively. In the FWS, TSS concentrations were mainly removed by plants which physically retard the pathways of wastewater enhancing sedimentation of suspended solids. In the SF, the main mechanism was the media acting as filter beds as in filtration processes, thereby aiding physical removal of suspended solids through straining.

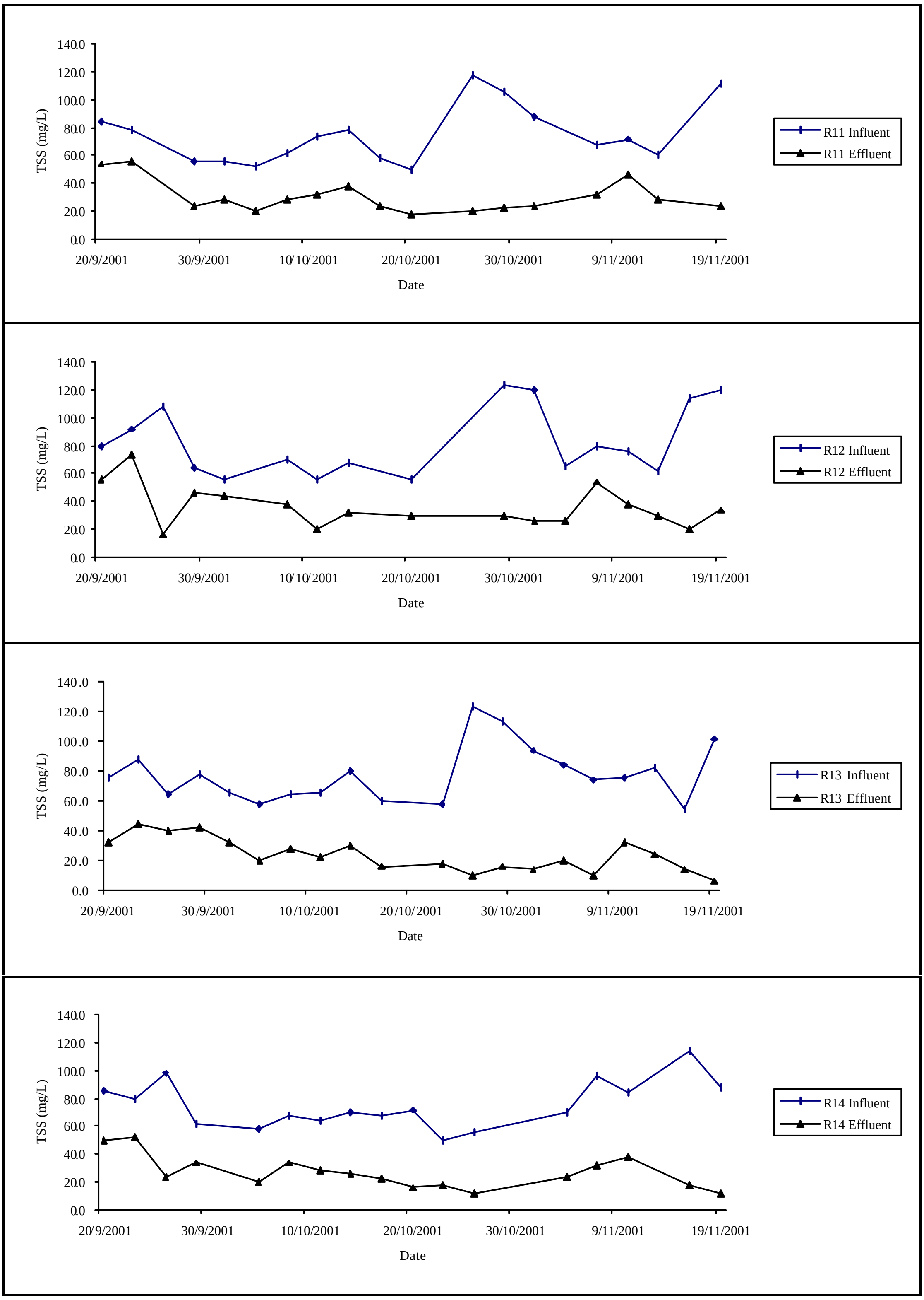


Figure 4.32 The influent and effluent TSS concentrations in four reactors during Run I

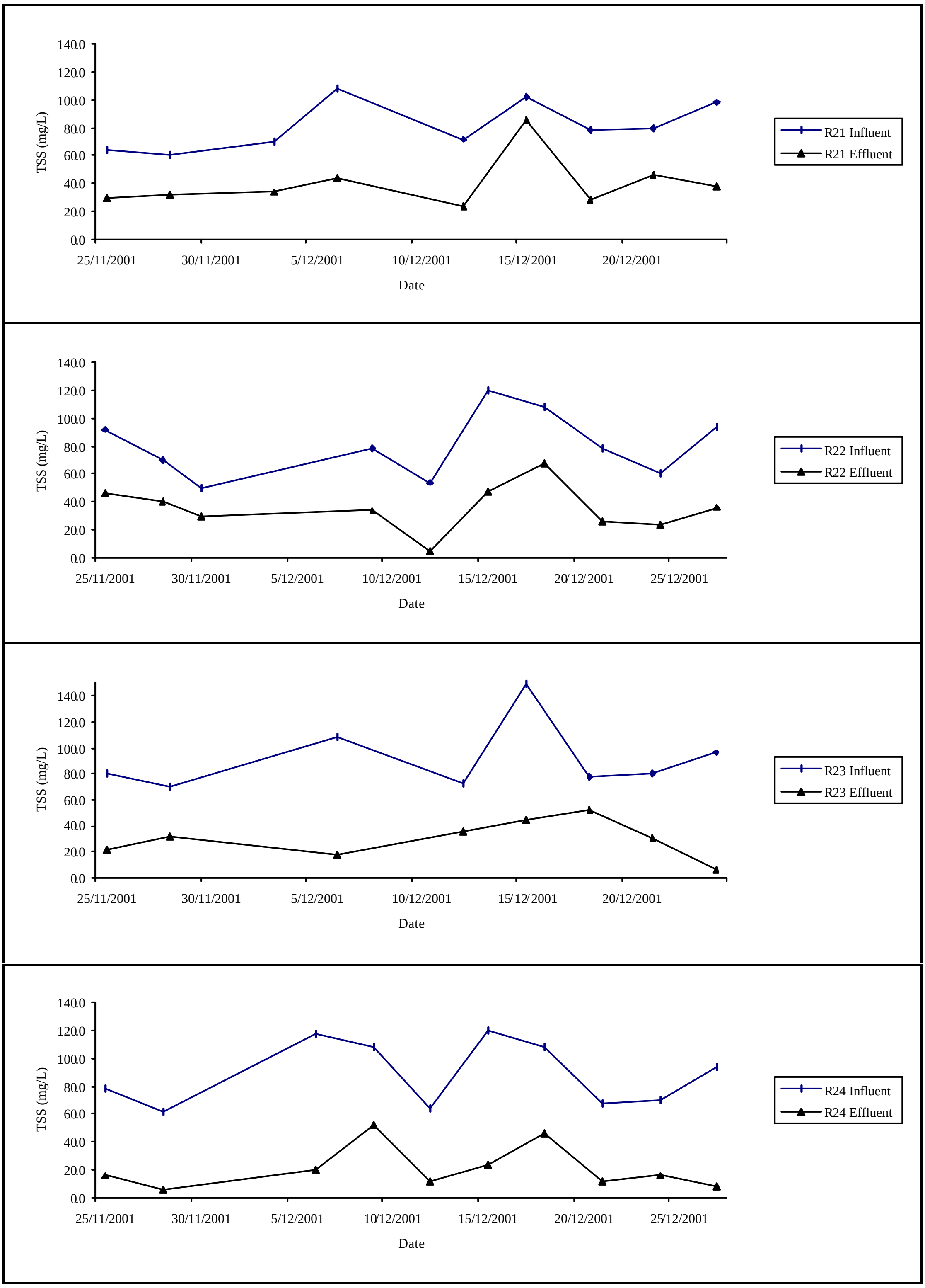


Figure 4.33 The influent and effluent TSS concentrations in four reactors during Run II

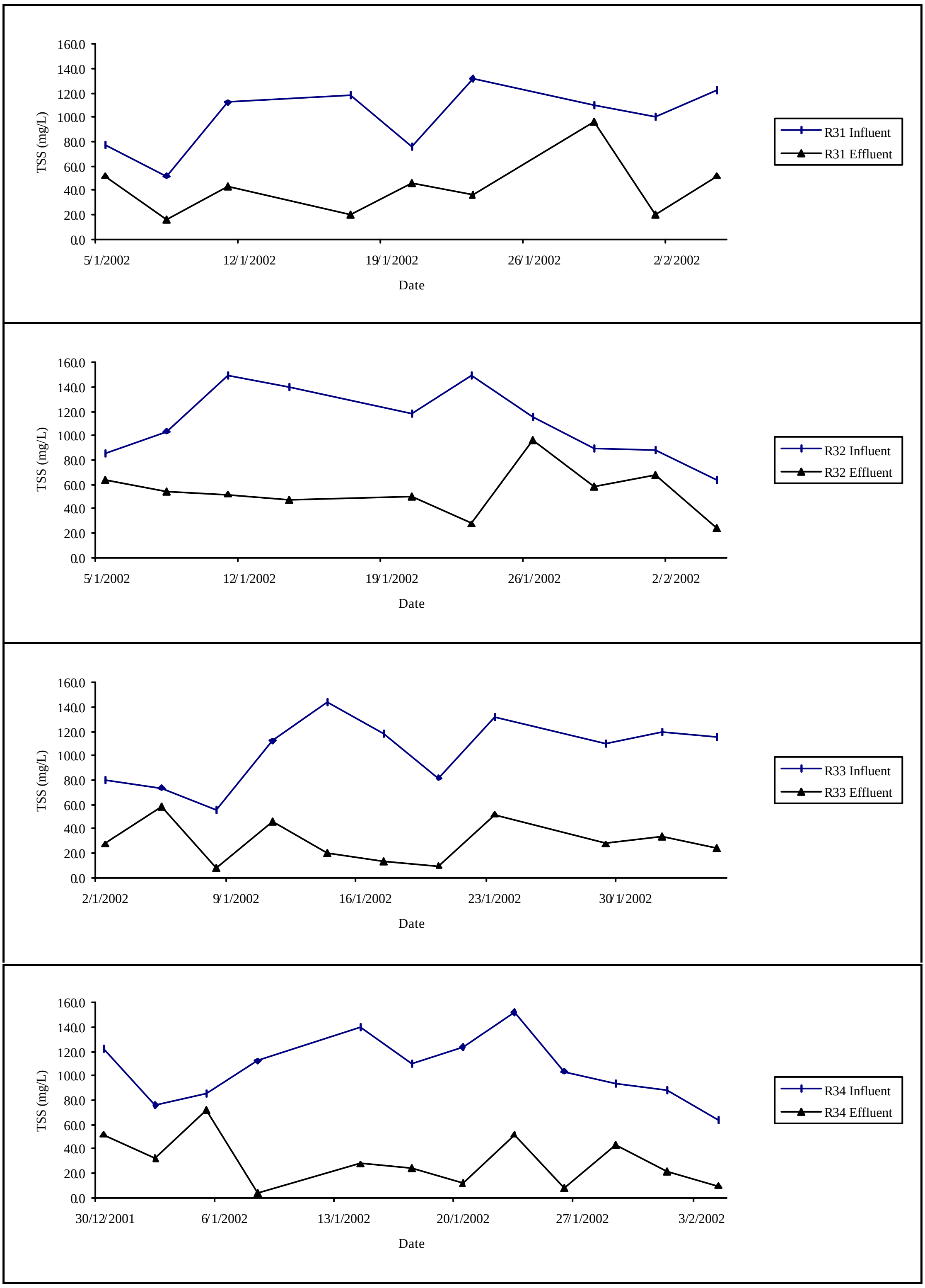


Figure 4.34 The influent and effluent TSS concentrations in four reactors during Run III

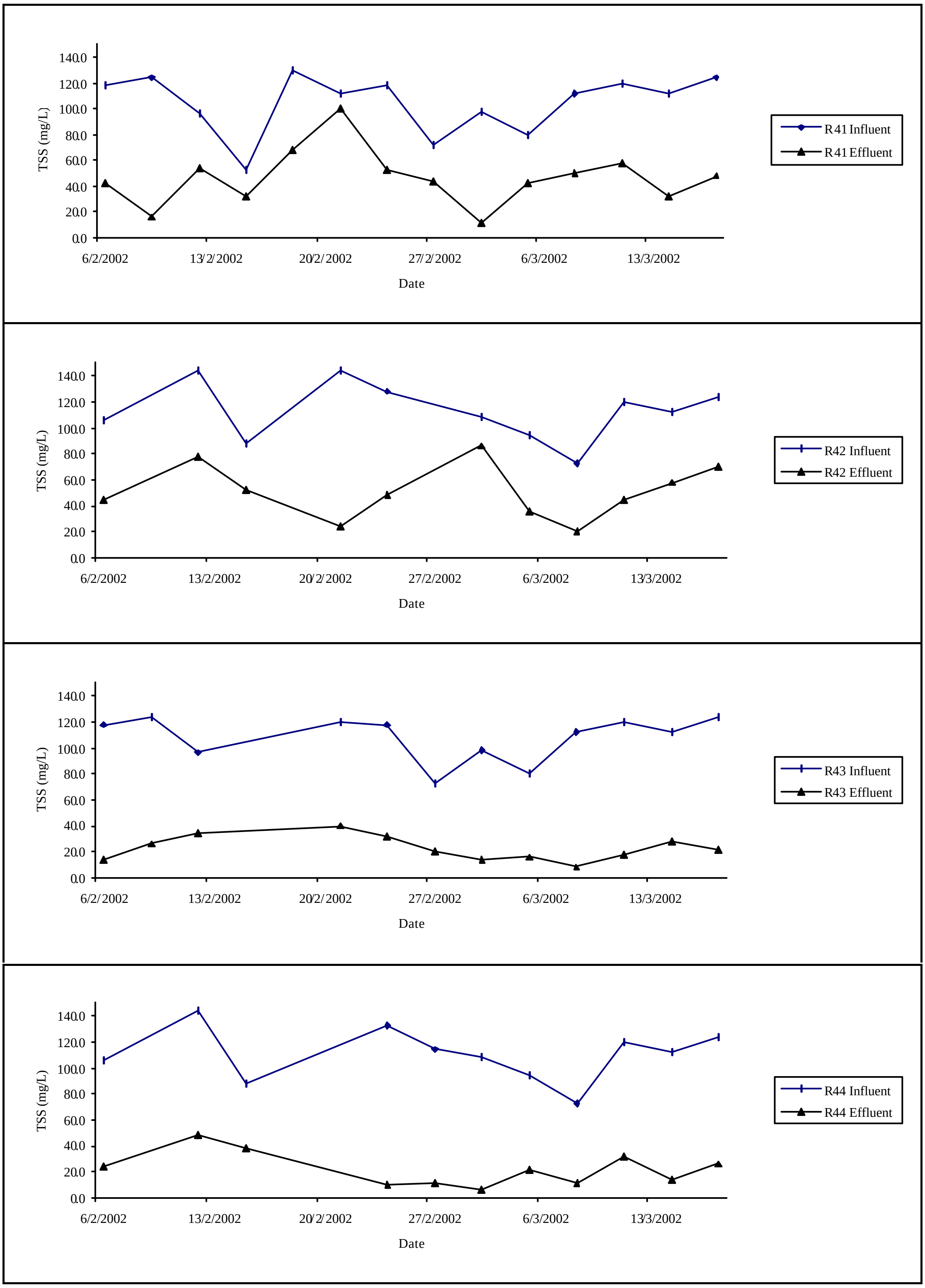


Figure 4.35 The influent and effluent TSS concentrations in four reactors during Run IV

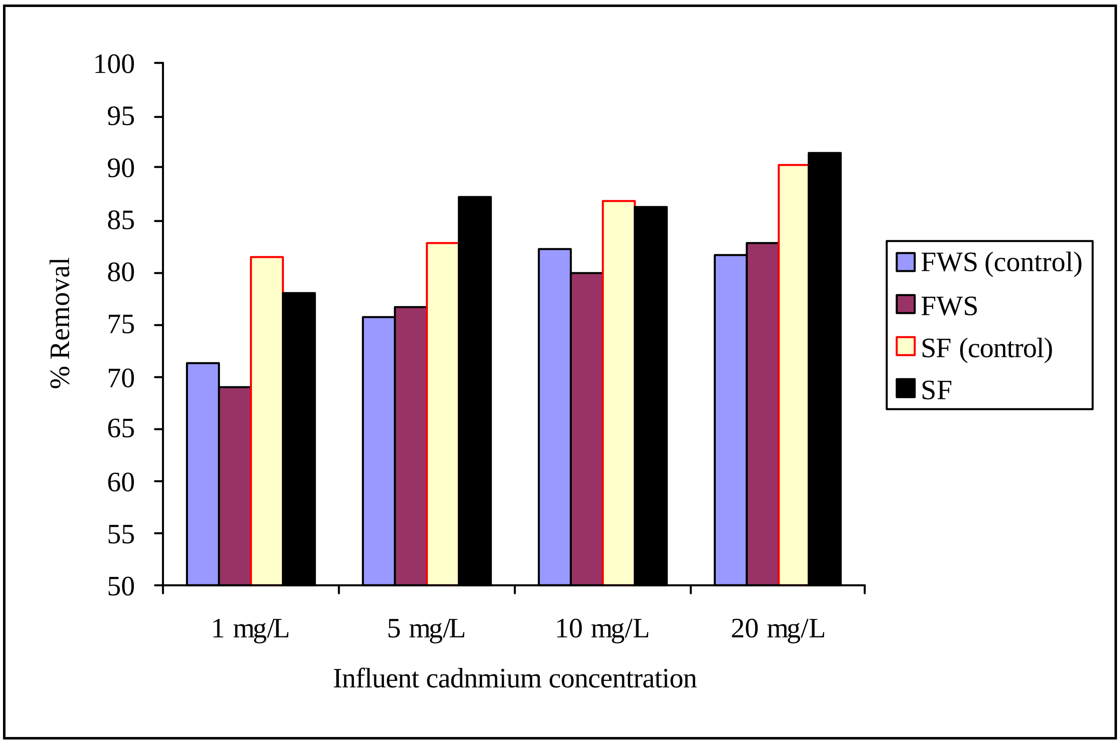


Figure 4.36 The mean TSS removal efficiencies during the four runs

4.2.8 Volatile suspended solid (VSS) removal

The results of VSS removal in the two wetland systems are shown in Figures 4.37-4.40 (Appendix B). The average mass removal efficiencies during four experimental runs were in the range of 51.6-76.8%, 50.1-72.5%, 62.9-84.0%, and 62.1-83.6% for reactors R1, R2, R3, and R4, respectively as shown in Figure 4.41.

From the results of mass removal efficiencies of COD, TKN, TP, TSS, and VSS, the statistical analysis was done as shown in Appendix D. There were no significant differences in removal efficiencies between control units and experimental units of both systems. Hence, the four cadmium concentrations at 1, 5, 10, and 20 mg/L were not affecting the treatment mechanisms for above parameters in wetland systems.

4.2.9 Cadmium removal

The cadmium chloride was used in the experiment, which has the solubility of 1,400 g/L of water at 20°C and 1,500 g/L of water at 100 °C(King, 1994).

Removal of cadmium in wetlands may occur through a number of processes, including plant uptake and soil adsorption (binding to soil particles).

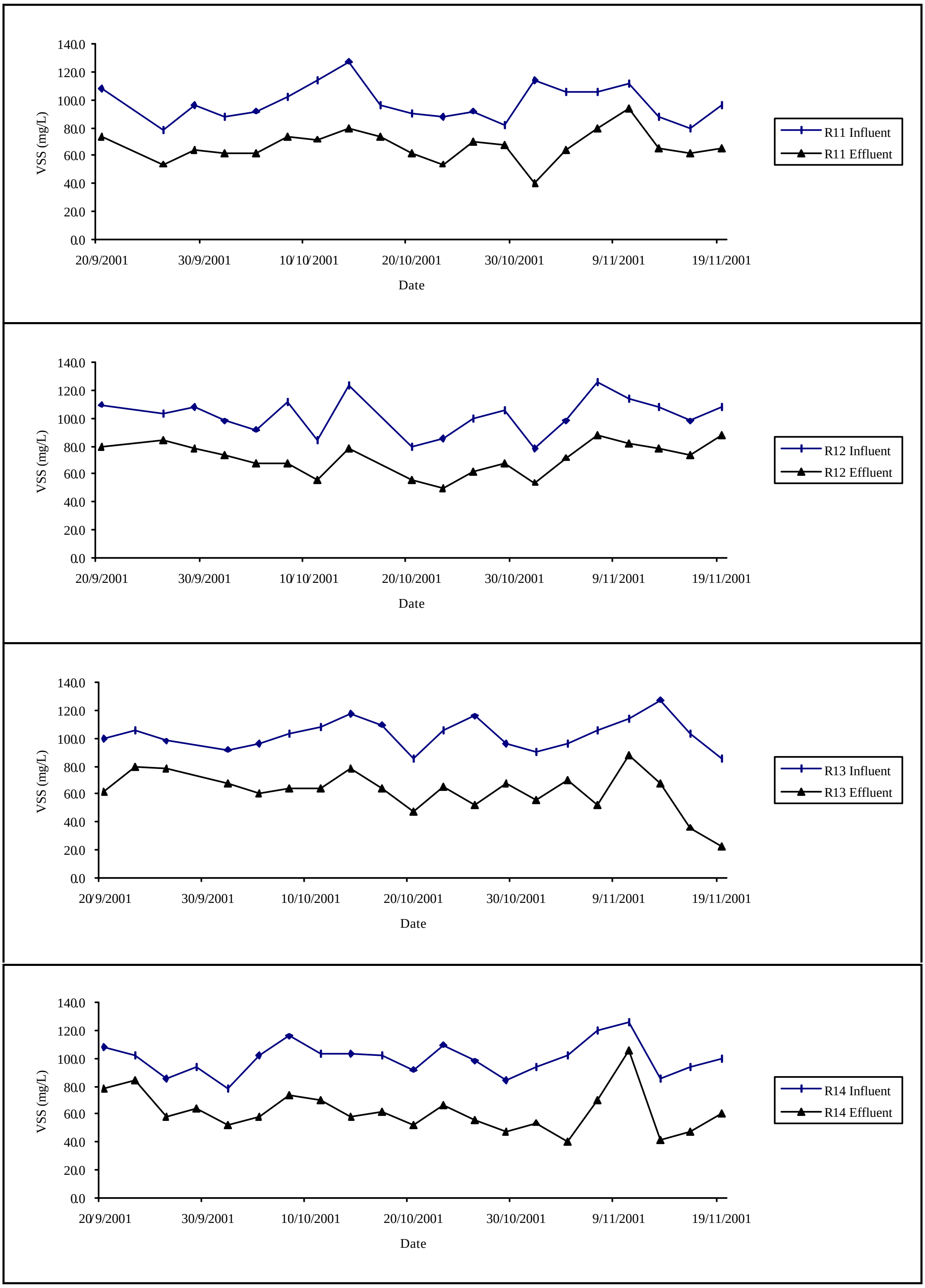


Figure 4.37 The influent and effluent VSS concentrations in four reactors during Run I

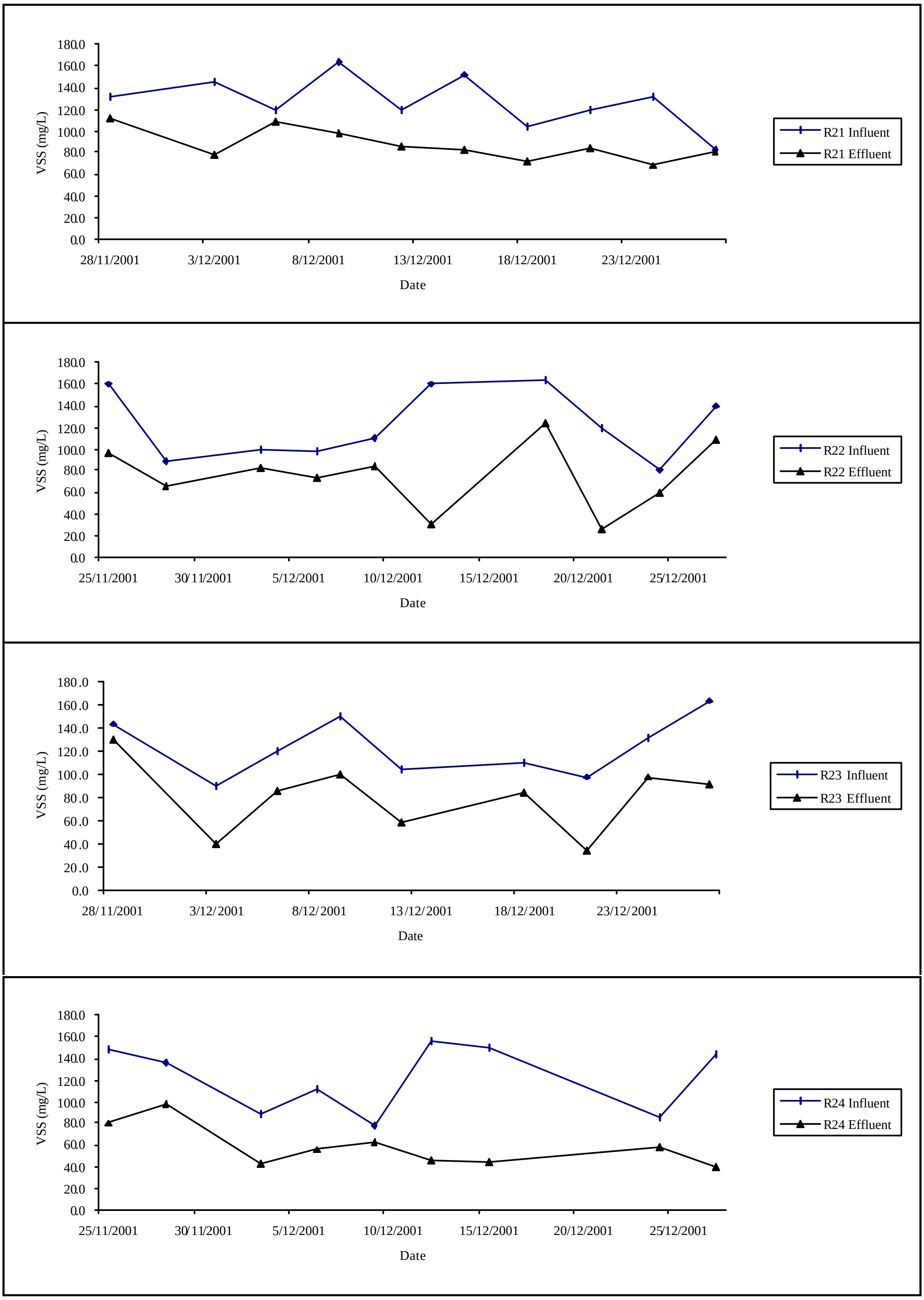


Figure 4.38 The influent and effluent VSS concentrations in four reactors during Run II

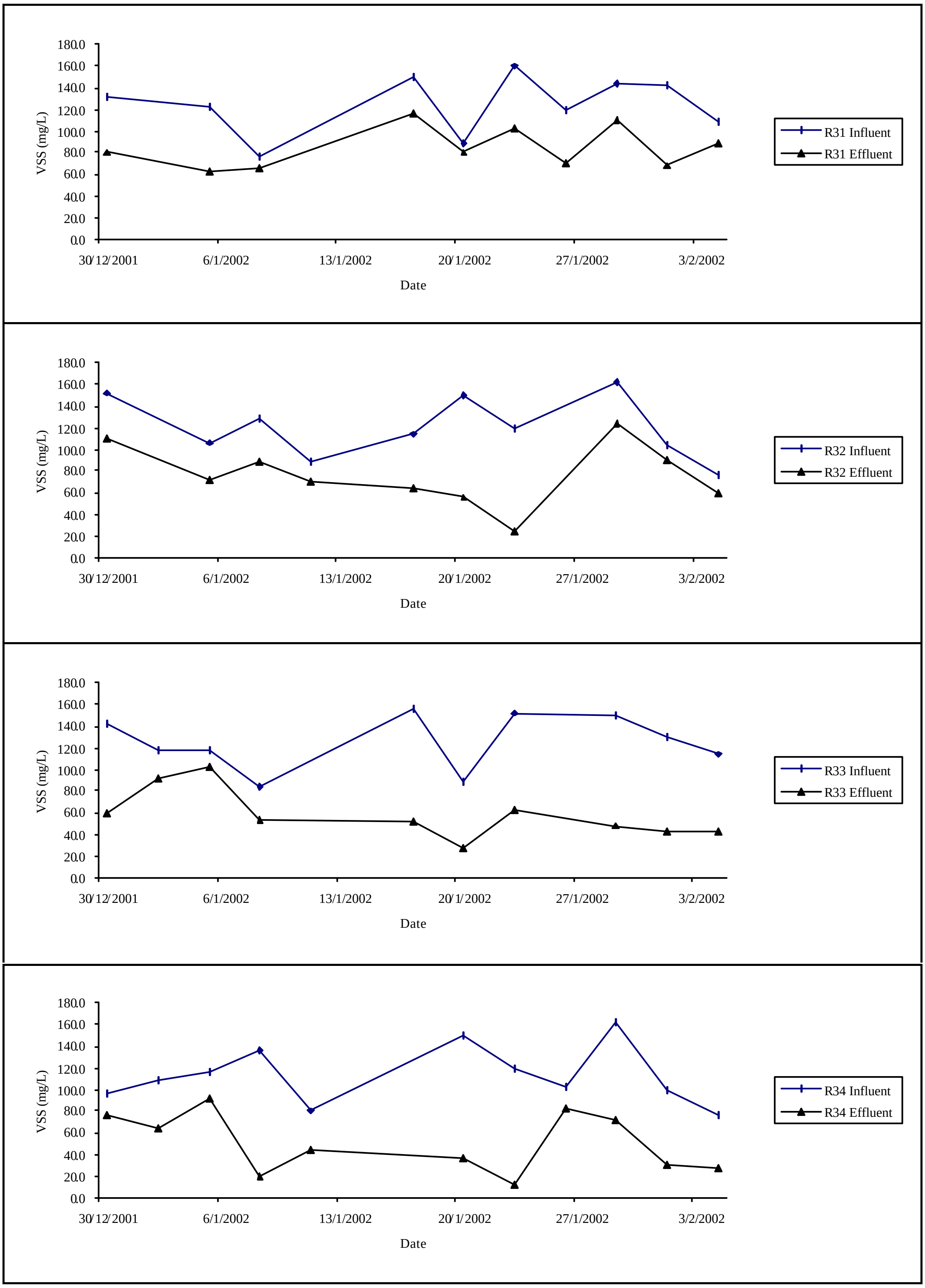


Figure 4.39 The influent and effluent VSS concentrations in four reactors during Run III

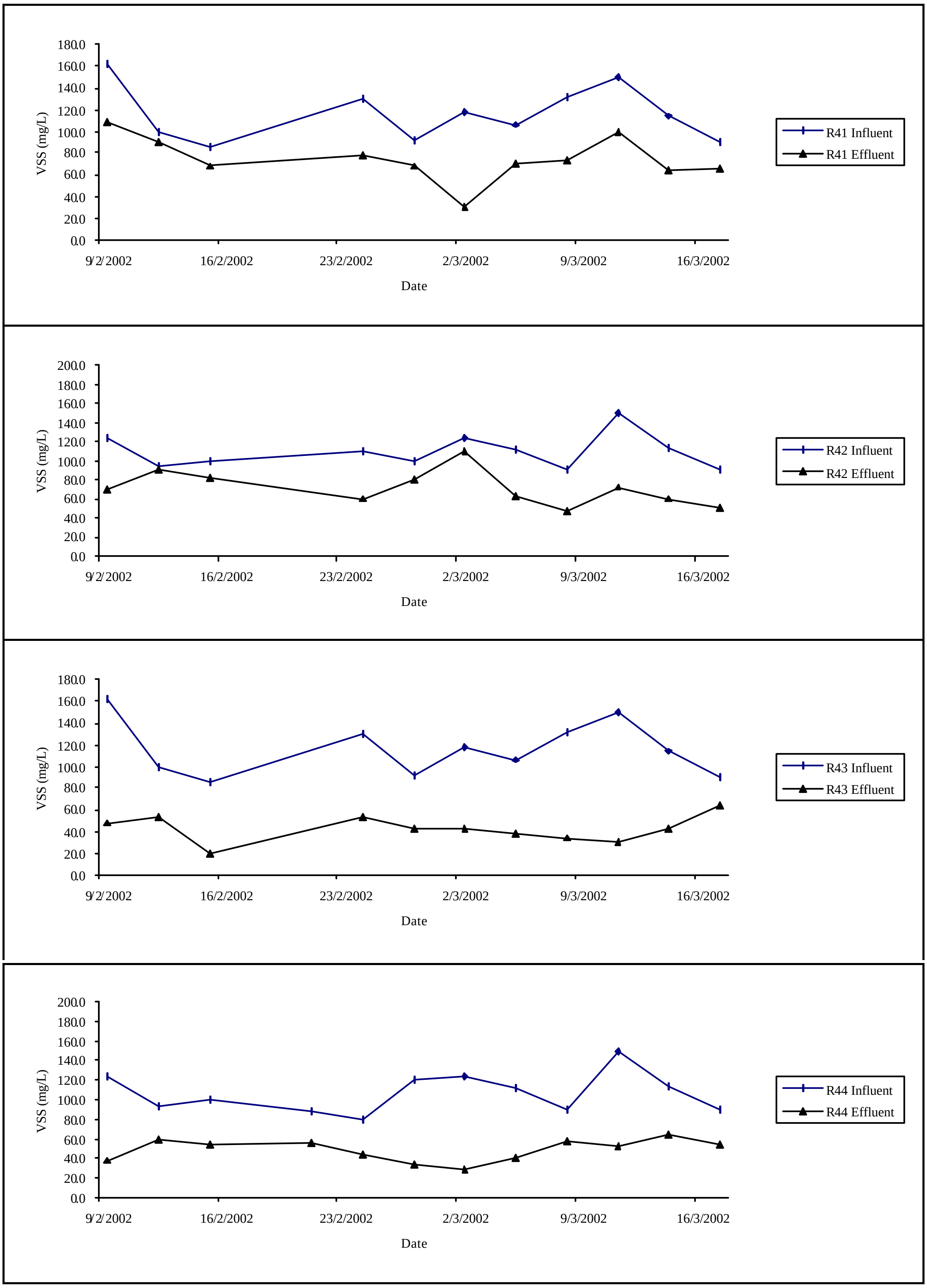


Figure 4.40 The influent and effluent VSS concentrations in four reactors during Run IV

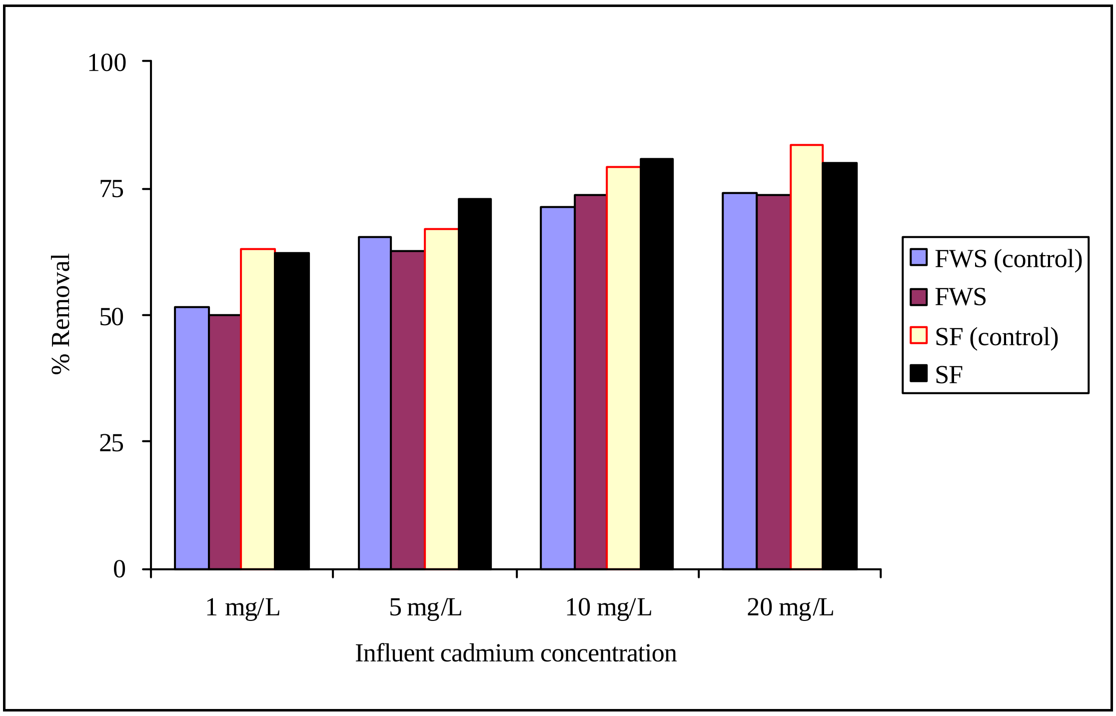


Figure 4.41 The mean VSS removal efficiencies during the four runs

Chemical reactions between substances, especially metals, can lead to their precipitation from the water column as insoluble compounds.

Figures 4.42-4.45 show the influent and effluent of cadmium concentrations during each run. The overall results indicate very effective removal of cadmium in the wetland systems, the detailed data are given in Appendix B. The removal efficiencies of cadmium are shown in Figure 4.46. Although the lab-scale control units were fed only synthetic wastewater, small amounts of cadmium were present in the influent which could be due to contamination from the constituents of synthetic wastewater and tap water.

High removal efficiencies were obtained in both wetland systems. The removal efficiencies of subsurface flow wetland were slightly higher than free water surface wetland system. The average removal efficiencies of free water surface wetland were 98.6%, 99.5%, 99.4% and 99.6% for Run I, II, III, and IV, respectively. For subsurface flow wetland, the average removal efficiencies were about 99.3%, 99.8%, 99.9%, 99.9% in Run I, II, III, and IV, respectively.

For free water surface wetland system, the mean effluent concentrations of Cd were 0.02, 0.05, 0.15, and 0.16 mg/L, during Run I, II, III, and

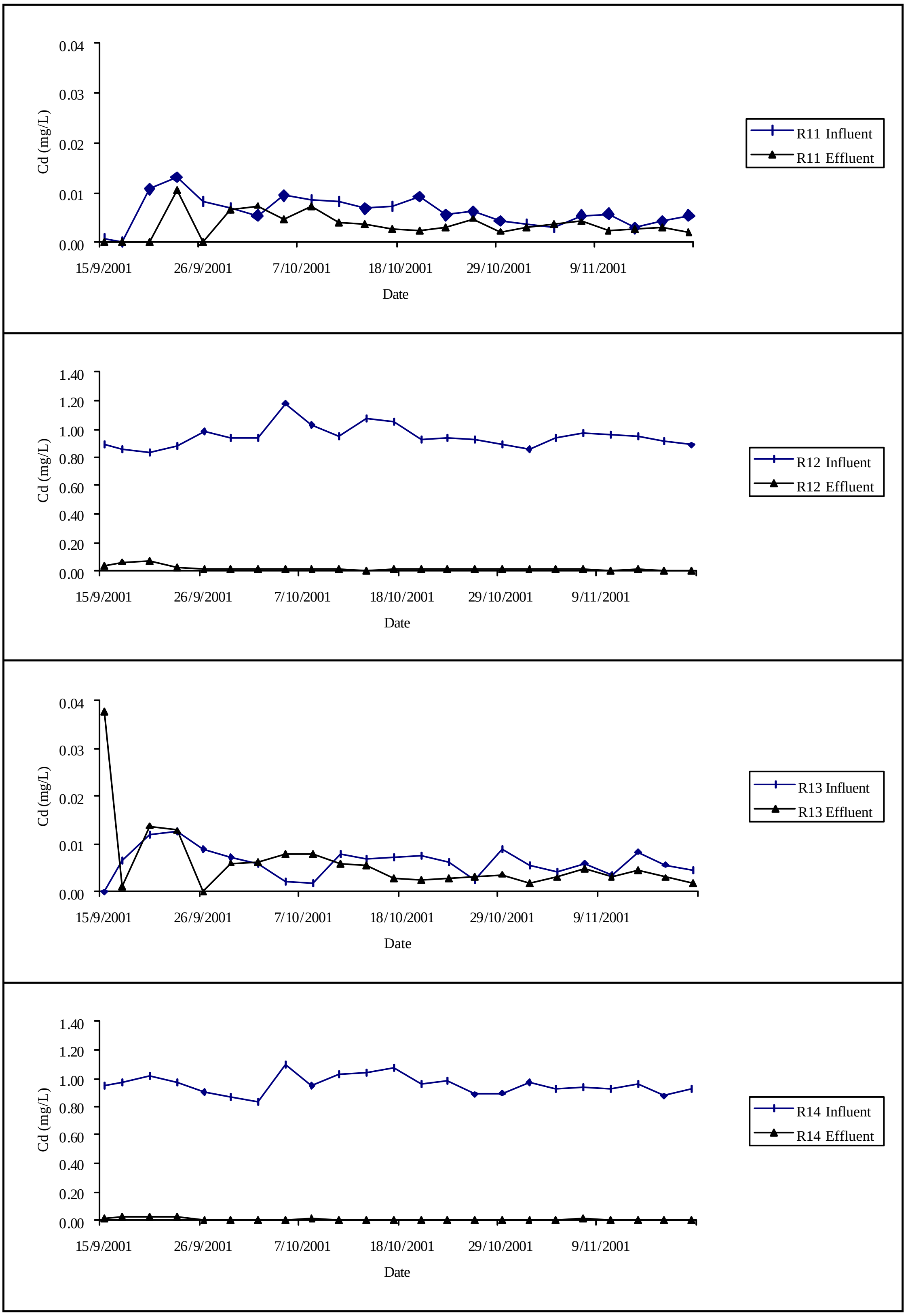


Figure 4.42 The Influent and effluent Cd concentrations in four reactors during Run I

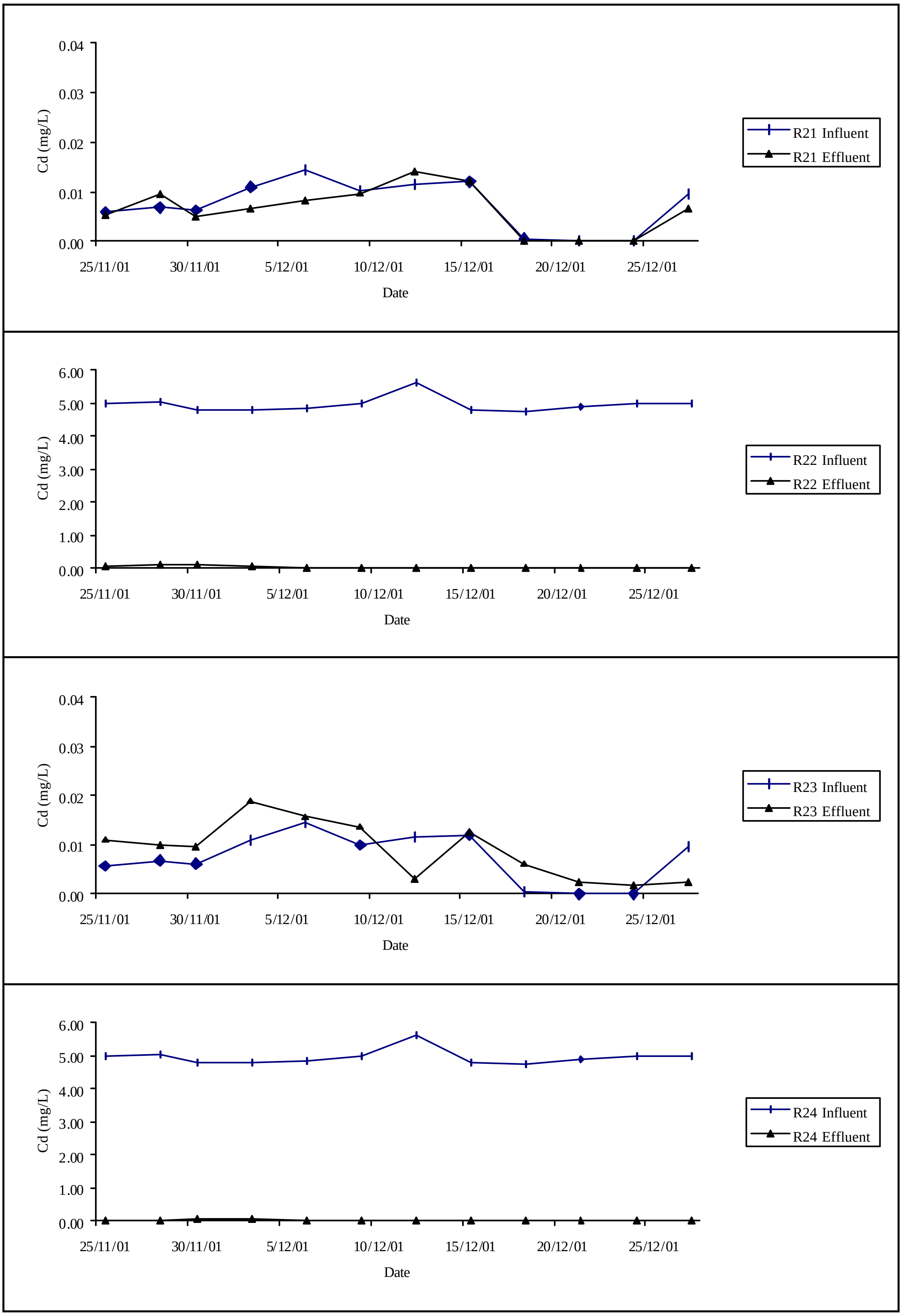


Figure 4.43 The Influent and effluent Cd concentrations in four reactors during Run II

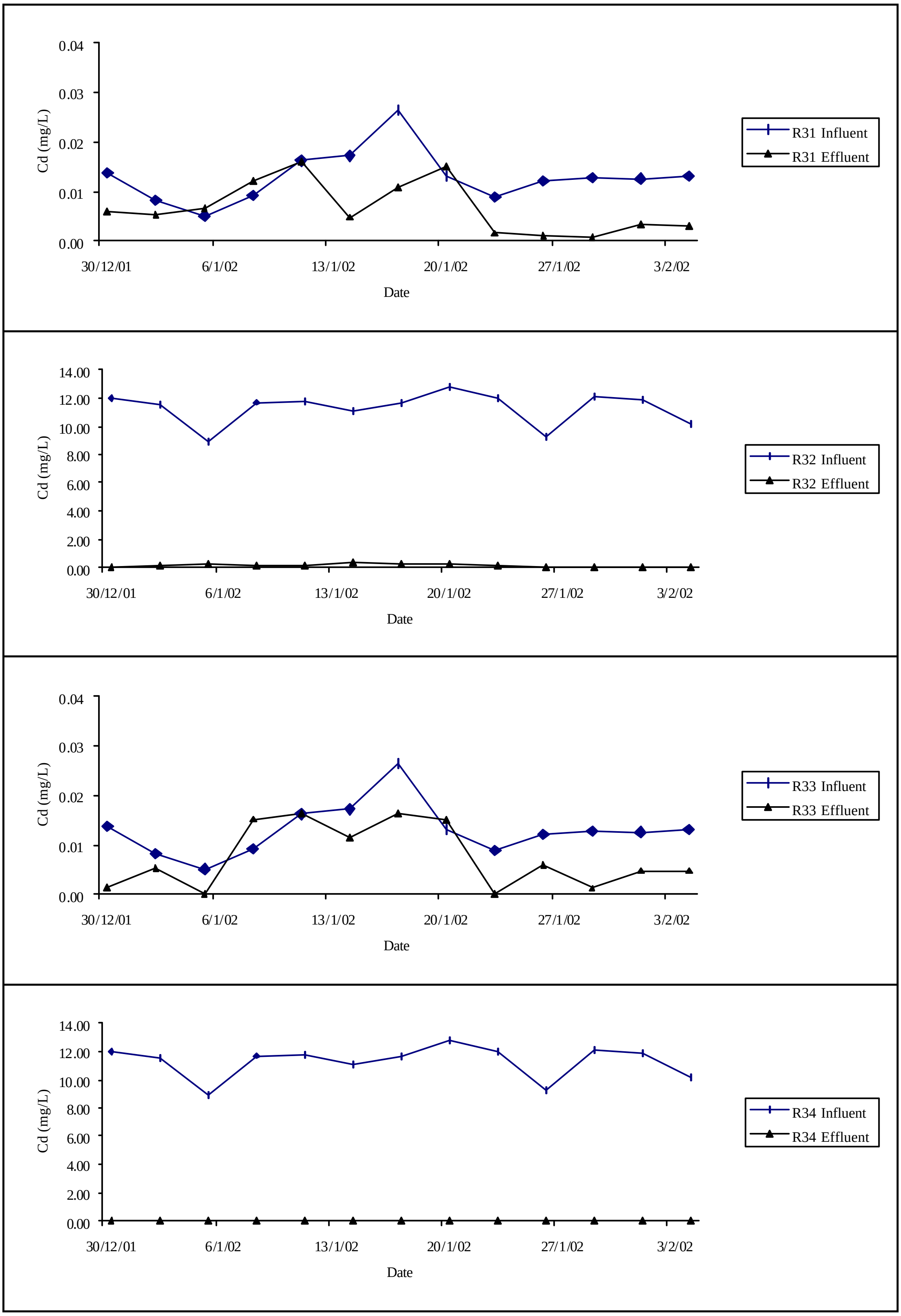


Figure 4.44 The Influent and effluent Cd concentrations in four reactors during Run III

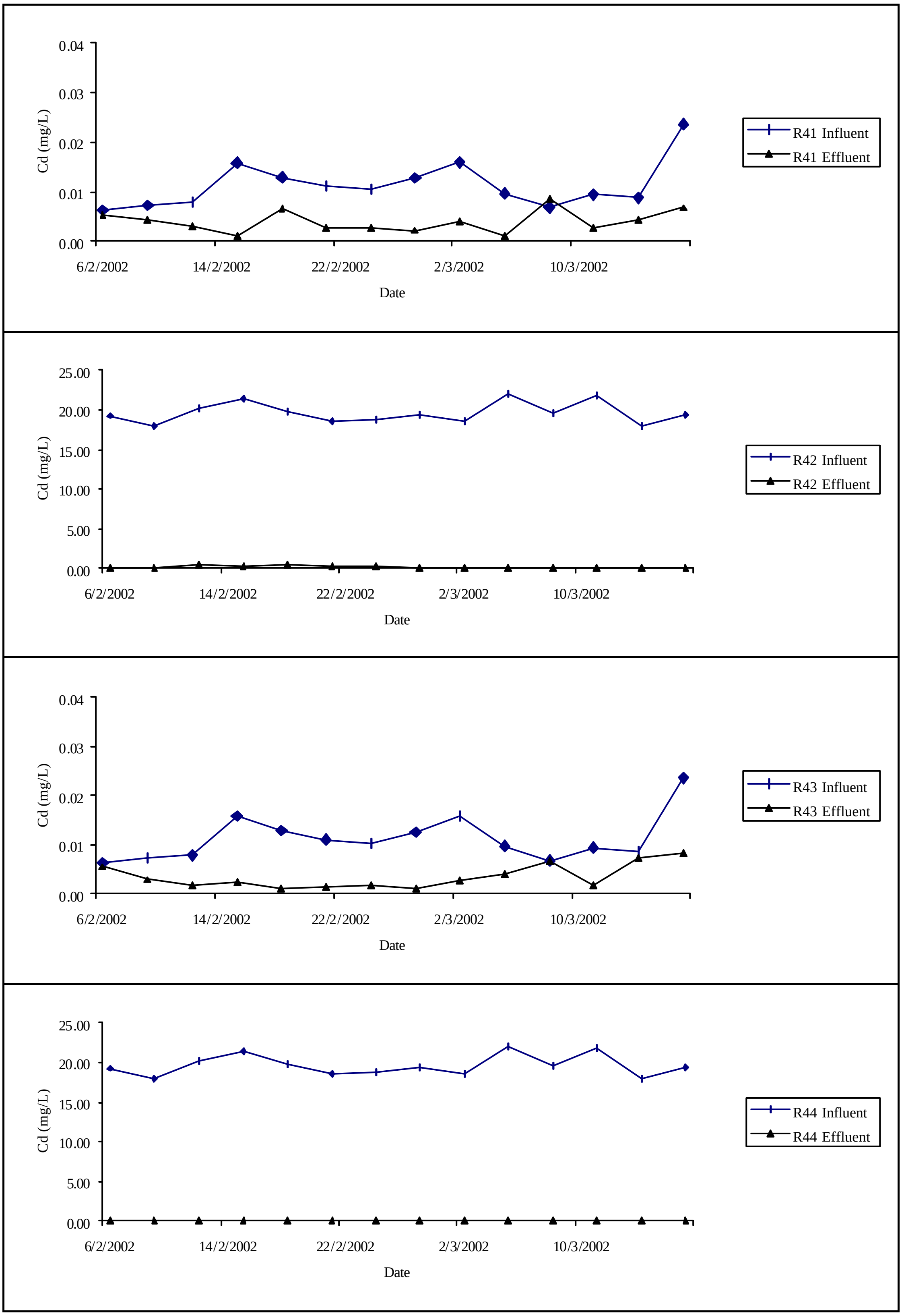


Figure 4.45 The Influent and effluent Cd concentrations in four reactors during Run IV

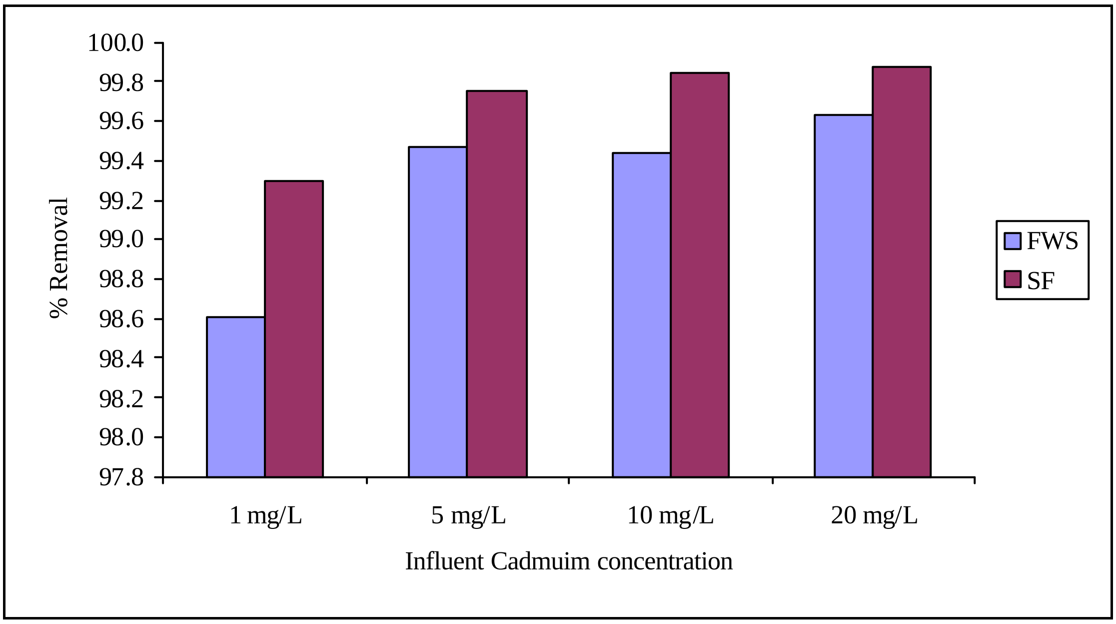


Figure 4.46 The average Cd removal efficiencies during four runs

IV, respectively. While in subsurface flow wetland system, they were 0.01, 0.02, 0.04, and 0.06 mg/L, during Run I, II, III, and IV, respectively. These results were compared with the industrial effluent standards in Thailand (Ministry of Science, Technology and Environment, 1996). The average effluent concentrations of cadmium during Run I and II of subsurface flow wetland were below the industrial effluent standards (0.03 mg/L). However, in Run III, and IV, the average effluent concentrations were higher than 0.03 mg/L. While for free water surface wetland, the average effluent concentrations of cadmium were in general higher than the industrial effluent standards during Run II, III and IV.

Appendix C shows the calculations of mass inflow and outflow rates of cadmium. For free water surface wetland, the total amounts of influent Cd in each run were 1,957.49, 5,347.69, 13,217.50, and 24,692.40 mg/d for Run I, II, III, and IV, respectively. The total amounts of cadmium effluent were 27.21, 28.41, 74.32, and 90.76 mg/d for Run I, II, III, and IV, respectively. For subsurface flow wetland, the total amounts of influent Cd were 592.25, 1,604.91, 3,965.25,and 7,407.72 mg/d for Run I, II, III, and IV, respectively. The total amounts of cadmium effluent were 4.13, 4.04, 6.21, and 9.92 mg/d for Run I, II, III, and IV, respectively. The amount of cadmium in the effluent was 0.5% and 0.18% of the total influent cadmium for free water surface and subsurface flow wetland, respectively.

4.2.10 Cadmium removal in soil

Wetland soils are potentially effective traps, or sinks for metals, due to the relative immobility of most metals in wetland soils. Cadmium form nearly insoluble compounds with sulfides under anaerobic conditions in wetland soils.

Soil samples were collected along reactor lengths at the distances of 0.5, 1.5, 2.5, and 3.5 m from the inlet, and at the depths of 15, and 25 cm of the soil bed. Figures 4.47-4.48 show the cadmium concentrations in the soil during the four runs. Details are shown in Appendix E.

At the end of Run IV, the total accumulation of cadmium in soil could be determined. The results showed that the concentrations were very high near the inlet and decreased with the distances along the reactor lengths for the both wetland systems. The cadmium concentrations in soil at the different depths are shown in Figures 4.49-4.50. Concentrations at the depth of 15 cm were higher than at the depth of 25 cm. It may be because of the fact that most of cadmium could be adsorbed by soil. Figures 4.51-4.52 show total mass of cadmium accumulations (g) in soil in the two wetland systems during the experimental period.

4.2.11 Cadmium removal by plant uptake

Plant uptake rates and tolerance of metals varies considerably among plant species. Some terrestrial plant species are known to be capable of storing high concentrations of metals in roots and other issues. Metals may also tend to accumulate on the root surfaces, rather than being absorbed into the plant (Sundaravadivel and Vigneswaran, 2001).

Cattail plants could uptake Cd from the roots to stems and leaves issues. At the end of experiments, the cadmium accumulation was determined in each part of plants. Table 4.2 shows mass density and moisture contents of cattail plants in four reactors at the end of Run IV. Figures 4.53-4.54 show the total cadmium uptake by the plants at the end of Run IV. Raw data is shown in Appendix F. The results show that cattail plants could remove some cadmium from wastewater through uptake by roots, stems, and leaves. Total cadmium accumulation in plants were about 2.4% and 4.0 % for free water surface wetland and subsurface flow wetland systems, respectively. Sintumongkolchai (1996) reported on the removal of cadmium in free water surface system (FWS) were 1-6% by plant uptake.

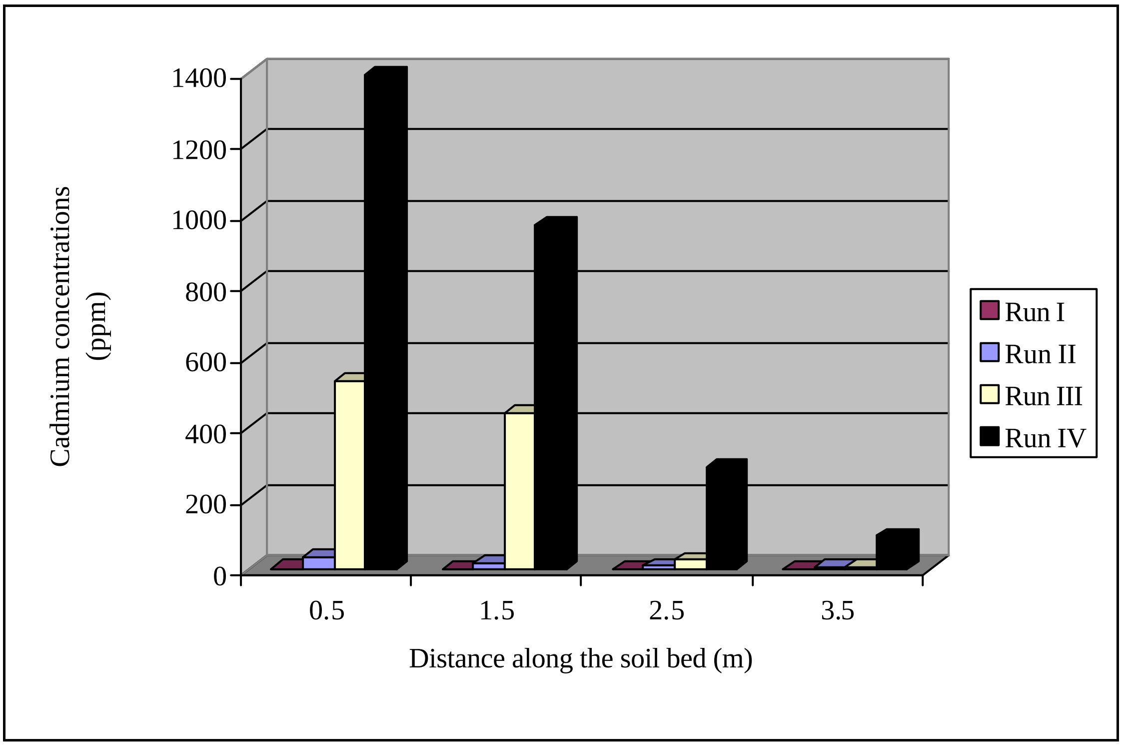


Figure 4.47 Cadmium concentrations in soil at the distances of 0.5, 1.5, 2.5 and 3.5m along the soil bed of free water surface wetland system

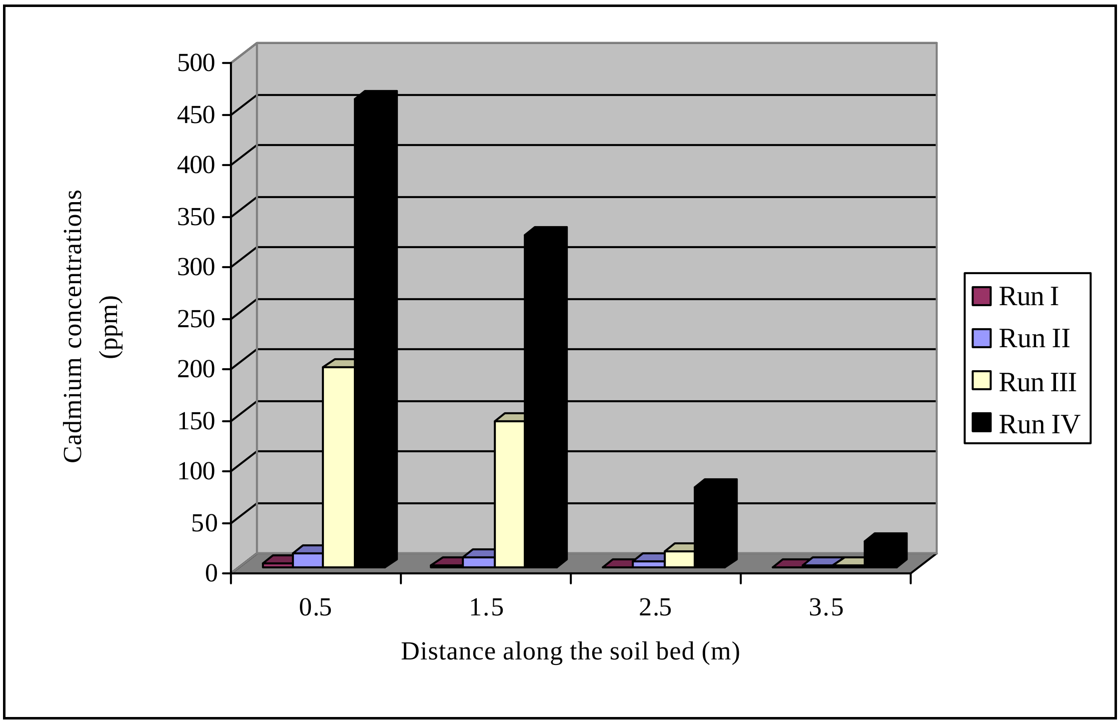


Figure 4.48 Cadmium concentrations in soil at the distances of 0.5, 1.5, 2.5 and 3.5m along the soil bed of subsurface flow wetland system

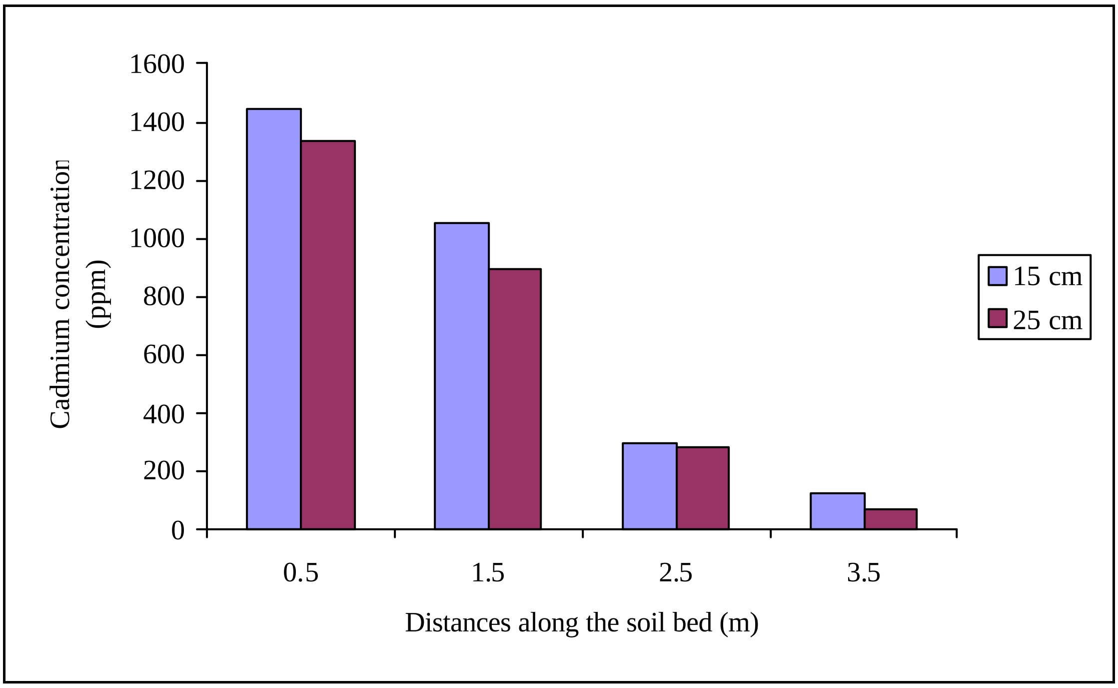


Figure 4.49 Cadmium concentrations in soil during the experimental period at the depth of 15 and 25 cm in free water surface wetland system

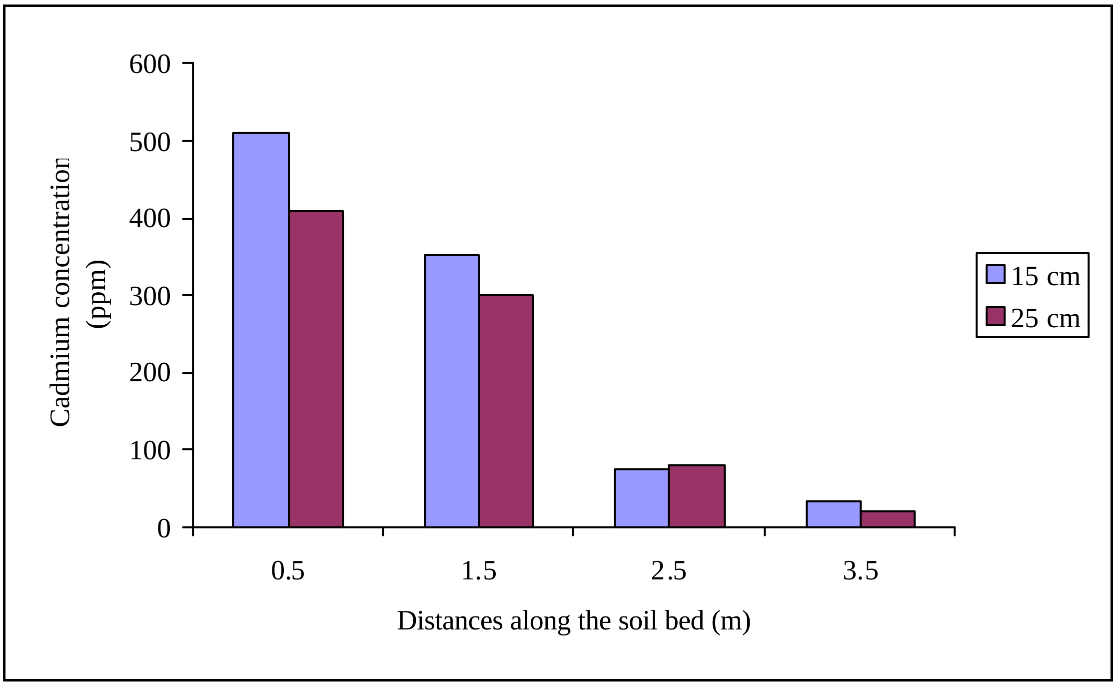


Figure 4.50 Cadmium concentrations in soil during the experimental period at the depth of 15 and 25 cm in subsurface flow wetland system

Figures 4.51-4.52 show that cadmium accumulation in soil increased from Runs I –IV.

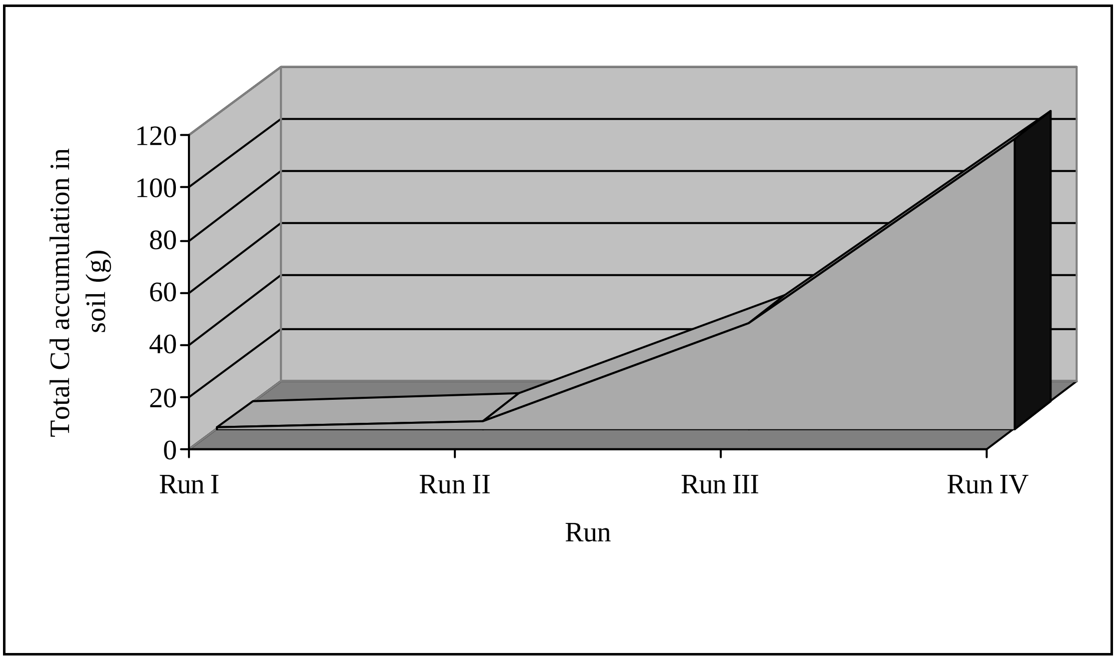


Figure 4.51 Total cadmium accumulation in soil during four experimental runs in free water surface wetland system

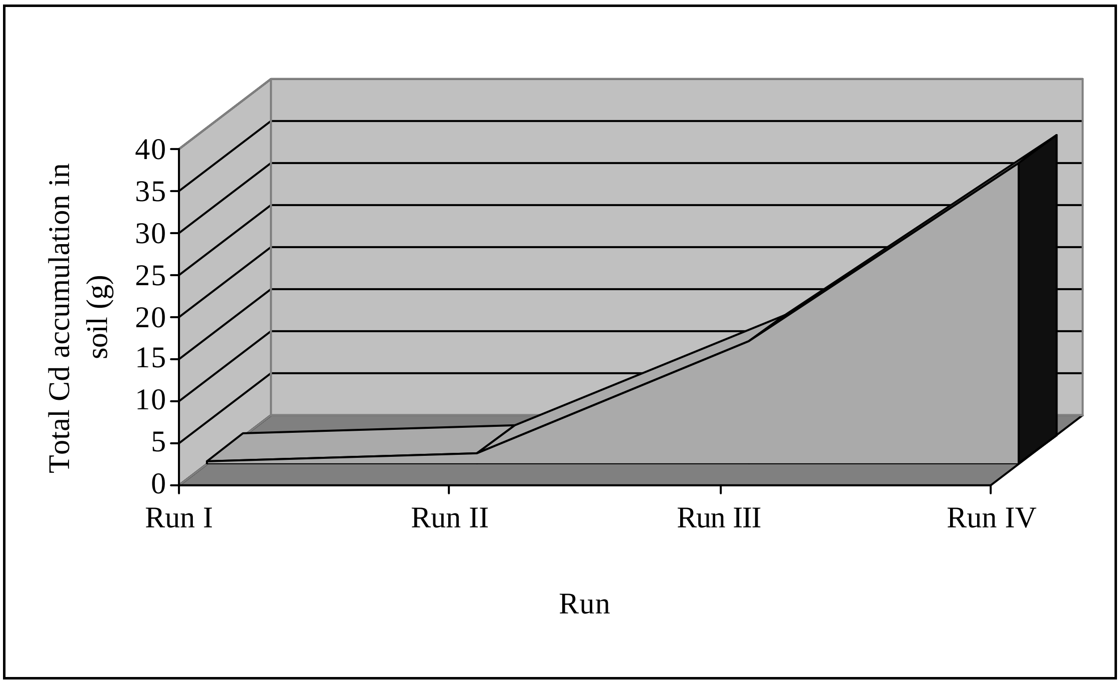


Figure 4.52 Total cadmium accumulation in soil during four experimental runs in subsurface flow wetland system

Table4.2 Mass density and moisture contents of the cattail plants in four wetland units

Reactors	Wet Weight(kg/m^2)	Moisture (%)
R1	24.0	54.64
R2	19.8	53.49
R3	12.6	48.80
R4	13.0	45.03

It can be seen from Table 4.2, the yield of cattail plants in SF was less than FWS. The reasons could be that the water in SF was not enough, and the cooler temperatures in the winter seasons were not suitable for the cattail growth.

Figures 4.53-4.54 show the profiles of Cd accumulation in the cattail plants along the reactor lengths. It can be seen that the cadmium concentrations were very high in the plants near the inlet and decreased with the distances along the soil bed.

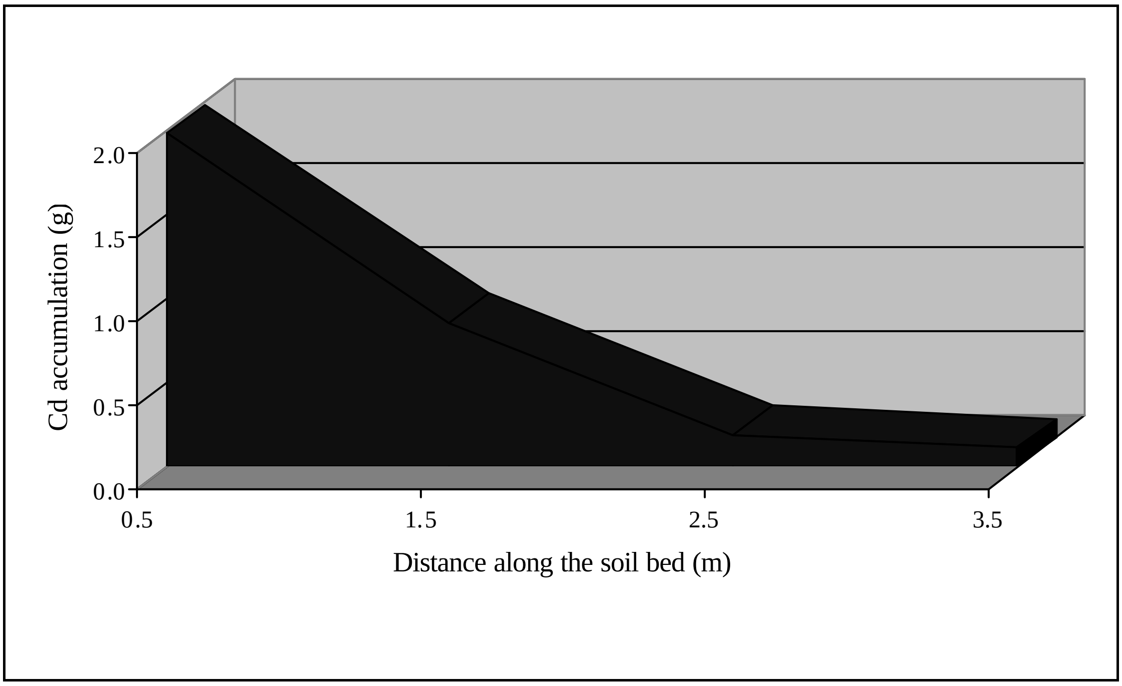


Figure 4.53 Cadmium profiles in plants at the end of Run IV of free water surface wetland system

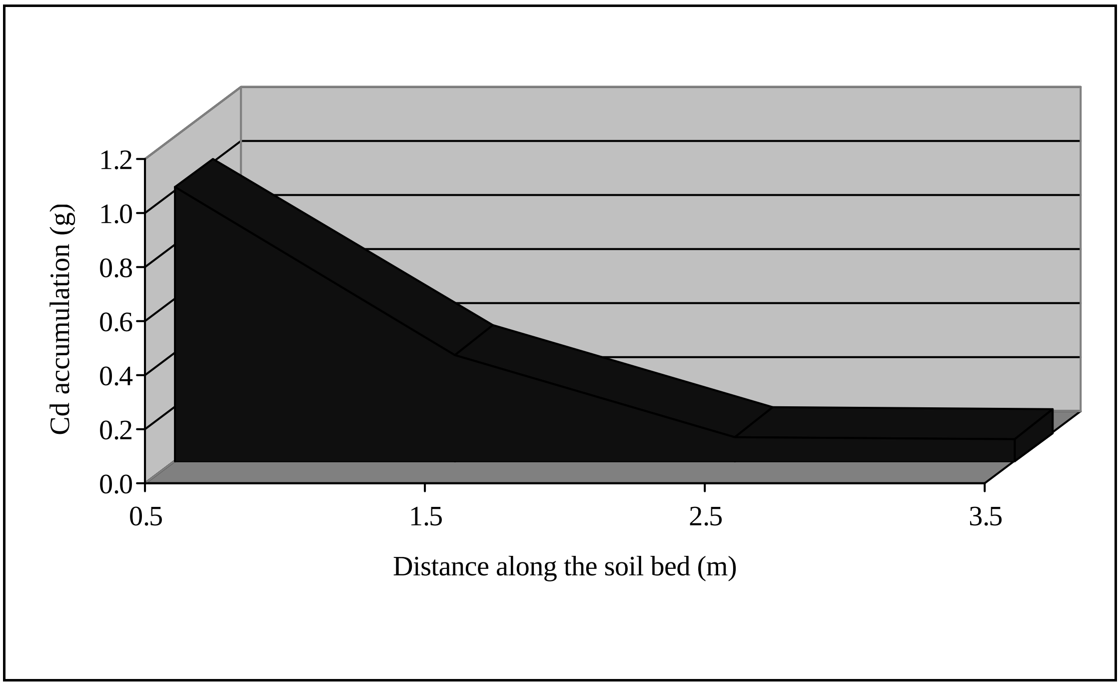


Figure 4.54 Cadmium profiles in plants at the end of Run IV of subsurface wetland system

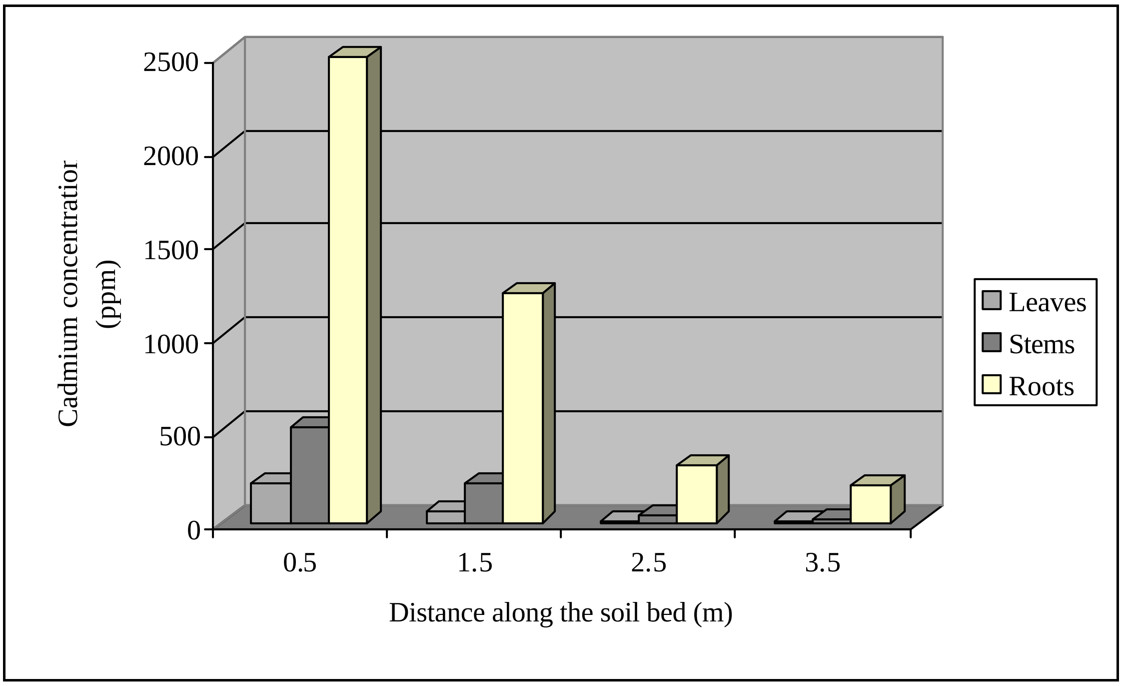


Figure 4.55 Cadmium in plants at the distances of 0.5, 1.5, 2.5 and 3.5m along the soil bed of free water surface wetland system

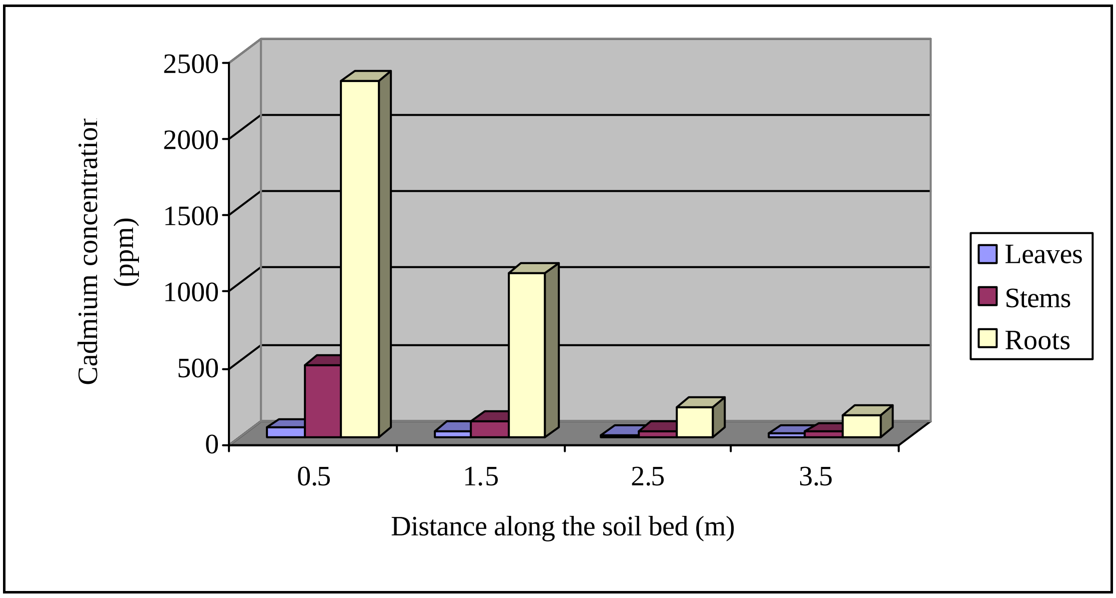


Figure 4.56 Cadmium in plants at the distances of 0.5, 1.5, 2.5 and 3.5m along the soil bed of subsurface flow wetland

Cadmium uptake by each part of the plants until the end of Run IV are shown in Figures 4.55-4.58. It can be seen cadmium from these figures that cadmium uptake by the roots were higher than the stems and leaves in both wetland systems.

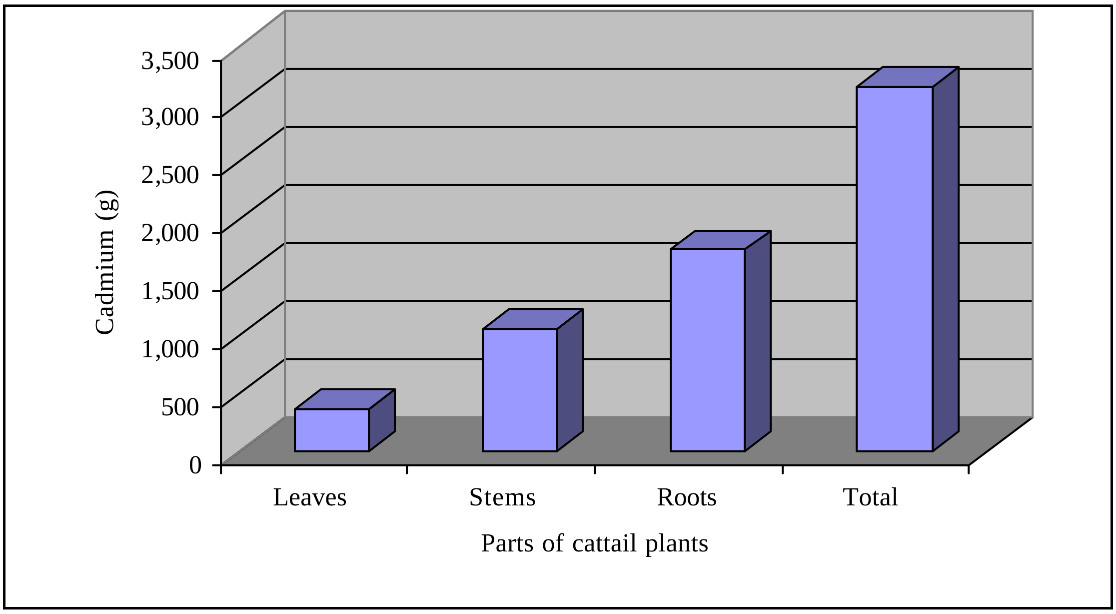


Figure 4.57 Total cadmium in each part of plants at the end of experiment of free water surface wetland system

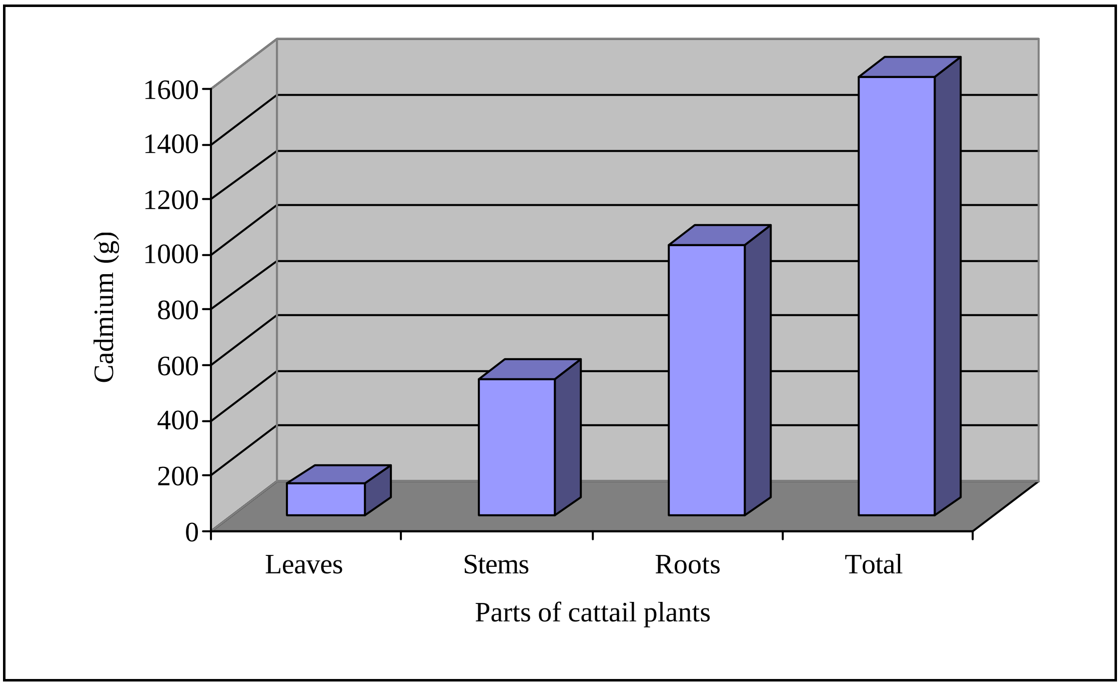


Figure 4.58 Total cadmium in each part of plants at the end of experiment of subsurface flow wetland system

The cadmium uptake in roots was about 55.2% and 61.6%of the total plant uptake in free water surface and subsurface flow wetland systems, respectively. About 33.3% and 31.2% of cadmium was uptaken in stems in free water surface and subsurface flow wetland systems, respectively. Cadmium uptake in leaves of cattail plants were only about 11.5% and 7.2% in free water surface and subsurface flow wetland systems, respectively. As the plant roots contain high levels of organic acids and amino acids, which can chelate many metals, they can uptake cadmium more than other parts of cattails (Thayalakumaran, 1994). As the cattail plants could uptake upto 3200 and 2800 ppm of cadmium for FWS and SF, respectively, they may be classified as the heavy metals'hyperaccumulators. However, as uptake by roots accounted for more 50% of influent Cd loading, it is difficult to use phytoremediation for these plants after they are used for heavy metals'removal in wetlands.

For removal of cadmium, the overall performance of the wetlands was very good. The soil and plants were the sinks for the accumulation of cadmium. In subsurface flow wetland, cadmium could be mainly removed by the media acting as filter beds. The adsorption of cadmium by the media was very effective because of the wastewater flowing through the soil bed. For Free water surface wetland, the water level was maintained above the soil bed. Thus some of cadmium was not attached to the soil bed. In addition to the soil bed, the stems of cattail plants also act as a filter for cadmium removal. Moreover, the precipitation of cadmium could have occurred in both systems.

4.3 Mass balance of cadmium in constructed wetland systems

From the results of experiments in this study, the total amount of accumulated cadmium in each component of wetland systems during the experimental period could be determined. The mass balance of cadmium in the system can be shown by equation below.

$$Cd_{inf} = Cd_{eff} + Cd_{soil} + Cd_{plants} + \text{others}$$

Free water surface wetland system

$$Cd_{inf} = Cd_{eff} + Cd_{soil} + Cd_{plants} + \text{others}$$

$$131.402\ g = (0.653 + 111.103 + 3.140 + 19.884)\ g$$

The mass balance of cadmium in free water surface wetland shows some of cadmium lost in the system. This loss could be accounted by the remaining wastewater that had cadmium. Some of the cadmium was precipitated and settled down at the bottom of reactor, as well as some stuck to the reactor walls. The decayed plants could be the other sink of cadmium removed from wastewater. The total amount of cadmium removed through effluent was about 0.5 % of total cadmium intake during the experimental period. The mass of cadmium accumulation in soil and plants were 84.6% and 2.4 %, respectively of total cadmium intake. About 12.6 % of cadmium intake was attributed to the others (lost through precipitation, sink, and evaporation, etc.).

Subsurface flow wetland system

$$Cd_{inf} = Cd_{eff} + Cd_{soil} + Cd_{plants} + \text{others}$$

$$39.437\ g = (0.071 + 36.017 + 1.594 + 1.753)\ g$$

This loss of cadmium in the system was due to the precipitation and settling to the bottom and walls of the reactors and the evaporation. Also, some wastewater containing cadmium remained in the reactor. Figures 4.59-4.60 show cadmium in each component of wetland systems. The total amount of cadmium removed through effluent was about 0.2 % of total cadmium intake. Cadmium accumulations in soil and plants were 91.3% and 4.0 %, respectively of total cadmium intake. The lost Cd via other sinks was about 4.5 % of total cadmium intake.

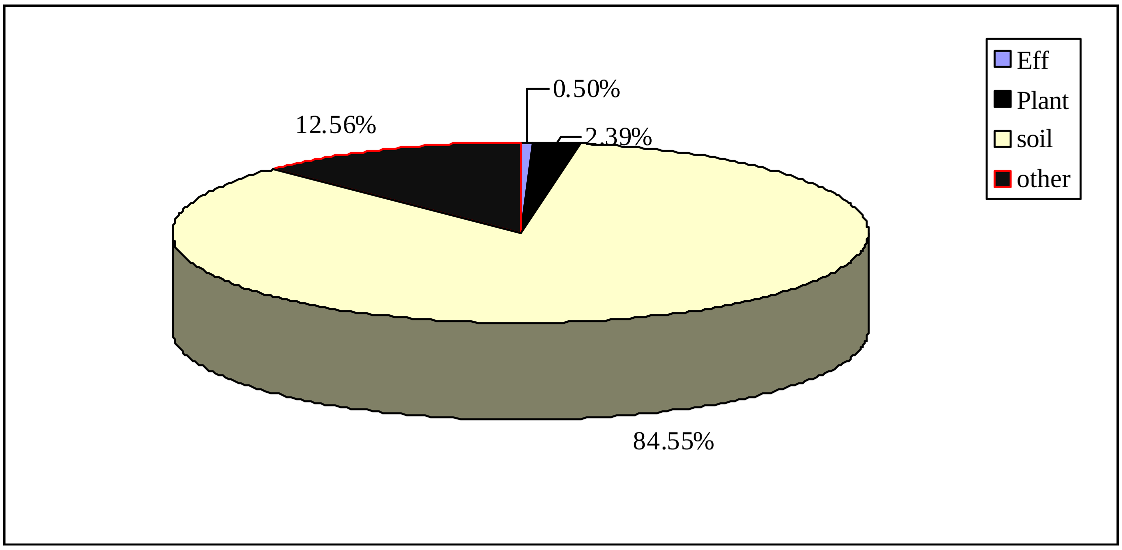


Figure 4.59 The cadmium mass balance in the free water surface wetland

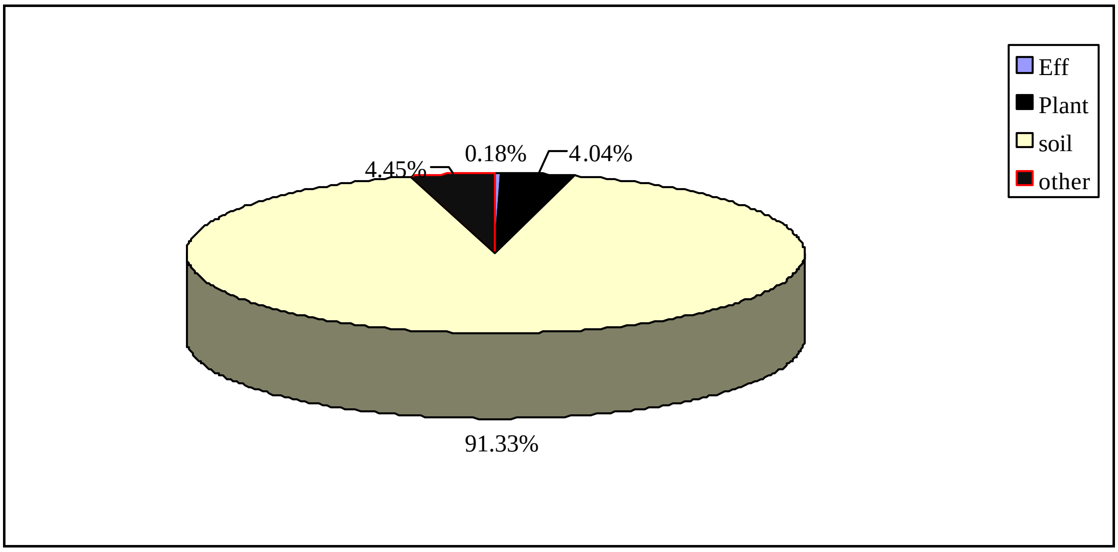


Figure 4.60 The cadmium mass balance in subsurface flow wetland

Breen (1990) researched on the "green box" approach for many wetland wastewater treatment studies. In general, they considered that a mass balance approach was required and that experiments be specifically designed to investigate particular aspects of wetlands and wastewater treatment, for example, system hydrology, substratum characterization and nutrient removal mechanisms.

A simple model (Figure 4.61) can illustrate major factors of importance for wastewater treatment in wetlands. In Figure 4.61, the input and output are represented by x and y, respectively, while k_1 and k_2 are the composite uptake and release rate coefficients for the fixed components. For a conservative material, assuming steady state conditions and first-order rates, changes in y can be described by equation 4.5.

$$y = x - (k_1 - k_2)\, x \qquad (4.5)$$

Measuring the change in storage $(k_1 - k_2)\ x$ for the whole system simply involves monitoring x and y. However changes in the storage of individual components can be similarly described and measured.

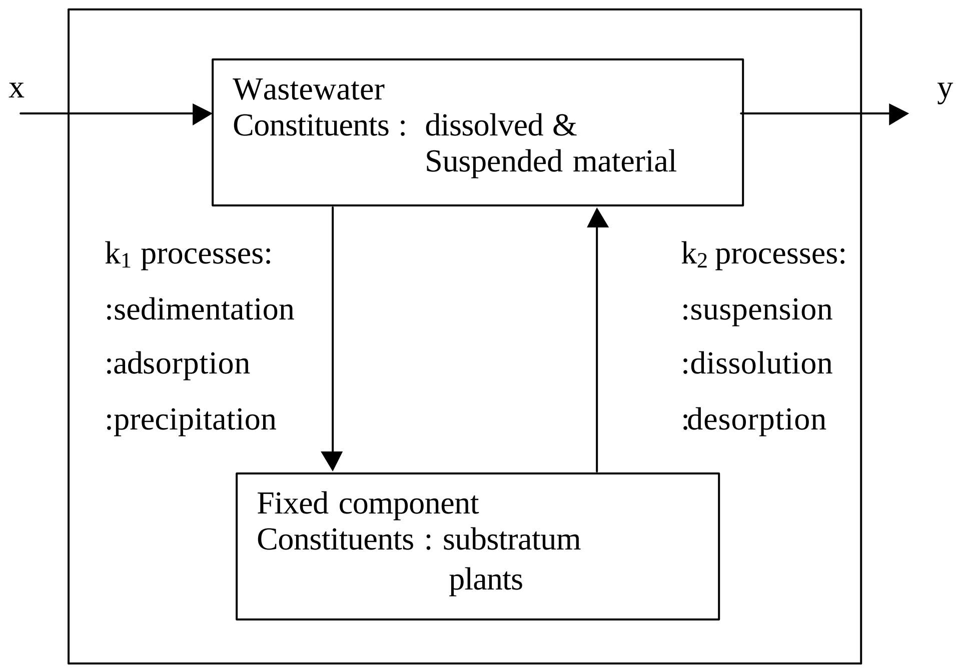


Figure 4.61 Diagrammatic wetland model, where the outflow (y) is determined by the inflow (x) and the general exchange equilibria (k_1 and k_2) between storage components

The intention of the study was to develop a systematic method for assessing the potential of wetland systems to treat wastewaters based on the above model. Figures 4.62-4.63 show the plots of average influent loading versus effluent loadings during the four runs in the two wetland systems.

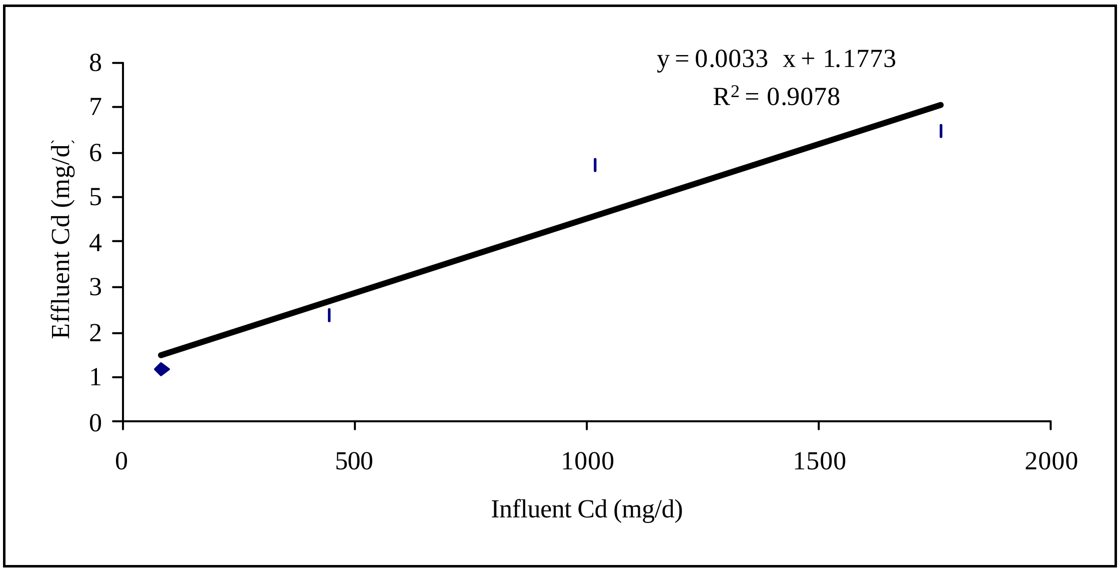


Figure 4.62 Relationship between average influent and effluent cadmium loadings during the four runs in free water surface wetland system

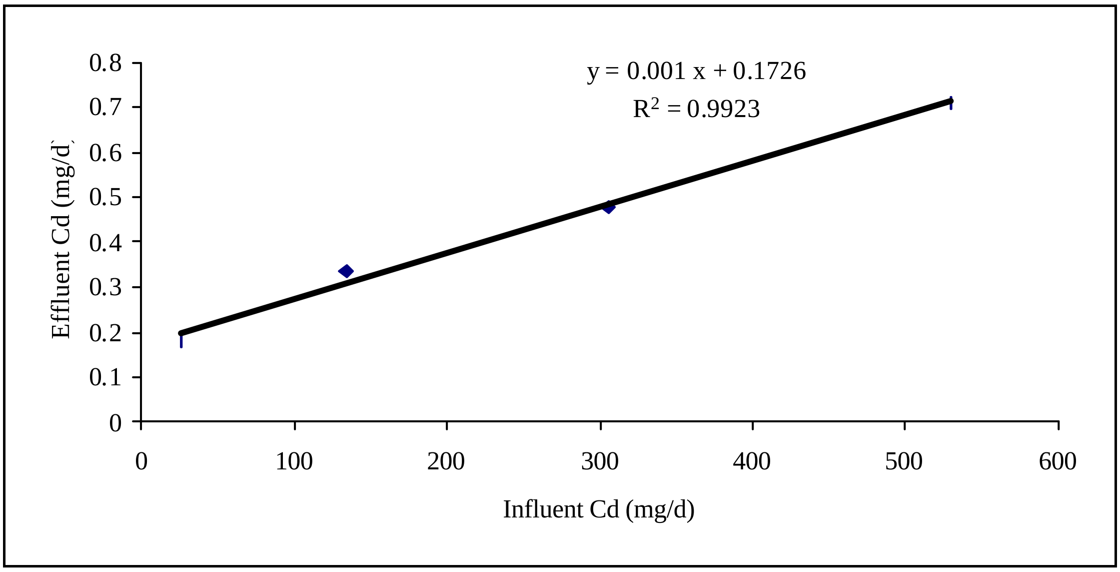


Figure 4.63 Relationship between average influent and effluent cadmium loadings during the four runs in subsurface flow wetland system

As shown in the above figures, the empirical relationships between influent and effluent loadings can be described by simple linear equations:

$$Cd_{eff} = Cd_{inf} \times 0.0033 + 1.1773 \quad (R^2 = 0.9078) \text{ for FWS} \quad (4.6)$$

$$Cd_{eff} = Cd_{inf} \times 0.0010 + 0.1726 \quad (R^2 = 0.9923) \text{ for SF} \quad (4.7)$$

From the above equations, the outflow could be obtained by the inflow with the coefficients of determinations as 0.9078 and 0.9923 for free water surface and subsurface flow wetland, respectively. The constants "k" of the above equations were 0.0033 and 0.0010 for FWS and SF, respectively. The FWS had higher k values than SF. The removal efficiencies are dependent on k. Low k value causes low effluent loadings, thus high removal efficiencies could be achieved. Table 4.3 and Figures 4.64-4.65 show the estimated cadmium concentrations in effluent of two wetland systems by using above equations. These equations could be only used to explain the performance in the treatment low concentrations of cadmium (1-20 mg/L) in wetlands.

Table 4.3 Experimental and estimated effluent cadmium loadings for the two wetland systems

Run	FWS		SF	
	Experimental (mg/d)	Estimated (mg/d)	Experimental (mg/d)	Estimated (mg/d)
Run I	1.18	1.46	0.18	0.20
Run II	2.37	2.65	0.34	0.31
Run III	5.72	4.53	0.48	0.48
Run IV	6.48	7.00	0.71	0.70
Average	3.94	3.91	0.43	0.42

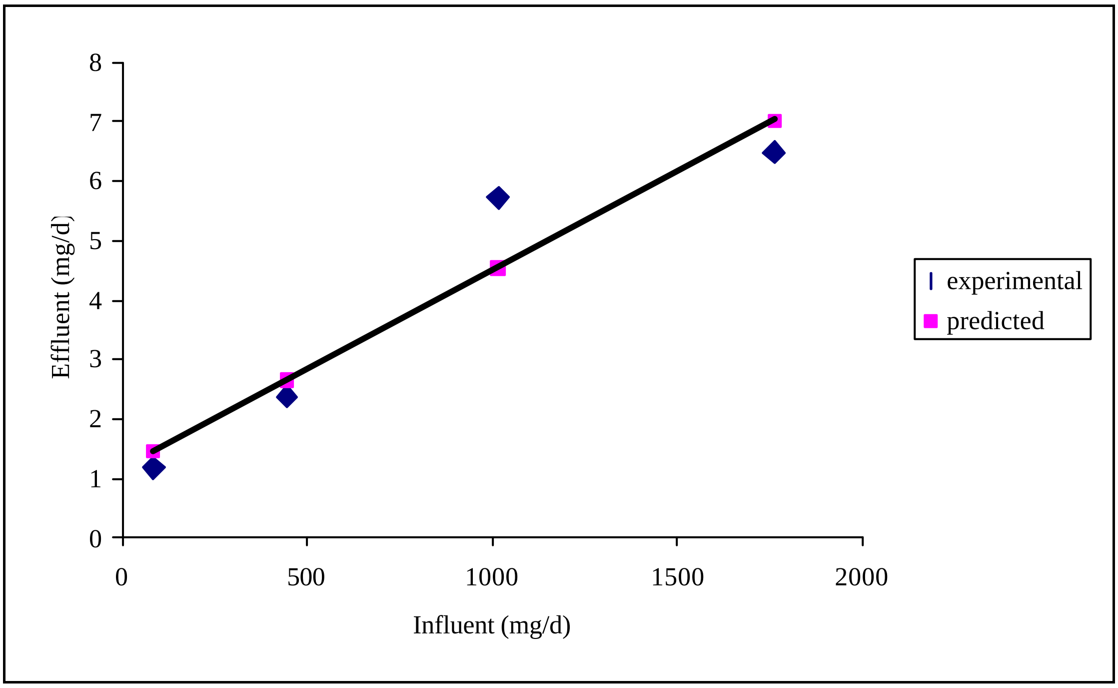


Figure 4.64 The experimental and predicted effluent cadmium loadings in free water surface wetland system

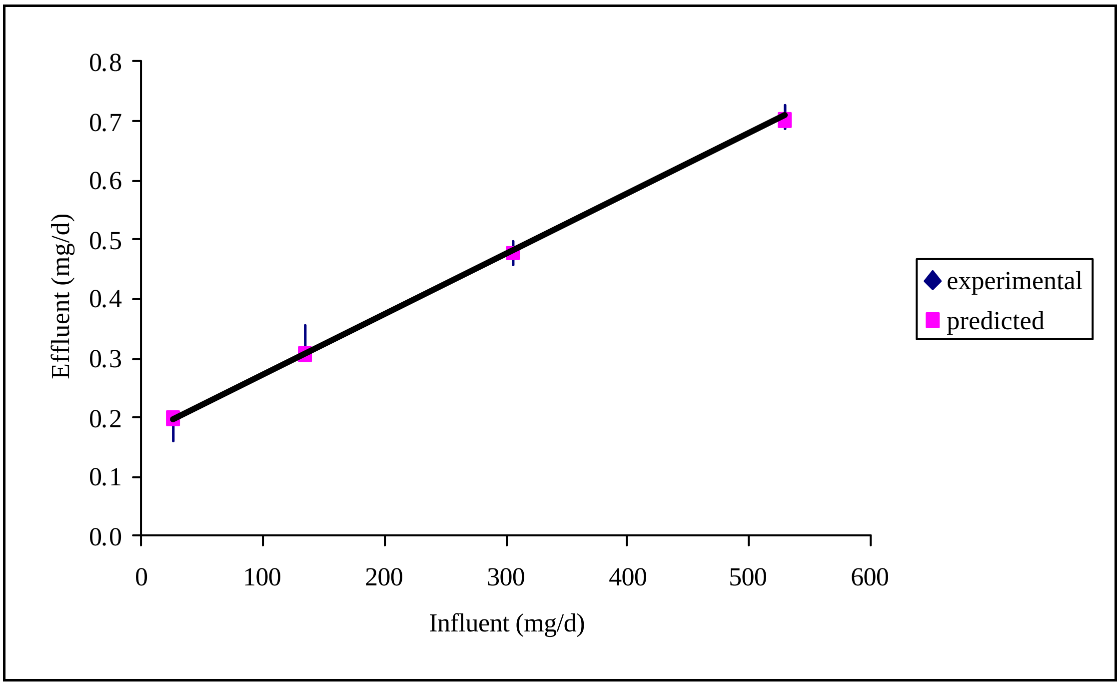


Figure 4.65 The experimental and predicted effluent cadmium loadings in subsurface flow wetland system

Table 4.4 shows the coefficient of variation in the experimental and predicted effluent loadings.

Table 4.4 The coefficient of variation for effluent cadmium loadings in FWS and SF wetland systems

FWS	Experimental (mg/d)	3.94
	Predicted (mg/d)	3.91
	Mean	3.93
	Standard deviation	0.02
	Coefficient of variation	0.51
SF	Experimental (mg/d)	0.43
	Predicted (mg/d)	0.42
	Mean	0.43
	Standard deviation	0.01
	Coefficient of variation	2.33

It could be seen from Table 4.4 that there was no significant difference in predicted and experimental effluent loadings in the two wetland systems. Therefore, the equations (4.6,4.7) can be used to explain the cadmium removal mechanisms of the two wetlands for the range of 1-20 mg/L of influent cadmium concentrations.

Chapter V
Conclusions and recommendations

5.1 Conclusions

Treatment performance of the two systems of constructed wetlands were investigated by determining the removal efficiencies. The effluent cadmium concentrations were compared for the two wetland systems.

The removal efficiencies of some monitored parameters were not significantly different in the control and experimental reactor units of the two constructed wetlands. For free water surface (FWS) wetland, the overall removal efficiencies ranged from 78.4-88.1%, 64.7-85.4%, 61.6-86.1%, 69.1-82.7%, 50.1-74.2% for COD, TKN, TP, TSS, and VSS, respectively. While, the removal efficiencies of these parameters in subsurface flow (SF) wetland were in the range of 87.9-92.2%, 85.1-91.3%, 74.3-90.5%, 78.0-91.4%, 62.1-83.7%, for COD, TKN, TP, TSS, and VSS, respectively.

Overall cadmium removals of 98.6-99.6% and 99.3-99.9% were achieved for free water surface and subsurface flow wetland, respectively. Most of the cadmium was removed by soil. About 85-91% of total influent cadmium could be absorbed by soils.

Cattail plants could uptake Cd through the roots to stems and leaves issues. Of the total cadmium intakes, about 2-4% were accumulated in plants The cadmium uptake by cattail plants were very high near of the reactor inlets and decreased with the distances along the soil beds. Cadmium accumulation in the roots were more than stems and leaves in both systems. The cadmium accumulated in roots was about 55-62%of the total plant uptake. Of the total plant uptake, about 31-33% and 7-11% were accumulated in stems and leaves, respectively. As the cattail plants could uptake upto 3200 and 2800 ppm of cadmium for FWS and SF, respectively, they may be classified as the heavy metals'hyperaccumulators. However, as uptake by roots accounted for more 50% of influent Cd loading, it is difficult to use phytoremediation for these plants after they are used for heavy metals'removal in wetlands.

Based on the results of this study, it could be concluded that the two types of constructed wetlands had high cadmium removal efficiencies. The removal efficiencies were not significantly different for the two wetland systems. It could also be observed that cadmium at the low concentrations in wastewater could be efficiently removed by using free water surface and subsurface flow wetland systems. Thus wetland system can be used to improve the quality of final effluents from industrial wastewater treatment plants before their disposal into receiving water bodies.

5.2 Recommendations

Based on the results of this study, some recommendations for further research are suggested as follows:

5.2.1 The feasibility study on the reuse/remediation of cattail plants, and soil after the treatment runs in the wetland systems should be conducted in order to avoid public health problems resulting from toxicity of accumulated cadmium in them.

5.2.2 Evaluation of long-term performance of wetlands for treatment of wastewater containing heavy metals, as well as their environmental impact should be investigated.

5.2.3 Effect of HRT as well as the depth of water should be studied to find the optimum conditions for wastewater treatment by wetland systems.

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APPENDIX A

Tracer Study

Table A.1 Data of tracer study of reactor R1

t_i (min)	dt_i	C (mg/l)	C/Co = C_i	C_i t_i	C_i t_i dt_i	C_i dt_i	$t_i^2 C_i$ dt_i
20.00	0.00	8.82	0.00	0.04	0.00	0.00	0.00
40.00	20.00	44.12	0.01	0.35	7.06	0.18	282.39
60.00	20.00	70.60	0.01	0.85	16.94	0.28	1,016.61
80.00	20.00	167.67	0.03	2.68	53.65	0.67	4,292.36
100.00	20.00	220.62	0.04	4.41	88.25	0.88	8,824.76
120.00	20.00	255.92	0.05	6.14	122.84	1.02	14,740.88
140.00	20.00	264.74	0.05	7.41	148.26	1.06	20,755.84
160.00	20.00	317.69	0.06	10.17	203.32	1.27	32,531.61
180.00	20.00	397.11	0.08	14.30	285.92	1.59	51,466.02
200.00	20.00	423.59	0.08	16.94	338.87	1.69	67,774.18
220.00	20.00	450.06	0.09	19.80	396.06	1.80	87,132.18
240.00	20.00	529.49	0.11	25.42	508.31	2.12	121,993.53
260.00	20.00	661.86	0.13	34.42	688.33	2.65	178,966.20
280.00	20.00	529.49	0.11	29.65	593.02	2.12	166,046.75
300.00	20.00	458.89	0.09	27.53	550.67	1.84	165,199.57
320.00	20.00	432.41	0.09	27.67	553.49	1.73	177,116.53
340.00	20.00	264.74	0.05	18.00	360.05	1.06	122,417.12
360.00	20.00	238.27	0.05	17.16	343.11	0.95	123,518.45
380.00	20.00	185.32	0.04	14.08	281.69	0.74	107,040.85
400.00	20.00	176.50	0.04	14.12	282.39	0.71	112,956.97
420.00	20.00	167.67	0.03	14.08	281.69	0.67	118,308.31
450.00	30.00	132.37	0.03	11.91	357.40	0.79	160,831.31
500.00	50.00	132.37	0.03	13.24	661.86	1.32	330,928.63
550.00	50.00	88.25	0.02	9.71	485.36	0.88	266,949.10
600.00	50.00	79.42	0.02	9.53	476.54	0.79	285,922.34
700.00	100.00	61.77	0.01	8.65	864.83	1.24	605,378.77
800.00	100.00	35.30	0.01	5.65	564.78	0.71	451,827.89
900.00	100.00	26.47	0.01	4.77	476.54	0.53	428,883.50
1,000.00	100.00	17.65	0.00	3.53	352.99	0.35	352,990.54
1,100.00	100.00	8.82	0.00	1.94	194.14	0.18	213,559.28
1,200.00	100.00	8.82	0.00	2.12	211.79	0.18	254,153.19
1,300.00	100.00	8.82	0.00	2.29	229.44	0.18	298,277.01
1,400.00	100.00	8.82	0.00	2.47	247.09	0.18	345,930.73
				sum	11,226.69	32.35	5,678,013.43

Table A.2 Data of tracer study of reactor R2

t_i (min)	dt_i	C (mg/l)	C/Co = C_i	$C_i\ t_i$	$C_i\ t_i\ dt_i$	$C_i\ dt_i$	$t_i^2 C_i\ dt_i$
20.00	0.00	8.82	0.00	0.04	0.00	0.00	0.00
40.00	20.00	35.30	0.01	0.28	5.65	0.14	225.91
60.00	20.00	88.25	0.02	1.06	21.18	0.35	1,270.77
80.00	20.00	123.55	0.02	1.98	39.53	0.49	3,162.80
100.00	20.00	247.09	0.05	4.94	98.84	0.99	9,883.74
120.00	20.00	264.74	0.05	6.35	127.08	1.06	15,249.19
140.00	20.00	308.87	0.06	8.65	172.97	1.24	24,215.15
160.00	20.00	352.99	0.07	11.30	225.91	1.41	36,146.23
180.00	20.00	476.54	0.10	17.16	343.11	1.91	61,759.22
200.00	20.00	520.66	0.10	20.83	416.53	2.08	83,305.77
220.00	20.00	529.49	0.11	23.30	465.95	2.12	102,508.45
240.00	20.00	547.14	0.11	26.26	525.25	2.19	126,059.98
260.00	20.00	644.21	0.13	33.50	669.98	2.58	174,193.77
280.00	20.00	503.01	0.10	28.17	563.37	2.01	157,744.41
300.00	20.00	441.24	0.09	26.47	529.49	1.76	158,845.74
320.00	20.00	370.64	0.07	23.72	474.42	1.48	151,814.17
340.00	20.00	352.99	0.07	24.00	480.07	1.41	163,222.83
360.00	20.00	335.34	0.07	24.14	482.89	1.34	173,840.78
380.00	20.00	264.74	0.05	20.12	402.41	1.06	152,915.50
400.00	20.00	202.97	0.04	16.24	324.75	0.81	129,900.52
420.00	20.00	176.50	0.04	14.83	296.51	0.71	124,535.06
450.00	30.00	158.85	0.03	14.30	428.88	0.95	192,997.58
500.00	50.00	123.55	0.02	12.35	617.73	1.24	308,866.72
550.00	50.00	105.90	0.02	11.65	582.43	1.06	320,338.91
600.00	50.00	88.25	0.02	10.59	529.49	0.88	317,691.49
700.00	100.00	79.42	0.02	11.12	1,111.92	1.59	778,344.14
800.00	100.00	26.47	0.01	4.24	423.59	0.53	338,870.92
900.00	100.00	35.30	0.01	6.35	635.38	0.71	571,844.67
1,000.00	100.00	17.65	0.00	3.53	352.99	0.35	352,990.54
1,100.00	100.00	17.65	0.00	3.88	388.29	0.35	427,118.55
1,200.00	100.00	8.82	0.00	2.12	211.79	0.18	254,153.19
1,300.00	100.00	8.82	0.00	2.29	229.44	0.18	298,277.01
1,400.00	100.00	8.82	0.00	2.47	247.09	0.18	345,930.73
				sum	12,424.91	35.33	6,358,224.43

Table A.3 Data of tracer study of reactor R3

t_i (min)	dt_i	C (mg/l)	C/Co = C_i	$C_i\ t_i$	$C_i\ t_i\ dt_i$	$C_i\ dt_i$	$t_i^2 C_i\ dt_i$
20.00	0.00	8.82	0.00	0.04	0.00	0.00	0.00
40.00	20.00	17.65	0.00	0.14	2.82	0.07	112.96
60.00	20.00	70.60	0.01	0.85	16.94	0.28	1,016.61
80.00	20.00	97.07	0.02	1.55	31.06	0.39	2,485.05
100.00	20.00	132.37	0.03	2.65	52.95	0.53	5,294.86
120.00	20.00	176.50	0.04	4.24	84.72	0.71	10,166.13
140.00	20.00	308.87	0.06	8.65	172.97	1.24	24,215.15
160.00	20.00	335.34	0.07	10.73	214.62	1.34	34,338.92
180.00	20.00	397.11	0.08	14.30	285.92	1.59	51,466.02
200.00	20.00	441.24	0.09	17.65	352.99	1.76	70,598.11
220.00	20.00	529.49	0.11	23.30	465.95	2.12	102,508.45
240.00	20.00	547.14	0.11	26.26	525.25	2.19	126,059.98
260.00	20.00	635.38	0.13	33.04	660.80	2.54	171,807.56
280.00	20.00	555.96	0.11	31.13	622.68	2.22	174,349.09
300.00	20.00	476.54	0.10	28.59	571.84	1.91	171,553.40
320.00	20.00	450.06	0.09	28.80	576.08	1.80	184,345.78
340.00	20.00	405.94	0.08	27.60	552.08	1.62	187,706.25
360.00	20.00	397.11	0.08	28.59	571.84	1.59	205,864.08
380.00	20.00	361.82	0.07	27.50	549.96	1.45	208,984.52
400.00	20.00	326.52	0.07	26.12	522.43	1.31	208,970.40
420.00	20.00	220.62	0.04	18.53	370.64	0.88	155,668.83
450.00	30.00	132.37	0.03	11.91	357.40	0.79	160,831.31
500.00	50.00	105.90	0.02	10.59	529.49	1.06	264,742.90
550.00	50.00	88.25	0.02	9.71	485.36	0.88	266,949.10
600.00	50.00	70.60	0.01	8.47	423.59	0.71	254,153.19
700.00	100.00	52.95	0.01	7.41	741.28	1.06	518,896.09
800.00	100.00	17.65	0.00	2.82	282.39	0.35	225,913.94
1,000.00	200.00	17.65	0.00	3.53	705.98	0.71	705,981.08
1,100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
1,200.00	100.00	8.82	0.00	2.12	211.79	0.18	254,153.19
1,300.00	100.00	8.82	0.00	2.29	229.44	0.18	298,277.01
1,400.00	100.00	8.82	0.00	2.47	247.09	0.18	345,930.73
				sum	11,418.36	33.62	5,393,340.68

Table A.4 Data of tracer study of reactor R4

t_i (min)	dt_i	C (mg/l)	C/Co = C_i	$C_i\ t_i$	$C_i\ t_i\ dt_i$	$C_i\ dt_i$	$t_i^2 C_i\ dt_i$
20.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40.00	20.00	17.65	0.00	0.14	2.82	0.07	112.96
60.00	20.00	44.12	0.01	0.53	10.59	0.18	635.38
80.00	20.00	61.77	0.01	0.99	19.77	0.25	1,581.40
100.00	20.00	132.37	0.03	2.65	52.95	0.53	5,294.86
120.00	20.00	202.97	0.04	4.87	97.43	0.81	11,691.05
140.00	20.00	264.74	0.05	7.41	148.26	1.06	20,755.84
160.00	20.00	300.04	0.06	9.60	192.03	1.20	30,724.30
180.00	20.00	317.69	0.06	11.44	228.74	1.27	41,172.82
200.00	20.00	370.64	0.07	14.83	296.51	1.48	59,302.41
220.00	20.00	432.41	0.09	19.03	380.52	1.73	83,715.24
240.00	20.00	555.96	0.11	26.69	533.72	2.22	128,093.21
260.00	20.00	653.03	0.13	33.96	679.15	2.61	176,579.99
280.00	20.00	520.66	0.10	29.16	583.14	2.08	163,279.30
300.00	20.00	476.54	0.10	28.59	571.84	1.91	171,553.40
320.00	20.00	405.94	0.08	25.98	519.60	1.62	166,272.66
340.00	20.00	361.82	0.07	24.60	492.07	1.45	167,303.40
360.00	20.00	291.22	0.06	20.97	419.35	1.16	150,966.99
380.00	20.00	264.74	0.05	20.12	402.41	1.06	152,915.50
400.00	20.00	202.97	0.04	16.24	324.75	0.81	129,900.52
420.00	20.00	176.50	0.04	14.83	296.51	0.71	124,535.06
450.00	30.00	123.55	0.02	11.12	333.58	0.74	150,109.23
500.00	50.00	105.90	0.02	10.59	529.49	1.06	264,742.90
550.00	50.00	79.42	0.02	8.74	436.83	0.79	240,254.19
600.00	50.00	61.77	0.01	7.41	370.64	0.62	222,384.04
700.00	100.00	44.12	0.01	6.18	617.73	0.88	432,413.41
800.00	100.00	35.30	0.01	5.65	564.78	0.71	451,827.89
900.00	100.00	35.30	0.01	6.35	635.38	0.71	571,844.67
1,000.00	100.00	17.65	0.00	3.53	352.99	0.35	352,990.54
1,100.00	100.00	8.82	0.00	1.94	194.14	0.18	213,559.28
1,200.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
1,300.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
1,400.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
				sum	10,287.73	30.25	4,686,512.43

APPENDIX B

Data of experiment

Table B.1 Data of COD of RUN I

Date	COD											
	R11		%Removal	R12		%Removal	R13		%Removal	R14		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
15/9/01	103.05	30.53	70.37	99.23	30.53	69.23	99.23	19.08	80.77	103.25	19.08	81.52
17/9/01	106.87	22.90	78.57	103.05	34.35	66.67	103.05	11.45	88.89	106.87	19.08	82.15
20/9/01	101.88	33.96	66.67	100.00	37.74	62.26	101.88	19.32	81.04	98.11	13.20	86.55
23/9/01	90.56	32.08	64.58	96.22	33.96	64.71	94.33	15.09	84.00	103.78	18.87	81.82
26/9/01	92.30	33.96	63.21	98.72	44.80	54.62	101.22	20.12	80.12	103.02	20.72	79.89
29/9/01	95.20	35.64	62.56	98.72	34.62	64.93	98.74	23.04	76.67	98.65	23.04	76.64
2/10/01	100.50	50.05	50.20	102.38	36.13	64.71	98.74	23.04	76.67	97.72	25.78	73.62
5/10/01	118.27	34.09	71.18	121.21	37.93	68.71	116.14	22.73	80.43	121.21	26.10	78.47
8/10/01	125.23	35.98	71.27	128.26	39.77	68.99	118.16	22.73	80.76	120.27	22.73	81.10
11/10/01	119.86	34.09	71.56	116.72	37.87	67.55	114.26	24.62	78.45	112.27	22.73	79.75
14/10/01	110.25	33.27	69.82	106.25	36.15	65.98	112.54	24.87	77.90	108.30	23.32	78.47
17/10/01	112.94	30.12	73.33	110.48	32.48	70.60	109.78	29.72	72.93	107.36	24.41	77.26
20/10/01	116.47	25.46	78.14	114.97	25.14	78.13	113.47	22.56	80.12	120.34	22.11	81.63
23/10/01	120.68	20.61	82.92				117.41	15.22	87.04	126.45	19.32	84.72
26/10/01							100.28	10.18	89.85	117.62	14.52	87.66
29/10/01	99.64	15.64	84.30	101.84	20.15	80.21	98.67	16.49	83.29	107.11	12.54	88.29
1/11/01	98.46	19.84	79.85	105.75	19.82	81.26	99.34	15.22	84.68	112.35	16.18	85.60
4/11/01	103.48	26.16	74.72	113.26	30.15	73.38	104.23	19.61	81.19	108.25	20.04	81.49
7/11/01	105.64	32.16	69.56	110.45	32.44	70.63	105.56	24.62	76.68	104.31	22.15	78.77
10/11/01	118.48	22.90	80.67	112.32	24.10	78.54	109.62	23.51	78.55	113.55	23.28	79.50
13/11/01	109.46	34.42	68.55	108.54	32.96	69.63	111.05	24.36	78.06	110.25	24.20	78.05
16/11/01	104.37	33.79	67.62	108.61	33.00	69.62	104.53	22.42	78.55	107.65	23.51	78.16
19/11/01	111.25	34.07	69.38	103.54	33.16	67.97	106.69	23.59	77.89	109.54	24.22	77.89
Max	125.23	50.05	84.30	128.26	44.80	81.26	118.16	29.72	89.85	126.45	26.10	88.29
Min	90.56	15.64	50.20	96.22	19.82	54.62	94.33	10.18	72.93	97.72	12.54	73.62
Mean	107.49	30.53	71.32	107.64	32.73	69.44	106.04	20.59	80.63	109.49	20.92	80.83
SD	9.65	7.34	7.76	8.19	6.22	6.30	6.98	4.75	4.11	7.71	3.84	3.71
%Removal		71.60			69.60			80.58			80.89	

Table B.2 Data of TKN of RUN I

Date	TKN											
	R11		%Removal	R12		%Removal	R13		%Removal	R14		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
15/9/01	5.60	3.36	40.00	5.32	3.08	42.11	5.32	2.24	57.89	5.60	2.24	60.00
17/9/01	5.04	2.80	44.44	5.04	3.08	38.89	5.32	2.24	57.89	5.32	2.24	57.89
20/9/01	5.32	2.80	47.37	5.32	2.80	47.37	5.04	1.68	66.67	5.04	1.68	66.67
23/9/01	5.04	1.68	66.67	5.04	2.24	55.56	4.48	1.12	75.00	5.04	1.12	77.78
26/9/01	5.04	2.24	55.56				5.32	1.12	78.95	5.04	1.12	77.78
29/9/01	5.32	2.24	57.89	5.04	2.80	44.44	5.04	1.68	66.67	5.32	1.68	68.42
2/10/01	6.16	2.80	54.55	5.60	2.24	60.00	5.04	1.68	66.67	5.04	1.40	72.22
5/10/01	5.32	3.08	42.11	5.60	3.36	40.00	5.32	1.12	78.95	5.60	1.68	70.00
8/10/01	5.32	3.08	42.11	5.32	3.08	42.11	6.44	1.40	78.26	5.32	1.40	73.68
11/10/01	5.32	2.52	52.63	6.44	2.24	65.22	5.32	1.40	73.68	5.60	1.12	80.00
14/10/01	6.44	3.08	52.17	6.16	3.08	50.00	6.16	1.12	81.82	5.60	1.12	80.00
17/10/01	5.60	2.80	50.00	5.60	3.08	45.00	5.60	0.84	85.00	6.16	1.40	77.27
20/10/01	5.32	1.96	63.16	5.32	2.24	57.89	5.32	1.12	78.95	5.32	0.84	84.21
23/10/01	5.32	2.24	57.89	5.04	1.96	61.11	5.04	0.84	83.33	5.04	0.56	88.89
26/10/01	5.04	2.52	50.00	5.32	2.52	52.63	5.04	0.56	88.89	5.04	0.56	88.89
29/10/01	5.04	2.24	55.56	5.04	2.52	50.00	5.04	0.56	88.89	5.32	0.56	89.47
1/11/01	5.32	1.96	63.16	5.32	1.96	63.16	5.32	1.12	78.95	5.04	0.84	83.33
4/11/01	6.16	2.52	59.09	6.16	2.24	63.64	5.60	0.84	85.00	5.32	0.84	84.21
7/11/01	5.60	3.08	45.00	5.32	2.80	47.37	6.16	1.12	81.82	5.60	1.40	75.00
10/11/01	5.60	3.08	45.00	5.32	3.08	42.11	5.32	1.12	78.95	5.60	1.12	80.00
13/11/01	5.60	2.80	50.00	5.32	2.52	52.63	5.04	1.12	77.78	5.04	1.12	77.78
16/11/01	5.32	2.52	52.63	5.04	2.80	44.44	5.04	1.40	72.22	5.04	1.12	77.78
19/11/01	5.32	2.80	47.37	5.32	2.80	47.37	5.04	1.12	77.78	5.04	1.12	77.78
Max	6.44	3.36	66.67	6.44	3.36	65.22	6.44	2.24	88.89	6.16	2.24	89.47
Min	5.04	1.68	40.00	5.04	1.96	38.89	4.48	0.56	57.89	5.04	0.56	57.89
Mean	5.44	2.62	51.93	5.41	2.66	50.59	5.32	1.24	76.52	5.31	1.23	76.92
SD	0.38	0.44	7.28	0.39	0.41	8.26	0.44	0.44	8.53	0.30	0.46	8.35
%Removal		51.90			50.82			76.66			76.83	

Table B.3 Data of TP of RUN I

Date	TP											
	R11		%Removal	R12		%Removal	R13		%Removal	R14		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
15/9/01	1.39	1.02	26.62	1.50	1.02	32.00	1.50	0.80	46.67	1.02	0.80	21.57
17/9/01	1.44	1.10	23.61	1.50	1.10	26.67	1.39	1.10	20.86	1.10	0.80	27.27
20/9/01	1.50	0.96	36.00	1.44	0.96	33.33	1.50	0.96	36.00	1.44	0.80	44.44
23/9/01	1.23	0.91	26.02	1.39	0.96	30.94	1.39	0.80	42.45			
26/9/01	1.44	0.80	44.44	1.44	0.91	36.81	1.39	0.85	38.85	1.44	0.96	33.33
29/9/01	1.39	0.80	42.45	1.39	0.85	38.85	1.44	0.65	54.86	1.39	0.80	42.45
2/10/01	1.39	0.75	46.04	1.39	0.85	38.85	1.39	0.65	53.24	1.44	0.65	54.86
5/10/01	1.50	0.80	46.67	1.50	0.80	46.67	1.28	0.65	49.22	1.44	0.65	54.86
8/10/01	1.28	0.80	37.50	1.28	0.80	37.50	1.34	0.43	67.91	1.39	0.43	69.06
11/10/01	1.50	0.85	43.33	1.39	0.80	42.45	1.50	0.43	71.33	1.39	0.43	69.06
14/10/01	1.44	0.59	59.03	1.34	0.59	55.97	1.39	0.49	64.75	1.34	0.43	67.91
17/10/01	1.39	0.65	53.24	1.50	0.75	50.00	1.44	0.43	70.14	1.44	0.49	65.97
20/10/01	1.50	0.65	56.67	1.44	0.65	54.86	1.34	0.43	67.91	1.10	0.49	55.45
23/10/01	1.23	0.59	52.03	1.34	0.59	55.97	1.44	0.33	77.08	1.44	0.38	73.61
26/10/01	1.10	0.43	60.91	1.10	0.43	60.91	1.02	0.27	73.53	1.02	0.33	67.65
29/10/01				1.02	0.59	42.16	1.34	0.33	75.37	1.34	0.27	79.85
1/11/01	1.28	0.65	49.22	1.39	0.65	53.24	1.10	0.22	80.00	1.10	0.27	75.45
4/11/01	1.39	0.75	46.04	1.28	0.75	41.41	1.44	0.38	73.61	1.44	0.43	70.14
7/11/01	1.50	0.65	56.67	1.44	0.65	54.86	1.39	0.49	64.75	1.28	0.49	61.72
10/11/01	1.50	0.59	60.67	1.50	0.59	60.67	1.02	0.49	51.96	1.55	0.43	72.26
13/11/01	1.44	0.56	61.11	1.39	0.59	57.55	1.28	0.43	66.41	1.34	0.43	67.91
16/11/01	1.34	0.43	67.91	1.50	0.56	62.67	1.34	0.43	67.91	1.44	0.43	70.14
19/11/01	1.39	0.38	72.66	1.39	0.38	72.66	1.34	0.38	71.64	1.39	0.38	72.66
Max	1.50	1.10	72.66	1.50	1.10	72.66	1.50	1.10	80.00	1.55	0.96	79.85
Min	1.10	0.38	23.61	1.02	0.38	26.67	1.02	0.22	20.86	1.02	0.27	21.57
Mean	1.39	0.71	48.58	1.38	0.73	47.26	1.35	0.54	60.28	1.33	0.53	59.89
SD	0.11	0.19	13.23	0.12	0.19	12.08	0.13	0.23	15.42	0.16	0.20	16.33
%Removal		48.59			47.19			59.94			60.47	

Table B.4 Data of TSS of RUN I

Date	TSS											
	R11		%Removal	R12		%Removal	R13		%Removal	R14		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
15/9/01												
17/9/01												
20/9/01	84.00	54.00	35.71	80.00	56.00	30.00	76.00	32.00	57.89	86.00	50.00	41.86
23/9/01	78.00	56.00	28.21	92.00	74.00	19.57	88.00	44.00	50.00	80.00	52.00	35.00
26/9/01				108.00	16.00	85.19	64.00	40.00	37.50	98.00	24.00	75.51
29/9/01	56.00	24.00	57.14	64.00	46.00	28.13	78.00	42.00	46.15	62.00	34.00	45.16
2/10/01	56.00	28.00	50.00	56.00	44.00	21.43	66.00	32.00	51.52			
5/10/01	52.00	20.00	61.54				58.00	20.00	65.52	58.00	20.00	65.52
8/10/01	62.00	28.00	54.84	70.00	38.00	45.71	64.00	28.00	56.25	68.00	34.00	50.00
11/10/01	74.00	32.00	56.76	56.00	20.00	64.29	66.00	22.00	66.67	64.00	28.00	56.25
14/10/01	78.00	38.00	51.28	68.00	32.00	52.94	80.00	30.00	62.50	70.00	26.00	62.86
17/10/01	58.00	24.00	58.62				60.00	16.00	73.33	68.00	22.00	67.65
20/10/01	50.00	18.00	64.00	56.00	30.00	46.43				72.00	16	77.78
23/10/01							58	18.00	68.97	50.00	18	64.00
26/10/01	118.00	20.00	83.05				124.00	10.00	91.94	56.00	12.00	78.57
29/10/01	106.00	22.00	79.25	124.00	30.00	75.81	114.00	16.00	85.96			
1/11/01	88.00	24.00	72.73	120.00	26.00	78.33	94.00	14.00	85.11			
4/11/01				66.00	26.00	60.61	84.00	20.00	76.19	70.00	24.00	65.71
7/11/01	68.00	32.00	52.94	80.00	54.00	32.50	74.00	10.00	86.49	96.00	32.00	66.67
10/11/01	72.00	46.00	36.11	76.00	38.00	50.00	76.00	32.00	57.89	84.00	38.00	54.76
13/11/01	60.00	28.00	53.33	62.00	30.00	51.61	82.00	24.00	70.73			
16/11/01				114.00	20.00	82.46	54.00	14.00	74.07	114.00	18.00	84.21
19/11/01	112.00	24.00	78.57	120.00	34.00	71.67	102.00	6.00	94.12	88.00	12.00	86.36
Max	118.00	56.00	83.05	124.00	74.00	85.19	124.00	44.00	94.12	114.00	52.00	86.36
Min	50.00	18.00	28.21	56.00	16.00	19.57	54.00	6.00	37.50	50.00	12.00	35.00
Mean	74.82	30.47	57.30	83.06	36.12	52.74	78.10	23.50	67.94	75.53	27.06	63.40
SD	21.01	11.57	15.39	24.78	14.96	21.49	18.92	11.09	15.79	16.96	11.79	14.77
%Removal		59.28			56.52			69.91			64.17	

Table B.5 Data of VSS of RUN I

Date	VSS											
	R11		%Removal	R12		%Removal	R13		%Removal	R14		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
15/9/01												
17/9/01												
20/9/01	108.00	74.00	31.48	110.00	80.00	27.27	100.00	62.00	38.00	108.00	78.00	27.78
23/9/01							106.00	80.00	24.53	102.00	84.00	17.65
26/9/01	78.00	54.00	30.77	104.00	84.00	19.23	98.00	78.00	20.41	86.00	58.00	32.56
29/9/01	96.00	64.00	33.33	108.00	78.00	27.78				94.00	64.00	31.91
2/10/01	88.00	62.00	29.55	98.00	74.00	24.49	92.00	68.00	26.09	78.00	52.00	33.33
5/10/01	92.00	62.00	32.61	92.00	68.00	26.09	96.00	60.00	37.50	102.00	58.00	43.14
8/10/01	102.00	74.00	27.45	112.00	68.00	39.29	104.00	64.00	38.46	116.00	74.00	36.21
11/10/01	114.00	72.00	36.84	84.00	56.00	33.33	108.00	64.00	40.74	104.00	70.00	32.69
14/10/01	128.00	80.00	37.50	124.00	78.00	37.10	118.00	78.00	33.90	104.00	58.00	44.23
17/10/01	96.00	74.00	22.92				110.00	64.00	41.82	102.00	62.00	39.22
20/10/01	90.00	62.00	31.11	80.00	56.00	30.00	86	48	44.19	92.00	52	43.48
23/10/01	88.00	54.00	38.64	86.00	50.00	41.86	106	66.00	37.74	110.00	67	39.09
26/10/01	92.00	70.00	23.91	100.00	62.00	38.00	116.00	52.00	55.17	98.00	56.00	42.86
29/10/01	82.00	68.00	17.07	106.00	68.00	35.85	96.00	68.00	29.17	84.00	48.00	42.86
1/11/01	114.00	40.00	64.91	78.00	54.00	30.77	90.00	56.00	37.78	94.00	54.00	42.55
4/11/01	106.00	64.00	39.62	98.00	72.00	26.53	96.00	70.00	27.08	102.00	40.00	60.78
7/11/01	106.00	80.00	24.53	126.00	88.00	30.16	106.00	52.00	50.94	120.00	70.00	41.67
10/11/01	112.00	94.00	16.07	114.00	82.00	28.07	114.00	88.00	22.81	126.00	106.00	15.87
13/11/01	88.00	66.00	25.00	108.00	78.00	27.78	128.00	68.00	46.88	86.00	42.00	51.16
16/11/01	80.00	62.00	22.50	98.00	74.00	24.49	104.00	36.00	65.38	94.00	48.00	48.94
19/11/01	96.00	66.00	31.25	108.00	88.00	18.52	86.00	22.00	74.42	100.00	60.00	40.00
Max	128.00	94.00	64.91	126.00	88.00	41.86	128.00	88.00	74.42	126.00	106.00	60.78
Min	78.00	40.00	16.07	78.00	50.00	18.52	86.00	22.00	20.41	78.00	40.00	15.87
Mean	97.80	67.10	30.85	101.79	71.47	29.82	103.00	62.20	39.65	100.10	61.95	38.47
SD	13.14	11.32	10.42	13.51	11.54	6.43	10.98	15.26	13.96	11.94	15.17	10.29
%Removal		31.39			29.78			39.61			38.11	

Table B.6 Data of Cd of RUN I

Date	Cd											
	R11		%Removal	R12		%Removal	R13		%Removal	R14		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
15/9/01	0.00	0.00		0.89	0.03	96.11	0.00	0.04		0.95	0.02	98.12
17/9/01	0.00	0.00		0.86	0.07	92.39	0.01	0.00		0.97	0.03	97.32
20/9/01	0.01	0.00		0.83	0.07	91.47	0.01	0.01		1.02	0.03	97.40
23/9/01	0.01	0.01		0.88	0.02	97.35	0.01	0.01		0.97	0.03	97.02
26/9/01	0.01	0.00		0.98	0.02	98.25	0.01	0.00		0.90	0.00	100.00
29/9/01	0.01	0.01		0.94	0.01	98.67	0.01	0.01		0.87	0.01	98.95
2/10/01	0.01	0.01		0.93	0.01	98.68	0.01	0.01		0.84	0.01	99.03
5/10/01	0.01	0.00		1.18	0.01	99.15	0.00	0.01		1.09	0.01	99.44
8/10/01	0.01	0.01		1.03	0.01	98.85	0.00	0.01		0.95	0.02	98.26
11/10/01	0.01	0.00		0.95	0.02	98.06	0.01	0.01		1.03	0.01	99.20
14/10/01	0.01	0.00		1.07	0.01	99.27	0.01	0.01		1.04	0.01	99.16
17/10/01	0.01	0.00		1.05	0.01	98.85	0.01	0.00		1.07	0.01	99.25
20/10/01	0.01	0.00		0.92	0.01	98.61	0.0075	0.0024		0.95	0.0085	99.11
23/10/01	0.01	0.00		0.94	0.01	98.81	0.0064	0.00		0.98	0.0074	99.25
26/10/01	0.01	0.00		0.92	0.01	98.60	0.00	0.00		0.89	0.01	99.16
29/10/01	0.00	0.00		0.89	0.01	98.90	0.01	0.00		0.90	0.01	99.11
1/11/01	0.00	0.00		0.86	0.01	98.76	0.01	0.00		0.97	0.01	99.33
4/11/01	0.00	0.00		0.94	0.01	98.77	0.00	0.00		0.92	0.01	99.42
7/11/01	0.01	0.00		0.97	0.01	98.83	0.01	0.01		0.94	0.01	98.90
10/11/01	0.01	0.00		0.96	0.01	99.23	0.00	0.00		0.92	0.01	99.11
13/11/01	0.00	0.00		0.94	0.01	98.88	0.01	0.00		0.96	0.01	99.38
16/11/01	0.00	0.00		0.91	0.01	99.08	0.01	0.00		0.88	0.00	99.76
19/11/01	0.01	0.00		0.89	0.01	99.17	0.00	0.00		0.92	0.00	99.80
Max	0.01	0.01		1.18	0.07	99.27	0.01	0.04		1.09	0.03	100.00
Min	0.00	0.00		0.83	0.01	91.47	0.00	0.00		0.84	0.00	97.02
Mean	0.01	0.00		0.95	0.02	98.03	0.01	0.01		0.95	0.01	98.93
SD	0.00	0.00		0.08	0.02	2.05	0.00	0.01		0.07	0.01	0.79
%Removal					98.11						98.93	

Table B.7 Data of DO of RUN I

Date	DO							
	R11		R12		R13		R14	
	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)
15/9/01	0.30	4.50	0.30	5.60	0.30	6.00	0.30	6.00
17/9/01	0.20	5.00	0.30	5.00	0.30	5.50	0.30	5.90
20/9/01	0.20	4.80	0.20	4.00	0.20	5.60	0.20	5.60
23/9/01	0.20	4.80	0.30	4.50	0.30	5.80	0.20	5.50
26/9/01	-	5.15	-	4.90	-	6.40	-	6.60
29/9/01	-	4.65	-	4.50	-	6.00	-	5.90
2/10/01	-	3.70	-	4.20	-	6.20	-	6.50
5/10/01	-	4.30	-	4.30	-	5.90	-	5.60
8/10/01	-	4.00	-	3.80	-	5.50	-	6.00
11/10/01	-	4.10	-	4.40	-	5.80	-	5.50
14/10/01	-	4.40	-	4.40	-	5.50	-	5.65
17/10/01	-	4.80	-	4.30	-	5.75	-	6.15
20/10/01	-	6.00	-	5.85	-	5.65	-	5.85
23/10/01	-	5.70	-	5.90	-	6.10	-	5.90
26/10/01	-	5.90	-	6.15	-	6.30	-	6.20
29/10/01	-	5.50	-	6.00	-	6.45	-	6.35
1/11/01	-	5.70	-	5.95	-	6.50	-	6.55
4/11/01	-	5.00	-	5.20	-	6.20	-	6.10
7/11/01	-	5.20	-	4.90	-	6.00	-	5.40
10/11/01	-	4.55	-	4.45	-	5.95	-	5.50
13/11/01	-	3.90	-	4.35	-	6.15	-	5.70
16/11/01	-	4.50	-	4.30	-	5.85	-	5.90
19/11/01	-	4.60	-	4.50	-	6.05	-	5.50
Max	0.30	6.00	0.30	6.15	0.30	6.50	0.30	6.60
Min	0.20	3.70	0.20	3.80	0.20	5.50	0.20	5.40
Mean	0.23	4.82	0.28	4.85	0.28	5.96	0.25	5.91
SD	0.05	0.64	0.05	0.72	0.05	0.30	0.06	0.36

Table B.8 Data of pH of RUN I

Date	pH							
	R11		R12		R13		R14	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
15/9/01	6.40	7.08	6.33	7.22	6.44	7.18	6.20	6.90
17/9/01	6.72	7.14	6.63	7.25	6.84	7.12	7.17	7.00
20/9/01	6.40	7.16	6.47	7.15	6.44	6.86	6.59	6.96
23/9/01	6.54	7.04	6.50	7.20	6.62	7.11	6.42	6.89
26/9/01	6.50	7.21	6.50	7.25	6.30	7.51	6.37	7.20
29/9/01	6.80	7.31	6.32	7.18	6.40	7.32	6.35	7.22
2/10/01	6.72	7.18	6.47	7.22	6.51	7.41	6.48	7.30
5/10/01	6.52	7.06	6.78	7.46	6.55	7.43	6.73	7.36
8/10/01	6.62	7.31	6.56	7.19	6.60	7.16	6.48	7.01
11/10/01	6.47	7.12	6.48	7.17	6.54	7.07	6.29	7.08
14/10/01	6.62	7.23	6.57	7.05	6.73	7.11	6.57	7.19
17/10/01	6.78	7.38	6.46	7.22	6.48	7.44	6.46	7.27
20/10/01	6.53	7.16	6.48	7.51	6.79	7.53	6.92	7.38
23/10/01	6.59	7.40	6.37	7.24	6.34	7.15	6.24	7.19
26/10/01	6.12	7.24	6.24	7.55	6.47	7.26	6.34	7.35
29/10/01	6.53	7.35	6.54	7.49	6.34	7.44	6.42	7.16
1/11/01	6.75	7.27	6.84	7.29	6.85	7.23	6.69	7.22
4/11/01	6.43	7.49	6.48	7.44	6.36	7.05	6.85	7.30
7/11/01	6.52	7.28	6.71	7.29	6.67	7.29	6.48	7.25
10/11/01	6.47	7.08	6.52	7.11	6.42	7.16	6.51	7.07
13/11/01	6.39	7.14	6.48	7.09	6.53	7.34	6.62	7.31
16/11/01	6.67	7.20	6.76	7.24	6.34	7.31	7.02	7.22
19/11/01	6.81	7.29	6.67	7.32	6.29	7.41	6.85	7.34
Max	6.81	7.49	6.84	7.55	6.85	7.53	7.17	7.38
Min	6.12	7.04	6.24	7.05	6.29	6.86	6.20	6.89
Mean	6.56	7.22	6.53	7.27	6.52	7.26	6.57	7.18
SD	0.16	0.12	0.15	0.14	0.17	0.17	0.26	0.15

Table B.9 Data of temperature of RUN I

Date	Ambient temperature (°C)	Temperature							
		R11		R12		R13		R14	
		Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)
15/9/01	31.50	29.40	29.10	29.60	29.40	29.00	29.40	29.40	28.60
17/9/01	31.00	28.90	29.70	28.90	28.30	28.90	29.30	28.50	28.40
20/9/01	32.00	29.30	28.80	29.50	28.50	30.30	28.90	28.20	28.40
23/9/01	31.70	28.50	28.90	30.00	30.20	29.40	29.20	29.60	29.90
26/9/01	32.00	30.80	30.10	30.20	30.10	30.80	29.00	30.50	29.90
29/9/01	32.50	30.40	30.20	30.10	29.80	30.50	28.90	31.10	29.50
2/10/01	32.50	31.10	31.00	29.90	29.50	31.00	29.70	30.80	28.90
5/10/01	33.00	30.80	30.00	30.90	30.00	31.40	29.80	31.20	29.80
8/10/01	32.70	28.60	29.40	29.10	29.00	28.20	28.60	28.70	29.00
11/10/01	33.20	29.10	28.50	30.10	28.80	30.10	27.60	29.80	28.70
14/10/01	30.50	29.50	29.00	29.40	28.20	29.80	28.10	29.50	28.40
17/10/01	34.00	31.00	30.80	29.50	29.00	30.20	28.40	29.30	28.70
20/10/01	30.20	30.00	29.80	29.70	29.10	29.60	27.90	29.60	28.10
23/10/01	29.80	29.40	28.80	29.60	28.30	29.40	28.50	29.30	28.30
26/10/01	28.70	28.10	28.00	28.00	27.80	28.10	26.50	28.20	26.70
29/10/01	28.50	27.80	27.60	27.70	27.60	27.70	26.10	27.60	26.20
1/11/01	28.00	27.40	27.50	27.50	27.50	27.80	26.40	27.80	25.90
4/11/01	31.40	30.40	30.10	30.40	30.20	30.20	27.40	30.60	28.10
7/11/01	32.60	31.80	31.60	31.60	31.60	31.50	28.20	31.20	28.20
10/11/01	31.10	30.20	30.10	30.10	30.00	30.10	27.50	30.10	27.60
13/11/01	30.50	29.90	29.50	29.80	29.60	29.60	27.10	29.50	27.20
16/11/01	25.50	24.10	24.00	24.40	24.10	24.10	23.10	24.40	23.20
19/11/01	24.30	22.40	22.10	22.70	22.80	22.40	21.40	22.60	21.30
Max	34.00	31.80	31.60	31.60	31.60	31.50	29.80	31.20	29.90
Min	24.30	22.40	22.10	22.70	22.80	22.40	21.40	22.60	21.30
Mean	30.75	29.08	28.90	29.07	28.67	29.13	27.70	29.02	27.78
SD	2.41	2.17	2.13	1.99	1.93	2.15	2.02	2.05	2.06

Table B.10 Data of flow rate of RUN I

Date	Q							
	R11		R12		R13		R14	
	Influent (l/d)	Effluent (l/d)	Influent (l/d)	Effluent (l/d)	Influent (l/d)	Effluent (l/d)	Influent (l/d)	Effluent (l/d)
15/9/01	90.00	63.76	90.00	74.88	27.00	23.40	27.00	21.60
17/9/01	90.00	69.12	90.00	63.76	27.00	19.80	27.00	19.80
20/9/01	90.00	71.90	90.00	72.00	27.00	18.00	27.00	18.00
23/9/01	90.00	63.76	90.00	69.12	27.00	18.00	27.00	18.00
26/9/01	90.00	69.12	90.00	69.12	27.00	18.00	27.00	18.00
29/9/01	90.00	69.12	90.00	63.76	27.00	16.20	27.00	17.10
2/10/01	90.00	63.76	90.00	63.76	27.00	16.20	27.00	16.20
5/10/01	90.00	66.24	90.00	66.24	27.00	17.10	27.00	16.20
8/10/01	90.00	60.48	90.00	66.24	27.00	16.20	27.00	16.20
11/10/01	90.00	59.04	90.00	60.48	27.00	16.20	27.00	15.30
14/10/01	90.00	66.24	90.00	63.76	27.00	16.20	27.00	15.30
17/10/01	90.00	63.36	90.00	63.76	27.00	15.30	27.00	15.30
20/10/01	90.00	71.90	90.00	71.19	27.00	16.20	27.00	16.20
23/10/01	90.00	74.88	90.00	71.19	27.00	16.20	27.00	19.80
26/10/01	90.00	71.90	90.00	74.88	27.00	18.00	27.00	18.00
29/10/01	90.00	66.24	90.00	66.24	27.00	18.00	27.00	18.00
1/11/01	90.00	66.24	90.00	66.24	27.00	17.10	27.00	17.10
4/11/01	90.00	63.36	90.00	63.36	27.00	17.10	27.00	16.20
7/11/01	90.00	63.36	90.00	63.36	27.00	16.20	27.00	15.30
10/11/01	90.00	46.08	90.00	43.20	27.00	15.30	27.00	15.30
13/11/01	90.00	57.60	90.00	60.48	27.00	14.40	27.00	15.30
16/11/01	90.00	51.84	90.00	60.48	27.00	15.30	27.00	15.30
19/11/01	90.00	57.60	90.00	57.60	27.00	15.30	27.00	14.40
Max	90.00	74.88	90.00	74.88	27.00	23.40	27.00	21.60
Min	90.00	46.08	90.00	43.20	27.00	14.40	27.00	14.40
Mean	90.00	64.21	90.00	65.00	27.00	16.94	27.00	16.87
SD	0.00	6.72	0.00	6.62	0.00	1.87	0.00	1.80

Table B.11 Data of COD of RUN II

Date	COD											
	R21		%Removal	R22		%Removal	R23		%Removal	R24		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
25/11/01	123.08	22.68	81.57				123.08	18.90	84.64	125.25	20.15	83.91
28/11/01	117.20	32.14	72.58				117.20	15.12	87.10	117.20	15.12	87.10
30/11/01				100.82	30.77	69.48				111.54	11.54	89.65
3/12/01	128.77	22.68	82.39	125.63	36.54	70.91	124.77	19.23	84.59	123.08	23.08	81.25
6/12/01	121.15	32.69	73.02	127.88	32.69	74.44	120.84	11.54	90.45			
9/12/01	119.23	30.77	74.19									
12/12/01				121.15	26.92	77.78	129.78	23.08	82.22			
15/12/01	129.77	30.77	76.29	117.20	25.00	78.67	128.77	21.15	83.58	117.20	21.15	81.95
18/12/01	125.25	31.44	74.90	120.44	30.48	74.69	128.44	11.43	91.10	116.72	22.47	80.75
21/12/01	111.27	25.24	77.32	127.36	32.33	74.62	113.42	24.23	78.64	127.36	25.93	79.64
24/12/01	100.56	28.47	71.69	120.88	30.48	74.78	98.81	14.98	84.84	118.29	22.23	81.21
27/12/01	120.38	30.25	74.87	122.34	31.24	74.46	120.38	22.63	81.20	122.34	25.41	79.23
Max	129.77	32.69	82.39	127.88	36.54	78.67	129.78	24.23	91.10	127.36	25.93	89.65
Min	100.56	22.68	71.69	100.82	25.00	69.48	98.81	11.43	78.64	111.54	11.54	79.23
Mean	119.67	28.71	75.88	120.41	30.72	74.43	120.55	18.23	84.84	119.89	20.79	82.74
SD	8.64	3.81	3.63	8.14	3.31	2.88	9.27	4.72	3.89	4.97	4.69	3.52
%Removal		76.01			74.49			84.88			82.66	

Table B.12 Data of TKN of RUN II

Date	TKN											
	R21		%Removal	R22		%Removal	R23		%Removal	R24		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
25/11/01	6.16	1.96	68.18	6.16	3.08	50.00	6.16	1.40	77.27	6.16	1.68	72.73
28/11/01	5.32	2.24	57.89	5.32	3.08	42.11	5.32	1.40	73.68	5.32	1.40	73.68
30/11/01	5.60	2.24	60.00	5.60	2.24	60.00	5.60	1.68	70.00	5.60	1.96	65.00
3/12/01	5.04	3.36	33.33	5.32	2.52	52.63	5.04	1.68	66.67	5.32	2.24	57.89
6/12/01	4.48	2.52	43.75	4.48	2.24	50.00	4.48	1.40	68.75	4.48	1.68	62.50
9/12/01	5.32	2.24	57.89	5.04	2.52	50.00	5.32	1.40	73.68	5.04	1.68	66.67
12/12/01	6.72	2.80	58.33	5.60	2.80	50.00	6.44	1.40	78.26	5.60	0.56	90.00
15/12/01	6.44	3.08	52.17	5.60	2.52	55.00	6.16	1.68	72.73	6.16	0.84	86.36
18/12/01	5.60	2.52	55.00	5.60	3.08	45.00	5.44	0.84	84.56	6.16	0.56	90.91
21/12/01	5.32	3.08	42.11	5.32	2.80	47.37	5.32	1.40	73.68	5.32	0.56	89.47
24/12/01	5.44	2.80	48.53	5.32	2.52	52.63	5.44	0.84	84.56	5.32	1.40	73.68
27/12/01	5.60	2.80	50.00	5.32	2.52	52.63	5.44	0.84	84.56	5.44	0.84	84.56
Max	6.72	3.36	68.18	6.16	3.08	60.00	6.44	1.68	84.56	6.16	2.24	90.91
Min	4.48	1.96	33.33	4.48	2.24	42.11	4.48	0.84	66.67	4.48	0.56	57.89
Mean	5.59	2.64	52.27	5.39	2.66	50.61	5.51	1.33	75.70	5.49	1.28	76.12
SD	0.61	0.42	9.41	0.40	0.30	4.63	0.53	0.32	6.24	0.50	0.59	11.75
%Removal		52.80			50.65			75.88			76.64	

Table B.13 Data of TP of RUN II

Date	TP											
	R21		%Removal	R22		%Removal	R23		%Removal	R24		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
25/11/01	1.02	0.59	42.16	1.44	0.56	61.11	1.02	0.43	57.84	1.44	0.43	70.14
28/11/01	1.44	0.56	61.11	1.32	0.59	55.30	1.44	0.27	81.25	1.32	0.56	57.58
30/11/01	1.44	0.43	70.14	1.44	0.56	61.11	1.44	0.33	77.08	1.44	0.59	59.03
3/12/01	1.50	0.59	60.67	1.44	0.94	34.72	1.44	0.43	70.14	1.50	0.38	74.67
6/12/01	1.34	0.56	58.21	1.29	0.65	49.61	1.39	0.49	64.75	1.39	0.22	84.17
9/12/01	1.29	0.65	49.61	1.34	0.59	55.97	1.29	0.27	79.07	1.39	0.27	80.58
12/12/01	1.71	0.54	68.42	1.50	0.54	64.00	1.66	0.27	83.73	1.39	0.22	84.17
15/12/01	1.70	0.43	74.71	1.61	0.59	63.35	1.70	0.33	80.59	1.61	0.27	83.23
18/12/01	1.50	0.33	78.00	1.66	0.38	77.11	1.44	0.43	70.14	1.66	0.33	80.12
21/12/01	1.29	0.43	66.67	1.66	0.43	74.10	1.39	0.38	72.66	1.71	0.27	84.21
24/12/01	1.44	0.56	61.11	1.50	0.43	71.33	1.39	0.22	84.17	1.50	0.38	74.67
27/12/01	1.44	0.54	62.50	1.32	0.43	67.42	1.39	0.27	80.58	1.44	0.22	84.72
Max	1.71	0.65	78.00	1.66	0.94	77.11	1.7	0.49	84.17	1.71	0.59	84.72
Min	1.02	0.33	42.16	1.29	0.38	34.72	1.02	0.22	57.84	1.32	0.22	57.58
Mean	1.43	0.52	62.77	1.46	0.56	61.26	1.42	0.34	75.17	1.48	0.35	76.44
SD	0.19	0.09	10.02	0.13	0.15	11.56	0.17	0.09	8.17	0.12	0.13	9.68
%Removal		63.71			61.82			75.75			76.73	

Table B.14 Data of TSS of RUN II

Date	TSS											
	R21		%Removal	R22		%Removal	R23		%Removal	R24		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
25/11/01	64.00	30.00	53.13	92.00	46.00	50.00	80.00	22.00	72.50	78.00	16.00	79.49
28/11/01	60.00	32.00	46.67	70.00	40.00	42.86	70.00	32.00	54.29	62.00	6.00	90.32
30/11/01				50.00	30.00	40.00						
3/12/01	70.00	34.00	51.43									
6/12/01	108.00	44.00	59.26				108.00	18.00	83.33	118.00	20.00	83.05
9/12/01				78.00	34.00	56.41				108.00	52.00	51.85
12/12/01	72.00	24.00	66.67	54.00	4.00	92.59	72.00	36.00	50.00	64.00	12.00	81.25
15/12/01	102.00	86.00	15.69	120.00	48.00	60.00	150.00	44.00	70.67	120.00	24.00	80.00
18/12/01	78.00	28.00	64.10	108.00	68.00	37.04	78.00	52.00	33.33	108.00	46.00	57.41
21/12/01	80.00	46.00	42.50	78.00	26.00	66.67	80.00	30.00	62.50	68.00	12.00	82.35
24/12/01	98.00	38.00	61.22	60.00	24.00	60.00	96.00	6.00	93.75	70.00	16.00	77.14
27/12/01				94.00	36.00	61.70				94.00	8.00	91.49
Max	108.00	86.00	66.67	120.00	68.00	92.59	150	52	93.75	120.00	52	91.49
Min	60.00	24.00	15.69	50.00	4.00	37.04	70	6.00	33.33	62.00	6	51.85
Mean	81.33	40.22	51.18	80.40	35.60	56.73	91.75	30.00	65.05	89.00	21.20	77.44
SD	17.32	18.61	15.54	23.11	16.97	16.11	26.74	14.66	19.27	23.16	15.64	12.91
%Removal		50.55			55.72			67.30			76.18	

Table B.15 Data of VSS of RUN II

Date	VSS											
	R21		%Removal	R22		%Removal	R23		%Removal	R24		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
25/11/01				160.00	96.00	40.00				148.00	80.00	45.95
28/11/01	132.00	112.00	15.15	88.00	66.00	25.00	144.00	130.00	9.72	136.00	98.00	27.94
30/11/01												
3/12/01	146.00	78.00	46.58	100.00	82.00	18.00	90.00	40.00	55.56	88.00	42.00	52.27
6/12/01	120.00	108.00	10.00	98.00	74.00	24.49	120.00	86.00	28.33	112.00	56.00	50.00
9/12/01	164.00	98.00	40.24	110.00	84.00	23.64	150.00	100.00	33.33	78.00	62.00	20.51
12/12/01	120.00	86.00	28.33	160.00	30.00	81.25	104.00	58.00	44.23	156.00	46.00	70.51
15/12/01	152.00	82.00	46.05							150.00	44.00	70.67
18/12/01	104.00	72.00	30.77	164.00	124.00	24.39	110.00	84.00	23.64	164.00	92.00	43.90
21/12/01	120.00	84.00	30.00	82.00	80.00	2.44	120.00	26.00	78.33	98.00	34.00	65.31
24/12/01	132.00	68.00	48.48	80.00	60.00	25.00	132.00	98.00	25.76	86.00	58.00	32.56
27/12/01				140.00	108.00	22.86				144.00	40.00	72.22
Max	164.00	112.00	48.48	164.00	124.00	81.25	150	130	78.33	164.00	98	72.22
Min	104.00	68.00	10.00	80.00	30.00	2.44	90	26.00	9.72	78.00	34	20.51
Mean	132.22	87.56	32.85	118.20	80.40	28.71	121.25	77.75	37.36	123.64	59.27	50.17
SD	18.83	15.36	13.83	34.25	26.09	20.59	20.23	34.30	21.52	31.77	21.77	18.15
%Removal		33.78			31.98			35.88			52.06	

Table B.16 Data of Cd of RUN II

Date	Cd											
	R21		%Removal	R22		%Removal	R23		%Removal	R24		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
25/11/01	0.01	0.01		4.99	0.08	98.43	0.01	0.01		4.99	0.01	99.73
28/11/01	0.01	0.01		5.04	0.11	97.89	0.01	0.01		5.04	0.02	99.70
30/11/01	0.01	0.01		4.78	0.12	97.46	0.01	0.01		4.78	0.04	99.16
3/12/01	0.01	0.01		4.79	0.08	98.41	0.01	0.02		4.79	0.04	99.12
6/12/01	0.01	0.01		4.84	0.02	99.56	0.01	0.02		4.84	0.03	99.32
9/12/01	0.01	0.01		4.99	0.03	99.49	0.01	0.01		4.99	0.02	99.51
12/12/01	0.01	0.01		5.63	0.03	99.51	0.01	0.00		5.63	0.02	99.59
15/12/01	0.01	0.01		4.78	0.03	99.43	0.01	0.01		4.78	0.03	99.45
18/12/01	0.00	0.00		4.76	0.02	99.60	0.00	0.01		4.76	0.01	99.70
21/12/01	0.00	0.00		4.88	0.01	99.79	0.00	0.00		4.88	0.02	99.66
24/12/01	0.00	0.00		4.99	0.01	99.71	0.00	0.00		4.99	0.02	99.60
27/12/01	0.01	0.01		4.98	0.02	99.69	0.01	0.00		4.98	0.02	99.69
Max	0.01	0.01		5.63	0.12	99.79	0.0144	0.019		5.63	0.0422	99.73
Min	0.00	0.00		4.76	0.01	97.46	0	0.00		4.76	0.0135	99.12
Mean	0.01	0.01		4.95	0.05	99.08	0.01	0.01		4.95	0.02	99.52
SD	0.00	0.00		0.24	0.04	0.81	0.00	0.01		0.24	0.01	0.21
%Removal					99.09						99.52	

Table B.17 Data of DO of RUN II

Date	DO							
	R21		R22		R23		R24	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
	-	5.55	-	4.3	-	5	-	5.5
28/11/01	-	4.30	-	4.00	-	5.50	-	5.00
30/11/01	-	4.20	-	4.75	-	5.20	-	5.90
3/12/01	-	5.45	-	4.20	-	5.30	-	5.50
6/12/01	-	4.80	-	4.65	-	5.80	-	5.30
9/12/01	-	4.60	-	4.90	-	5.40	-	5.30
12/12/01	-	5.00	-	5.20	-	5.55	-	5.70
15/12/01	-	4.55	-	5.05	-	5.90	-	5.45
18/12/01	-	4.30	-	4.40	-	5.75	-	5.65
21/12/01	-	4.90	-	4.50	-	5.25	-	5.10
24/12/01	-	4.65	-	4.70	-	5.40	-	5.05
27/12/01	-	4.30	-	4.40	-	5.10	-	5.20
Max	-	5.55	-	5.20	-	5.90	-	5.90
Min	-	4.20	-	4	-	5	-	5.00
Mean	-	4.72	-	4.59	-	5.43	-	5.39
SD	-	0.45	-	0.35	-	0.28	-	0.28

Table B.18 Data of pH of RUN II

Date	pH							
	R21		R22		R23		R24	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
	6.58	7.17	6.61	7.4	6.45	7.13	6.6	7.19
28/11/01	6.67	7.22	6.49	7.75	6.72	7.11	6.80	7.16
30/11/01	6.49	7.18	6.45	7.32	6.82	7.20	6.44	7.13
3/12/01	6.65	7.26	6.46	7.25	6.56	6.85	6.50	7.18
6/12/01	6.79	7.09	6.52	7.16	6.82	7.00	6.62	7.07
9/12/01	6.73	7.24	6.74	7.33	6.86	7.15	6.73	7.10
12/12/01	6.55	7.11	6.63	7.38	6.63	6.87	6.60	6.87
15/12/01	6.47	7.20	6.50	7.28	6.50	7.02	6.41	6.87
18/12/01	6.59	7.15	6.43	7.30	6.43	7.14	6.49	6.92
21/12/01	6.45	7.32	6.58	7.27	6.58	7.04	6.42	7.00
24/12/01	6.65	7.35	6.43	7.34	6.74	6.99	6.49	7.01
27/12/01	6.62	7.29	6.42	7.44	6.80	6.89	6.44	6.85
Max	6.79	7.35	6.74	7.75	6.86	7.20	6.80	7.19
Min	6.45	7.09	6.42	7.16	6.43	6.85	6.41	6.85
Mean	6.60	7.22	6.52	7.35	6.66	7.03	6.55	7.03
SD	0.10	0.08	0.10	0.15	0.15	0.12	0.13	0.13

Table B.19 Data of temperature of RUN II

Date	Ambient temperature (°C)	Temperature							
		R21		R22		R23		R24	
		Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)
25/11/01	29.00	28.50	28.20	29.20	28.00	28.50	28.00	29.10	28.70
28/11/01	29.50	28.60	28.70	28.50	28.90	28.60	28.20	29.00	29.00
30/11/01	30.00	30.10	29.40	29.50	28.90	30.00	29.40	29.50	29.20
3/12/01	30.50	30.50	29.00	30.00	30.10	30.40	29.40	30.10	29.00
6/12/01	29.00	29.00	28.60	28.60	29.70	28.20	28.10	28.60	28.30
9/12/01	29.00	28.60	28.60	28.70	28.40	28.40	28.00	28.70	28.40
12/12/01	24.00	23.20	22.60	24.20	24.00	23.20	23.30	24.00	22.50
15/12/01	22.00	21.50	20.70	21.30	20.50	21.50	21.00	21.50	20.30
18/12/01	20.00	20.50	20.10	20.00	18.80	20.00	20.50	19.50	19.20
21/12/01	17.50	18.50	18.50	18.50	18.50	18.30	18.50	18.50	18.20
24/12/01	21.00	24.70	23.30	25.00	25.50	24.50	22.80	26.20	26.20
27/12/01	20.00	19.70	20.00	19.80	19.30	19.50	19.50	19.50	19.30
Max	30.50	30.50	29.40	30.00	30.10	30.40	29.40	30.10	29.20
Min	17.50	18.50	18.50	18.50	18.50	18.30	18.50	18.50	18.20
Mean	25.13	25.28	24.81	25.28	25.05	25.09	24.73	25.35	24.86
SD	4.82	4.43	4.30	4.36	4.61	4.44	4.18	4.49	4.55

Table B.20 Data of flow rate of RUN II

Date	Q							
	R21		R22		R23		R24	
	Influent (l/d)	Effluent (l/d)	Influent (l/d)	Effluent (l/d)	Influent (l/d)	Effluent (l/d)	Influent (l/d)	Effluent (l/d)
25/11/01	90.00	57.60	90.00	57.60	27.00	23.40	27.00	18.00
28/11/01	90.00	51.84	90.00	51.84	27.00	18.00	27.00	21.60
30/11/01	90.00	40.32	90.00	63.36	27.00	12.60	27.00	16.20
3/12/01	90.00	57.60	90.00	51.84	27.00	14.40	27.00	14.40
6/12/01	90.00	63.36	90.00	57.60	27.00	16.20	27.00	12.60
9/12/01	90.00	51.84	90.00	57.60	27.00	14.40	27.00	14.40
12/12/01	90.00	28.80	90.00	23.04	27.00	8.64	27.00	12.60
15/12/01	90.00	20.16	90.00	28.80	27.00	12.60	27.00	14.40
18/12/01	90.00	46.80	90.00	40.32	27.00	12.60	27.00	18.00
21/12/01	90.00	51.84	90.00	51.84	27.00	14.40	27.00	10.08
24/12/01	90.00	46.08	90.00	51.84	27.00	11.52	27.00	8.64
27/12/01	90.00	40.32	90.00	40.32	27.00	10.08	27.00	11.52
Max	90.00	63.36	90.00	63.36	27.00	23.40	27.00	21.60
Min	90.00	20.16	90.00	23.04	27.00	8.64	27.00	8.64
Mean	90.00	46.38	90.00	48.00	27.00	14.07	27.00	14.37
SD	0.00	12.43	0.00	12.36	0.00	3.88	0.00	3.66

Table B.21 Data of COD of RUN III

Date	COD											
	R31		%Removal	R32		%Removal	R33		%Removal	R34		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
30/12/01	123.19	36.23	70.59	123.19	36.23	70.59	123.19	20.98	82.97	123.19	29.72	75.87
2/1/02	125.28	36.23	71.08	123.19	38.46	68.78	125.28	18.12	85.54	123.19	23.55	80.88
5/1/02	115.94	22.98	80.18	119.12	29.86	74.93	115.94	21.74	81.25	121.38	21.74	82.09
8/1/02	112.32	32.61	70.97	118.20	32.61	72.41	114.38	15.42	86.52	117.76	19.93	83.08
11/1/02	108.70	30.79	71.67	110.50	34.42	68.85	108.70	19.93	81.67	110.50	15.17	86.27
14/1/02	119.57	34.42	71.21	114.13	32.61	71.43	117.26	20.98	82.11	114.13	20.98	81.62
17/1/02	128.54	40.23	68.70	130.51	44.12	66.19	125.25	24.16	80.71	124.56	27.51	77.91
20/1/02												
23/1/02	105.69	34.55	67.31	90.56	34.03	62.42	103.82	22.75	78.09	89.43	16.09	82.01
26/1/02	101.63	30.49	70.00				100.62	24.86	75.29			
29/1/02	124.22	32.44	73.89	115.23	30.82	73.25	123.38	23.22	81.18	116.50	20.46	82.44
1/2/02	118.14	34.12	71.12	105.32	32.66	68.99	116.24	20.62	82.26	105.32	20.88	80.17
4/2/02	116.48	32.75	71.88	122.96	30.24	75.41	115.08	24.15	79.01	122.96	20.15	83.61
Max	128.54	40.23	80.18	130.51	44.12	75.41	125.28	24.86	86.52	124.56	29.72	86.27
Min	101.63	22.98	67.31	90.56	29.86	62.42	100.62	15.42	75.29	89.43	15.17	75.87
Mean	116.64	33.15	71.55	115.72	34.19	70.30	115.76	21.41	81.38	115.36	21.47	81.45
SD	8.28	4.16	3.17	10.82	4.17	3.84	8.09	2.73	3.04	10.52	4.28	2.79
%Removal		71.5768			70.4567			81.5044			81.3873	

Table B.22 Data of TKN of RUN III

Date	TKN											
	R31		%Removal	R32		%Removal	R33		%Removal	R34		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
30/12/01	5.44	2.80	48.53	6.16	2.80	54.55	5.60	1.40	75.00	6.16	0.56	90.91
2/1/02	5.32	2.24	57.89	6.16	3.08	50.00	5.32	1.68	68.42	6.44	1.12	82.61
5/1/02	5.60	3.36	40.00	5.32	2.80	47.37	5.60	1.12	80.00	5.32	1.68	68.42
8/1/02	6.16	3.36	45.45	5.44	3.08	43.38	5.60	1.12	80.00	5.44	1.12	79.41
11/1/02	5.32	2.80	47.37	5.44	3.36	38.24	5.32	1.96	63.16	5.60	1.12	80.00
14/1/02	5.32	2.24	57.89	5.04	2.24	55.56	5.32	2.24	57.89	5.04	1.96	61.11
17/1/02	5.44	2.52	53.68	5.32	2.52	52.63	5.44	1.96	63.97	5.32	2.24	57.89
20/1/02	5.60	1.40	75.00	5.44	1.40	74.26	5.60	1.68	70.00	5.60	2.24	60.00
23/1/02	5.60	1.12	80.00	5.60	1.40	75.00	5.44	0.56	89.71	5.60	0.56	90.00
26/1/02	5.32	0.84	84.21	5.32	2.24	57.89	5.04	0.56	88.89	5.44	0.56	89.71
29/1/02	5.32	0.56	89.47	5.44	0.56	89.71	5.32	0.56	89.47	5.44	0.56	89.71
1/2/02	5.44	0.56	89.71	5.32	0.56	89.47	5.44	0.56	89.71	5.44	0.56	89.71
4/2/02	5.44	0.56	89.71	5.32	0.56	89.47	5.32	0.56	89.47	5.32	0.56	89.47
Max	6.16	3.36	89.71	6.16	3.36	89.71	5.6	2.24	89.71	6.44	2.24	90.91
Min	5.32	0.56	40.00	5.04	0.56	38.24	5.04	0.56	57.89	5.04	0.56	57.89
Mean	5.49	1.87	66.07	5.49	2.05	62.89	5.41	1.23	77.36	5.55	1.14	79.15
SD	0.23	1.07	18.97	0.32	1.03	18.39	0.16	0.63	11.71	0.37	0.67	12.81
%Removal		65.8441			62.7033			77.3167			79.4346	

Table B.23 Data of TP of RUN III

Date	TP											
	R31		%Removal	R32		%Removal	R33		%Removal	R34		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
30/12/01	1.44	0.27	81.25	1.71	0.43	74.85	1.50	0.17	88.67	1.71	0.38	77.78
2/1/02	1.39	0.33	76.26	1.77	0.49	72.32	1.39	0.27	80.58	1.77	0.27	84.75
5/1/02	1.44	0.33	77.08	1.39	0.38	72.66	1.44	0.43	70.14	1.39	0.38	72.66
8/1/02	1.50	0.54	64.00	1.44	0.59	59.03	1.50	0.43	71.33	1.02	0.49	51.96
11/1/02	1.61	0.65	59.63	1.50	0.65	56.67	1.61	0.59	63.35	1.50	0.43	71.33
14/1/02	1.66	0.70	57.83	1.61	0.70	56.52	1.66	0.49	70.48	1.61	0.33	79.50
17/1/02	1.50	0.59	60.67	1.71	0.80	53.22	1.44	0.27	81.25	1.61	0.43	73.29
20/1/02	1.66	0.59	64.46	1.44	0.80	44.44	1.50	0.27	82.00	1.44	0.27	81.25
23/1/02	1.29	0.54	58.14	1.50	0.59	60.67	1.29	0.33	74.42	1.50	0.33	78.00
26/1/02	1.34	0.65	51.49	1.50	0.54	64.00	1.34	0.27	79.85	1.44	0.33	77.08
29/1/02	1.50	0.54	64.00	1.50	0.54	64.00	1.50	0.33	78.00	1.44	0.27	81.25
1/2/02	1.50	0.54	64.00	1.44	0.43	70.14	1.39	0.33	76.26	1.66	0.22	86.75
4/2/02	1.02	0.33	67.65	1.02	0.43	57.84	1.39	0.38	72.66	1.02	0.22	78.43
Max	1.66	0.70	81.25	1.77	0.80	74.85	1.66	0.59	88.67	1.77	0.49	86.75
Min	1.02	0.27	51.49	1.02	0.38	44.44	1.29	0.17	63.35	1.02	0.22	51.96
Mean	1.45	0.51	65.11	1.50	0.57	62.03	1.46	0.35	76.08	1.47	0.33	76.46
SD	0.17	0.14	8.54	0.19	0.14	8.81	0.10	0.11	6.61	0.23	0.08	8.61
%Removal		64.9867			62.2632			75.9367			77.237	

Table B.24 Data of TSS of RUN III

Date	TSS											
	R31		%Removal	R32		%Removal	R33		%Removal	R34		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
30/12/01										122.00	52.00	57.38
2/1/02							80.00	28.00	65.00	76.00	32.00	57.89
5/1/02	78.00	52.00	33.33	86.00	64.00	25.58	74.00	58.00	21.62	86.00	72.00	16.28
8/1/02	52.00	16.00	69.23	104.00	54.00	48.08	56.00	8.00	85.71	112.00	4.00	96.43
11/1/02	112.00	44.00	60.71	150.00	52.00	65.33	112.00	46.00	58.93			
14/1/02				140.00	48.00	65.71	144.00	20.00	86.11	140.00	28.00	80.00
17/1/02	118.00	20.00	83.05				118.00	14.00	88.14	110.00	24.00	78.18
20/1/02	76.00	46.00	39.47	118.00	50.00	57.63	82.00	10.00	87.80	124.00	12.00	90.32
23/1/02	132.00	36.00	72.73	150.00	28.00	81.33	132.00	52.00	60.61	152.00	52.00	65.79
26/1/02				116.00	96.00	17.24				104.00	8.00	92.31
29/1/02	110.00	96.00	12.73	90.00	58.00	35.56	110.00	28.00	74.55	94.00	44.00	53.19
1/2/02	100.00	20.00	80.00	88.00	68.00	22.73	120.00	34.00	71.67	88.00	22.00	75.00
4/2/02	122.00	52.00	57.38	64.00	24.00	62.50	116	24	79.31	64.00	10	84.38
Max	132.00	96.00	83.05	150.00	96.00	81.33	144	58.00	88.14	152.00	72	96.43
Min	52.00	16.00	12.73	64.00	24.00	17.24	56.00	8.00	21.62	64.00	4.00	16.28
Mean	100.00	42.44	56.51	110.60	54.20	48.17	104.00	29.27	70.86	106.00	30.00	70.60
SD	26.08	24.53	23.57	29.46	20.30	21.78	27.10	16.79	19.57	26.01	21.15	22.35
%Removal		57.5556			50.9946			71.8531			71.6981	

Table B.25 Data of VSS of RUN III

Date	VSS											
	R31		%Removal	R32		%Removal	R33		%Removal	R34		%Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
30/12/01	132.00	80.00	39.39	152.00	110.00	27.63	142.00	60.00	57.75	96.00	76.00	20.83
2/1/02							118.00	92.00	22.03	108.00	64.00	40.74
5/1/02	122.00	62.00	49.18	106.00	72.00	32.08	118.00	102.00	13.56	116.00	92.00	20.69
8/1/02	76.00	66.00	13.16	128.00	88.00	31.25	84.00	54.00	35.71	136.00	20.00	85.29
11/1/02				88.00	70.00	20.45				80.00	44.00	45.00
14/1/02												
17/1/02	150.00	116.00	22.67	114.00	64.00	43.86	156.00	52.00	66.67			
20/1/02	88.00	80.00	9.09	150.00	56.00	62.67	88.00	28.00	68.18	150.00	36.00	76.00
23/1/02	160.00	102.00	36.25	120.00	24.00	80.00	152.00	62.00	59.21	120.00	12.00	90.00
26/1/02	120.00	70.00	41.67							102.00	82.00	19.61
29/1/02	144.00	110.00	23.61	162.00	124.00	23.46	150.00	48.00	68.00	162.00	72.00	55.56
1/2/02	142.00	68.00	52.11	104.00	90.00	13.46	130.00	42.00	67.69	100.00	30.00	70.00
4/2/02	108.00	88.00	18.52	76.00	60.00	21.05	114	42	63.16	76.00	28	63.16
Max	160.00	116.00	52.11	162.00	124.00	80.00	156	102.00	68.18	162.00	92	90.00
Min	76.00	62.00	9.09	76.00	24.00	13.46	84.00	28.00	13.56	76.00	12.00	19.61
Mean	124.20	84.20	30.56	120.00	75.80	35.59	125.20	58.20	52.20	113.27	50.55	53.35
SD	27.15	19.24	15.15	28.28	28.59	20.94	25.60	22.79	20.63	27.24	27.57	25.97
%Removal		32.2061			36.8333			53.5144			55.3772	

Table B.26 Data of Cd of RUN III

Date	Cd											
	R31			R32			R33			R34		
	Influent (mg/L)	Effluent (mg/L)	%Removal	Influent (mg/L)	Effluent (mg/L)	%Removal	Influent (mg/L)	Effluent (mg/L)	%Removal	Influent (mg/L)	Effluent (mg/L)	%Removal
30/12/01	0.0137	0.0060		12.0100	0.0253	99.79	0.0137	0.0015		12.0100	0.0261	99.78
2/1/02	0.0082	0.0052		11.5100	0.1899	98.35	0.0082	0.0052		11.5100	0.0296	99.74
5/1/02	0.0051	0.0067		8.9270	0.2158	97.58	0.0051	0.0000		8.9270	0.0884	99.01
8/1/02	0.0092	0.0121		11.6900	0.1924	98.35	0.0092	0.0152		11.6900	0.0694	99.41
11/1/02	0.0162	0.0160		11.7500	0.1975	98.32	0.0162	0.0165		11.7500	0.0656	99.44
14/1/02	0.0172	0.0048		11.1200	0.3159	97.16	0.0172	0.0114		11.1200	0.0288	99.74
17/1/02	0.0265	0.0109		11.6700	0.2285	98.04	0.0265	0.0163		11.6700	0.0104	99.91
20/1/02	0.0131	0.0151		12.8400	0.2290	98.22	0.0131	0.0151		12.8400	0.0191	99.85
23/1/02	0.0090	0.0016		11.9600	0.0947	99.21	0.0090	0.0000		11.9600	0.0709	99.41
26/1/02	0.0121	0.0010		9.2541	0.0599	99.35	0.0121	0.0060		9.2541	0.0261	99.72
29/1/02	0.0128	0.0008		12.1000	0.0359	99.70	0.0128	0.0013		12.1000	0.0292	99.76
1/2/02	0.0126	0.0033		11.8500	0.0745	99.37	0.0126	0.0048		11.8500	0.0191	99.84
4/2/02	0.0131	0.0030		10.1800	0.0799	99.22	0.0131	0.0048		10.1800	0.0187	99.82
Max	0.0265	0.0160		12.8400	0.3159	99.79	0.0265	0.0165		12.8400	0.0884	99.91
Min	0.0051	0.0008		8.9270	0.0253	97.16	0.0051	0.0000		8.9270	0.0104	99.01
Mean	0.0130	0.0067		11.2970	0.1492	98.67	0.0130	0.0075		11.2970	0.0386	99.65
SD	0.0052	0.0052		1.1508	0.0914	0.83	0.0052	0.0065		1.1508	0.0254	0.26
%Removal					98.68						99.66	

Table B.27 Data of DO of RUN III

Date	DO							
	R31		R32		R33		R34	
	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)
30/12/01	-	4.50	-	4.60	-	5.40	-	4.90
2/1/02	-	4.35	-	4.30	-	5.60	-	5.40
5/1/02	-	4.20	-	4.25	-	5.15	-	5.00
8/1/02	-	4.00	-	4.00	-	5.45	-	5.25
11/1/02	-	4.35	-	4.20	-	5.55	-	5.65
14/1/02	-	4.15	-	4.15	-	5.20	-	5.60
17/1/02	-	4.20	-	4.30	-	5.10	-	5.50
20/1/02	-	4.30	-	4.25	-	5.30	-	5.25
23/1/02	-	4.00	-	4.15	-	5.50	-	5.80
26/1/02	-	5.00	-	4.55	-	5.30	-	5.20
29/1/02	-	4.50	-	4.85	-	5.20	-	5.40
1/2/02	-	4.95	-	4.40	-	6.20	-	5.90
4/2/02	-	5.15	-	4.70	-	5.10	-	6.00
Max	-	5.15	-	4.85	-	6.20	-	6.00
Min	-	4.00	-	4.00	-	5.10	-	4.90
Mean	-	4.43	-	4.36	-	5.39	-	5.45
SD	-	0.38	-	0.25	-	0.30	-	0.33

Table B.28 Data of pH of RUN III

Date	pH							
	R31		R32		R33		R34	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
30/12/01	6.58	7.27	6.57	7.34	6.58	7.00	6.58	6.64
2/1/02	6.57	7.28	6.60	7.38	6.57	7.06	6.60	6.98
5/1/02	6.62	7.14	6.40	7.40	6.62	7.08	6.40	6.88
8/1/02	6.59	7.25	6.54	7.33	6.59	6.92	6.52	6.90
11/1/02	6.74	7.30	6.55	7.29	6.74	6.98	6.55	6.93
14/1/02	6.68	7.15	6.67	7.35	6.68	6.95	6.65	7.03
17/1/02	6.42	7.22	6.55	7.42	6.42	7.25	6.56	7.08
20/1/02	6.55	7.34	6.37	7.25	6.55	7.14	6.35	6.94
23/1/02	6.58	7.13	6.62	7.22	6.58	7.19	6.60	7.10
26/1/02	6.79	7.26	6.55	7.26	6.79	7.12	6.55	7.05
29/1/02	6.48	7.21	6.22	7.16	6.48	7.00	6.22	6.84
1/2/02	6.46	7.22	6.41	7.11	6.46	6.97	6.42	7.02
4/2/02	6.44	7.28	6.40	7.15	6.44	6.88	6.40	7.06
Max	6.79	7.34	6.67	7.42	6.79	7.25	6.65	7.10
Min	6.42	7.13	6.22	7.11	6.42	6.88	6.22	6.64
Mean	6.58	7.23	6.50	7.28	6.58	7.04	6.49	6.96
SD	0.11	0.06	0.13	0.10	0.11	0.11	0.12	0.13

Table B.29 Data of temperature of RUN I

Date	Ambient temperature (°C)	Temperature							
		R31		R32		R33		R34	
		Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)
30/12/01	20.00	20.00	19.50	20.00	19.00	20.00	19.50	20.00	19.00
2/1/02	21.00	20.50	20.00	20.50	19.00	20.00	20.50	20.00	19.00
5/1/02	25.00	24.00	23.50	24.00	22.50	24.50	23.00	24.00	22.00
8/1/02	27.00	26.50	24.50	26.50	25.50	27.00	26.00	27.00	24.00
11/1/02	28.00	27.00	25.50	27.00	24.50	27.50	26.00	27.50	25.50
14/1/02	30.00	28.00	27.00	28.50	25.00	28.00	24.00	29.00	25.50
17/1/02	29.00	27.00	25.50	28.00	26.00	27.00	24.00	28.00	26.00
20/1/02	30.00	29.00	26.50	29.00	25.50	30.00	25.50	28.50	26.00
23/1/02	27.00	26.00	26.50	25.50	26.00	26.50	25.00	25.50	25.00
26/1/02	24.00	23.50	24.00	24.00	23.50	24.00	23.00	24.00	22.50
29/1/02	30.50	31.50	30.00	30.00	29.00	31.50	30.00	30.00	30.50
1/2/02	31.50	30.00	28.50	29.50	29.00	30.00	29.50	29.00	28.00
4/2/02	32.00	30.00	29.50	29.00	28.50	30.00	29.00	28.00	28.00
Max	32.00	31.50	30.00	30.00	29.00	31.50	30.00	30.00	30.50
Min	20.00	20.00	19.50	20.00	19.00	20.00	19.50	20.00	19.00
Mean	27.31	26.38	25.42	26.27	24.85	26.62	25.00	26.19	24.69
SD	3.84	3.56	3.20	3.31	3.26	3.65	3.21	3.31	3.39

Table B.30 Data of flow rate of RUN III

Date	Q							
	R31		R32		R33		R34	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
30/12/01	90.00	46.08	90.00	46.08	27.00	14.40	27.00	14.40
2/1/02	90.00	40.32	90.00	46.08	27.00	11.52	27.00	12.60
5/1/02	90.00	28.80	90.00	40.32	27.00	10.08	27.00	11.52
8/1/02	90.00	40.32	90.00	40.32	27.00	10.08	27.00	8.64
11/1/02	90.00	40.32	90.00	36.00	27.00	12.60	27.00	10.80
14/1/02	90.00	36.00	90.00	36.00	27.00	11.52	27.00	11.52
17/1/02	90.00	36.00	90.00	40.32	27.00	10.80	27.00	10.80
20/1/02	90.00	46.08	90.00	37.44	27.00	10.80	27.00	11.52
23/1/02	90.00	40.32	90.00	36.00	27.00	21.60	27.00	21.60
26/1/02	90.00	37.44	90.00	40.32	27.00	12.60	27.00	11.52
29/1/02	90.00	40.32	90.00	33.12	27.00	10.80	27.00	10.80
1/2/02	90.00	33.12	90.00	31.68	27.00	10.80	27.00	8.64
4/2/02	90.00	31.68	90.00	28.80	27.00	8.64	27.00	8.64
Max	90.00	46.08	90.00	46.08	27.00	21.60	27.00	21.60
Min	90.00	28.80	90.00	28.80	27.00	8.64	27.00	8.64
Mean	90.00	38.22	90.00	37.88	27.00	12.02	27.00	11.77
SD	0.00	5.11	0.00	5.10	0.00	3.21	0.00	3.38

Table B.31 Data of COD of RUN IV

Date	COD											
	R41		% Removal	R42		% Removal	R43		% Removal	R44		% Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
6/2/02	125.69	31.47	74.96	107.20	28.78	73.15	125.69	19.13	84.78	107.20	20.96	80.45
9/2/02	113.50	38.03	66.49	96.82	34.33	64.54	113.50	17.98	84.16	96.82	15.78	83.70
12/2/02	120.09	45.88	61.80	108.60	43.51	59.94	120.09	26.93	77.58	108.60	23.47	78.39
15/2/02	109.39	49.24	54.99	115.65	47.21	59.18	109.39	23.22	78.77	115.65	25.18	78.23
18/2/02	98.85	42.51	57.00	95.09	40.62	57.28	98.85	33.64	65.97	95.09	32.52	65.80
21/2/02	93.20	36.38	60.97	90.42	38.24	57.71	93.20	31.86	65.82	90.42	29.75	67.10
24/2/02	109.43	34.52	68.45	116.98	33.66	71.23	109.43	24.48	77.63	116.98	23.64	79.79
27/2/02	90.19	38.03	57.83	99.73	42.97	56.91	90.19	27.44	69.58	99.73	25.08	74.85
2/3/02	124.08	35.21	71.62	107.55	35.21	67.26	124.08	25.58	79.38	107.55	24.55	77.17
5/3/02	112.80	34.96	69.01	114.77	36.12	68.53	112.80	21.84	80.64	114.77	25.02	78.20
8/3/02	107.32	29.62	72.40	106.63	31.48	70.48	107.32	19.75	81.60	106.63	18.04	83.08
11/3/02	121.25	25.53	78.94	125.56	28.73	77.12	121.25	22.46	81.48	125.56	19.64	84.36
14/3/02	117.65	28.45	75.82	107.23	27.93	73.95	117.65	15.73	86.63	107.23	20.24	81.12
17/3/02	101.96	35.81	64.88	97.45	34.33	64.77	101.96	20.61	79.79	97.45	22.57	76.84
Max	125.69	49.24	78.94	125.56	47.21	77.12	125.69	33.64	86.63	125.56	32.52	84.36
Min	90.19	25.53	54.99	90.42	27.93	56.91	90.19	15.73	65.82	90.42	15.78	65.80
Mean	111.03	36.14	66.94	107.09	36.06	65.94	111.03	23.85	78.00	107.09	23.37	77.87
SD	11.17	6.54	7.53	9.77	5.94	6.84	11.17	5.12	6.57	9.77	4.39	5.53
%Removal		67.45			66.33			78.52			78.17	

Table B.32 Data of TKN of RUN IV

Date	TKN											
	R41		% Removal	R42		% Removal	R43		% Removal	R44		% Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
6/2/02	5.44	0.84	84.56	5.32	2.24	57.89	5.44	0.56	89.71	5.32	0.56	89.47
9/2/02	5.32	0.84	84.21	5.32	1.40	73.68	5.32	0.56	89.47	5.32	0.56	89.47
12/2/02	5.60	0.56	90.00	5.44	0.84	84.56	5.60	0.56	90.00	5.44	0.56	89.71
15/2/02	5.04	0.84	83.33	5.04	0.84	83.33	5.04	0.56	88.89	5.04	1.40	72.22
18/2/02	5.44	2.24	58.82	5.04	2.24	55.56	5.44	2.52	53.68	5.04	1.68	66.67
21/2/02	5.32	2.24	57.89	5.04	2.24	55.56	5.32	1.40	73.68	5.04	1.40	72.22
24/2/02	5.04	2.80	44.44	5.44	2.80	48.53	5.04	1.12	77.78	5.44	1.12	79.41
27/2/02	5.32	2.80	47.37	5.32	3.36	36.84	5.32	0.84	84.21	5.32	1.40	73.68
2/3/02	5.04	2.80	44.44	5.32	2.52	52.63	5.04	0.84	83.33	5.32	1.40	73.68
5/3/02	5.04	2.52	50.00	5.44	2.52	53.68	5.04	2.24	55.56	5.44	0.84	84.56
8/3/02	5.04	2.52	50.00	5.04	2.80	44.44	5.04	1.12	77.78	5.04	2.24	55.56
11/3/02	5.04	2.80	44.44	5.04	2.8	44.44	5.04	2.24	55.56	5.04	1.12	77.78
14/3/02	5.04	3.08	38.89	5.04	2.80	44.44	5.04	2.52	50.00	5.04	1.12	77.78
17/3/02	5.04	2.80	44.44	5.04	3.08	38.89	5.04	2.24	55.56	5.04	2.24	55.56
Max	5.60	3.08	90.00	5.44	3.36	84.56	5.60	2.52	90.00	5.44	2.24	89.71
Min	5.04	0.56	38.89	5.04	0.84	36.84	5.04	0.56	50.00	5.04	0.56	55.56
Mean	5.20	2.12	58.78	5.21	2.32	55.32	5.20	1.38	73.23	5.21	1.26	75.56
SD	0.20	0.92	18.38	0.18	0.78	15.21	0.20	0.80	15.65	0.18	0.55	11.10
%Removal		59.21			55.43			73.45			75.80	

Table B.33 Data of TP of RUN IV

Date	TP											
	R41		% Removal	R42		% Removal	R43		% Removal	R44		% Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
6/2/02	1.44	0.33	77.08	1.50	0.33	78.00	1.44	0.33	77.08	1.50	0.17	88.67
9/2/02	1.32	0.38	71.21	1.44	0.33	77.08	1.32	0.43	67.42	1.44	0.17	88.19
12/2/02	1.32	0.49	62.88	1.32	0.38	71.21	1.32	0.38	71.21	1.32	0.22	83.33
15/2/02	1.50	0.54	64.00	1.50	0.33	78.00	1.50	0.33	78.00	1.50	0.11	92.67
18/2/02	1.50	0.49	67.33	0.96	0.59	38.54	1.44	0.43	70.14	0.91	0.27	70.33
21/2/02	1.66	0.59	64.46	1.44	0.54	62.50	1.66	0.27	83.73	1.44	0.27	81.25
24/2/02	1.44	0.54	62.50	1.44	0.54	62.50	1.50	0.38	74.67	1.39	0.33	76.26
27/2/02	1.39	0.59	57.55	1.44	0.59	59.03	1.44	0.33	77.08	1.39	0.43	69.06
2/3/02	1.39	0.43	69.06	1.39	0.59	57.55	1.44	0.38	73.61	1.39	0.33	76.26
5/3/02	1.39	0.43	69.06	1.39	0.43	69.06	1.39	0.33	76.26	1.12	0.33	70.54
8/3/02	1.29	0.49	62.02	1.39	0.38	72.66	1.39	0.27	80.58	1.39	0.38	72.66
11/3/02	1.39	0.38	72.66	1.38	0.38	72.46	1.39	0.27	80.58	1.38	0.33	76.09
14/3/02	1.32	0.54	59.09	1.32	0.59	55.30	1.32	0.33	75.00	1.32	0.33	75.00
17/3/02	1.32	0.54	59.09	1.32	0.59	55.30	1.32	0.33	75.00	1.32	0.33	75.00
Max	1.66	0.59	77.08	1.50	0.59	78.00	1.66	0.43	83.73	1.50	0.43	92.67
Min	1.29	0.33	57.55	0.96	0.33	38.54	1.32	0.27	67.42	0.91	0.11	69.06
Mean	1.41	0.48	66.07	1.38	0.46	65.69	1.43	0.34	75.80	1.35	0.28	78.49
SD	0.10	0.08	5.71	0.13	0.11	11.25	0.09	0.05	4.36	0.16	0.09	7.45
%Removal		66.10			66.50			75.96			79.02	

Table B.34 Data of TSS of RUN IV

Date	TSS											
	R41		% Removal	R42		% Removal	R43		% Removal	R44		% Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
6/2/02	118.00	42.00	64.41	106.00	44.00	58.49	118.00	14.00	88.14	106.00	24.00	77.36
9/2/02	124.00	16.00	87.10				124.00	26.00	79.03			
12/2/02	96.00	54.00	43.75	144.00	78.00	45.83	96.00	34.00	64.58	144.00	48.00	66.67
15/2/02	52.00	32.00	38.46	88.00	52.00	40.91				88.00	38.00	56.82
18/2/02	130.00	68.00	47.69									
21/2/02	112.00	100.00	10.71	144.00	24.00	83.33	120.00	40.00	66.67			
24/2/02	118.00	52.00	55.93	128.00	48.00	62.50	118.00	32.00	72.88	132.00	10.00	92.42
27/2/02	72.00	44.00	38.89				72.00	20.00	72.22	114.00	12.00	89.47
2/3/02	98.00	12.00	87.76	108.00	86.00	20.37	98.00	14.00	85.71	108.00	6.00	94.44
5/3/02	80.00	42.00	47.50	94.00	36.00	61.70	80.00	16.00	80.00	94.00	22.00	76.60
8/3/02	112.00	50.00	55.36	72.00	20.00	72.22	112.00	8.00	92.86	72.00	12.00	83.33
11/3/02	120.00	58.00	51.67	120	44	63.33	120.00	18	85.00	120	32	73.33
14/3/02	112.00	32.00	71.43	112.00	58.00	48.21	112.00	28	75.00	112.00	14	87.50
17/3/02	124.00	48.00	61.29	124.00	70.00	43.55	124.00	22.00	82.26	124.00	26.00	79.03
Max	130.00	100.00	87.76	144.00	86.00	83.33	124.00	40.00	92.86	144.00	48.00	94.44
Min	52.00	12.00	10.71	72.00	20.00	20.37	72.00	8.00	64.58	72.00	6.00	56.82
Mean	104.86	46.43	54.42	112.73	50.91	54.59	107.83	22.67	78.70	110.36	22.18	79.73
SD	22.72	21.74	20.07	22.49	20.94	17.14	17.47	9.51	8.67	20.39	13.10	11.39
%Removal		55.72			54.84			78.98			79.90	

Table B.35 Data of VSS of RUN IV

Date	VSS											
	R41		% Removal	R42		% Removal	R43		% Removal	R44		% Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
6/2/02												
9/2/02	162.00	108.00	33.33	124.00	70.00	43.55	162.00	48.00	70.37	124.00	38.00	69.35
12/2/02	100.00	90.00	10.00	94.00	90.00	4.26	100.00	54.00	46.00	94.00	60.00	36.17
15/2/02	86.00	68.00	20.93	100.00	82.00	18.00	86.00	20.00	76.74	100.00	54.00	46.00
18/2/02												
21/2/02										88.00	56.00	36.36
24/2/02	130.00	78.00	40.00	110.00	60.00	45.45	130.00	54.00	58.46	80.00	44.00	45.00
27/2/02	92.00	68.00	26.09	100.00	80.00	20.00	92.00	42.00	54.35	120.00	34.00	71.67
2/3/02	118.00	30.00	74.58	124.00	110.00	11.29	118.00	42.00	64.41	124.00	28.00	77.42
5/3/02	106.00	70.00	33.96	112.00	62.00	44.64	106.00	38.00	64.15	112.00	40.00	64.29
8/3/02	132.00	74.00	43.94	90.00	48.00	46.67	132.00	34.00	74.24	90.00	58.00	35.56
11/3/02	150.00	100.00	33.33	150	72	52.00	150.00	30	80.00	150	52	65.33
14/3/02	114.00	64.00	43.86	114.00	60.00	47.37	114.00	42	63.16	114.00	64	43.86
17/3/02	90.00	66.00	26.67	90.00	50.00	44.44	90.00	64.00	28.89	90.00	54.00	40.00
Max	162.00	108.00	74.58	150.00	110.00	52.00	162.00	64.00	80.00	150.00	64.00	77.42
Min	86.00	30.00	10.00	90.00	48.00	4.26	86.00	20.00	28.89	80.00	28.00	35.56
Mean	116.36	74.18	35.15	109.82	71.27	34.33	116.36	42.55	61.89	107.17	48.50	52.58
SD	24.98	20.72	16.52	18.08	18.38	17.20	24.98	12.30	14.82	20.35	11.38	15.72
%Removal		36.25			35.10			63.44			54.74	

Table B.36 Data of Cd of RUN IV

Date	Cd											
	R41		% Removal	R42		% Removal	R43		% Removal	R44		% Removal
	Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)		Influent (mg/L)	Effluent (mg/L)	
6/2/02	0.01	0.01		19.28	0.05	99.74	0.01	0.01		19.28	0.07	99.62
9/2/02	0.01	0.00		17.94	0.05	99.72	0.01	0.00		17.94	0.02	99.90
12/2/02	0.01	0.00		20.14	0.38	98.14	0.01	0.00		20.14	0.14	99.28
15/2/02	0.02	0.00		21.45	0.35	98.38	0.02	0.00		21.45	0.09	99.59
18/2/02	0.01	0.01		19.78	0.48	97.56	0.01	0.00		19.78	0.06	99.71
21/2/02	0.01	0.00		18.50	0.25	98.67	0.01	0.00		18.50	0.06	99.68
24/2/02	0.01	0.00		18.77	0.20	98.91	0.01	0.00		18.77	0.03	99.87
27/2/02	0.01	0.00		19.43	0.10	99.48	0.01	0.00		19.43	0.04	99.80
2/3/02	0.02	0.00		18.48	0.08	99.57	0.02	0.00		18.48	0.05	99.75
5/3/02	0.01	0.00		22.05	0.07	99.70	0.01	0.00		22.05	0.06	99.75
8/3/02	0.01	0.01		19.51	0.06	99.67	0.01	0.01		19.51	0.06	99.68
11/3/02	0.01	0.00		21.75	0.0586	99.73	0.01	0.0019		21.75	0.0544	99.75
14/3/02	0.01	0.00		17.88	0.09	99.51	0.01	0.0074		17.88	0.0655	99.63
17/3/02	0.02	0.01		19.40	0.09	99.52	0.02	0.01		19.40	0.05	99.73
Max	0.02	0.01		22.05	0.48	99.74	0.02	0.01		22.05	0.14	99.90
Min	0.01	0.00		17.88	0.05	97.56	0.01	0.00		17.88	0.02	99.28
Mean	0.01	0.00		19.60	0.16	99.16	0.01	0.00		19.60	0.06	99.70
SD	0.00	0.00		1.34	0.14	0.71	0.00	0.00		1.34	0.03	0.15
%Removal					99.16						99.69	

Table B.37 Data of DO of RUN IV

Date	DO							
	R41		R42		R43		R44	
	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)	Influent (mg/L)	Effluent (mg/L)
6/2/02	-	4.50	-	4.80	-	5.50	-	5.05
9/2/02	-	4.25	-	4.50	-	5.80	-	5.55
12/2/02	-	4.15	-	4.25	-	5.55	-	5.45
15/2/02	-	4.25	-	4.10	-	6.00	-	5.80
18/2/02	-	4.15	-	4.25	-	6.00	-	4.30
21/2/02	0.63	5.22	0.63	6.25	0.64	6.42	0.63	5.45
24/2/02	0.66	5.16	0.62	5.14	0.66	5.44	0.62	6.45
27/2/02	0.60	4.75	0.61	4.14	0.60	5.28	0.61	6.00
2/3/02	0.43	4.55	0.42	4.52	0.43	5.78	0.42	5.27
5/3/02	0.40	5.14	0.40	4.75	0.40	6.04	0.40	6.18
8/3/02	0.40	5.35	0.42	4.55	0.40	6.54	0.42	6.45
11/3/02	0.38	6.26	0.33	5.52	0.38	6.72	0.33	6.57
14/3/02	0.61	6.00	0.60	6.44	0.61	6.11	0.60	6.38
17/3/02	0.66	5.75	0.56	6.41	0.66	6.62	0.56	6.42
Max	0.66	6.26	0.63	6.44	0.66	6.72	0.63	6.57
Min	0.38	4.15	0.33	4.10	0.38	5.28	0.33	4.30
Mean	0.53	4.96	0.51	4.97	0.53	5.99	0.51	5.81
SD	0.12	0.70	0.12	0.85	0.12	0.46	0.12	0.66

Table B.38 Data of pH of RUN IV

Date	pH							
	R41		R42		R43		R44	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
6/2/02	6.65	7.13	6.71	7.25	6.65	7.08	6.71	7.06
9/2/02	6.95	7.20	6.62	7.44	6.82	6.95	6.62	7.25
12/2/02	6.74	7.10	6.50	7.30	6.74	6.98	6.50	7.16
15/2/02	6.45	7.15	6.46	7.26	6.45	7.06	6.46	7.10
18/2/02	6.32	7.20	6.72	7.15	6.32	7.11	6.72	7.08
21/2/02	6.68	7.54	6.67	7.24	6.68	7.44	6.67	7.04
24/2/02	6.74	7.30	6.44	7.25	6.74	7.37	6.44	7.15
27/2/02	6.82	7.34	6.20	7.42	6.82	7.17	6.20	7.23
2/3/02	6.44	7.45	6.51	7.01	6.44	7.24	6.51	7.31
5/3/02	6.90	7.51	6.42	7.12	6.90	7.25	6.42	7.22
8/3/02	6.64	7.34	6.45	7.04	6.64	7.35	6.45	7.12
11/3/02	6.51	7.55	6.43	7.06	6.51	7.44	6.43	7.09
14/3/02	6.74	7.28	6.22	7.05	6.74	7.40	6.22	7.07
17/3/02	6.66	7.35	6.14	7.15	6.66	7.28	6.14	7.11
Max	6.95	7.55	6.72	7.44	6.90	7.44	6.72	7.31
Min	6.32	7.10	6.14	7.01	6.32	6.95	6.14	7.04
Mean	6.66	7.32	6.46	7.20	6.65	7.22	6.46	7.14
SD	0.18	0.15	0.18	0.14	0.17	0.17	0.18	0.08

Table B.39 Data of flow rate of RUN IV

Date	Q							
	R41		R42		R43		R44	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
6/2/02	90.00	36.00	90.00	36.00	27.00	14.35	27.00	12.60
9/2/02	90.00	40.32	90.00	43.20	27.00	12.60	27.00	12.60
12/2/02	90.00	46.06	90.00	36.00	27.00	10.80	27.00	10.80
15/2/02	90.00	41.76	90.00	40.32	27.00	10.80	27.00	10.80
18/2/02	90.00	46.06	90.00	46.06	27.00	17.98	27.00	12.60
21/2/02	90.00	36.00	90.00	41.76	27.00	12.60	27.00	14.40
24/2/02	90.00	41.76	90.00	40.32	27.00	14.40	27.00	14.40
27/2/02	90.00	43.20	90.00	43.20	27.00	14.40	27.00	12.60
2/3/02	90.00	31.68	90.00	31.68	27.00	12.60	27.00	11.52
5/3/02	90.00	23.04	90.00	36.00	27.00	10.80	27.00	11.52
8/3/02	90.00	36.00	90.00	31.68	27.00	10.08	27.00	10.80
11/3/02	90.00	36.00	90.00	36.00	27.00	10.08	27.00	11.52
14/3/02	90.00	23.04	90.00	28.08	27.00	12.60	27.00	11.52
17/3/02	90.00	28.80	90.00	28.08	27.00	11.52	27.00	11.52
Max	90.00	46.06	90.00	46.06	27.00	17.98	27.00	14.40
Min	90.00	23.04	90.00	28.08	27.00	10.08	27.00	10.80
Mean	90.00	36.41	90.00	37.03	27.00	12.54	27.00	12.09
SD	0.00	7.56	0.00	5.71	0.00	2.18	0.00	1.19

Table B.40 Data of temperature of RUN IV

Date	Ambient temperature (°C)	Temperature							
		R41		R42		R43		R44	
		Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)	Influent (°C)	Effluent (°C)
6/2/02	30.00	29.50	29.00	29.50	28.00	29.50	29.00	29.50	28.50
9/2/02	32.00	30.50	29.00	30.00	29.50	30.50	30.00	30.00	30.00
12/2/02	31.50	29.50	29.00	29.50	28.50	29.50	28.50	29.50	29.50
15/2/02	30.50	29.50	28.00	29.50	28.00	29.50	28.00	29.50	28.00
18/2/02	30.00	28.50	28.50	28.50	28.00	28.50	28.00	28.50	28.00
21/2/02	31.50	31.50	31.50	31.00	31.00	31.50	31.00	31.00	31.00
24/2/02	32.00	31.00	30.50	31.00	31.00	31.00	30.50	31.00	31.00
27/2/02	27.00	27.50	27.50	27.50	27.00	27.50	26.50	27.50	27.00
2/3/02	26.00	26.50	26.00	26.50	26.50	26.50	26.00	26.50	26.50
5/3/02	29.50	30.00	29.00	29.00	29.00	30.00	30.00	29.00	27.50
8/3/02	33.50	33.00	31.50	32.50	32.00	33.00	33.00	32.50	31.50
11/3/02	32.50	31.00	31.00	30.50	30.50	31.00	30.50	30.50	30.50
14/3/02	33.50	32.50	32.00	32.50	32.00	32.50	30.00	32.50	31.50
17/3/45	29.50	29.00	29.00	29.00	29.00	29.00	29.00	29.00	28.50
Max	33.50	33.00	32.00	32.50	32.00	33.00	33.00	32.50	31.50
Min	26.00	26.50	26.00	26.50	26.50	26.50	26.00	26.50	26.50
Mean	30.64	29.96	29.39	29.75	29.29	29.96	29.29	29.75	29.21
SD	2.21	1.80	1.71	1.70	1.77	1.80	1.84	1.70	1.72

APPENDIX C

Inflow and outflow rate of experimental data

Table C.1 Inflow and Outflow Rate of COD data of RUN I

Date	R11		R12		R13		R14	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
15/9/01	9,274.50	1,946.59	8,930.70	2,286.09	2,679.21	446.47	2,787.75	412.13
17/9/01	9,618.30	1,582.85	9,274.50	2,190.16	2,782.35	226.71	2,885.49	377.78
20/9/01	9,169.20	2,441.72	9,000.00	2,717.28	2,750.76	347.76	2,648.97	237.60
23/9/01	8,150.40	2,045.42	8,659.80	2,347.32	2,546.91	271.62	2,802.06	339.66
26/9/01	8,307.00	2,347.32	8,884.80	2,392.93	2,732.94	362.16	2,781.54	372.96
29/9/01	8,568.00	2,463.44	8,884.80	2,207.37	2,665.98	373.25	2,663.55	393.98
2/10/01	9,045.00	2,452.21	9,214.20	2,303.65	2,665.98	373.25	2,638.44	417.64
5/10/01	10,644.30	2,258.12	10,908.90	2,512.48	3,135.78	388.68	3,272.67	422.82
8/10/01	11,270.70	2,176.07	11,543.40	2,634.36	3,190.32	368.23	3,247.29	368.23
11/10/01	10,787.40	2,012.67	10,504.80	2,290.38	3,085.02	398.84	3,031.29	347.77
14/10/01	9,922.50	2,203.80	9,562.50	2,304.92	3,038.58	402.89	2,924.10	356.80
17/10/01	10,164.60	1,908.40	9,943.20	2,070.92	2,964.06	454.72	2,898.72	373.47
20/10/01	10,482.30	1,830.57	10,347.30	1,789.72	3,063.69	365.47	3,249.18	358.18
23/10/01	10,861.20	1,543.28	0.00	0.00	3,170.07	246.56	3,414.15	382.54
26/10/01	0.00	0.00	0.00	0.00	2,707.56	183.24	3,175.74	261.36
29/10/01	8,967.60	1,035.99	9,165.60	1,334.74	2,664.09	296.82	2,891.97	225.72
1/11/01	8,861.40	1,314.20	9,517.50	1,312.88	2,682.18	260.26	3,033.45	276.68
4/11/01	9,313.20	1,657.50	10,193.40	1,910.30	2,814.21	335.33	2,922.75	324.65
7/11/01	9,507.60	2,037.66	9,940.50	2,055.40	2,850.12	398.84	2,816.37	338.90
10/11/01	10,663.20	1,586.07	10,108.80	1,473.98	2,959.74	359.70	3,065.85	356.18
13/11/01	9,851.40	1,982.59	9,768.60	1,993.42	2,998.35	350.78	2,976.75	370.26
16/11/01	9,393.30	1,751.67	9,774.90	1,995.84	2,822.31	343.03	2,906.55	359.70
19/11/01	10,012.50	1,962.43	9,318.60	1,910.02	2,880.63	360.93	2,957.58	348.77
sum	212,835.60	42,540.59	203,446.80	44,034.16	65,850.84	7,915.55	67,992.21	8,023.77
% Removal		80.01		78.36		87.98		88.20

Table C.2 Inflow and Outflow Rate of COD data of RUN II

Date	R21		R22		R23		R24	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
25/11/01	11,077.20	1,306.37	0.00	0.00	3,323.16	442.26	3,381.75	362.70
28/11/01	10,548.00	1,666.14	0.00	0.00	3,164.40	272.16	3,164.40	326.59
30/11/01	0.00	0.00	9,073.80	1,949.59	0.00	0.00	3,011.58	186.95
3/12/01	11,589.30	1,306.37	11,306.70	1,894.23	3,368.79	276.91	3,323.16	332.35
6/12/01	10,903.50	2,071.24	11,509.20	1,882.94	3,262.68	186.95	0.00	0.00
9/12/01	10,730.70	1,595.12	0.00	0.00	0.00	0.00	0.00	0.00
12/12/01	0.00	0.00	10,903.50	620.24	3,504.06	199.41	0.00	0.00
15/12/01	11,679.30	620.32	10,548.00	720.00	3,476.79	266.49	3,164.40	304.56
18/12/01	11,272.50	1,471.39	10,839.60	1,228.95	3,467.88	144.02	3,151.44	404.46
21/12/01	10,014.30	1,308.44	11,462.40	1,675.99	3,062.34	348.91	3,438.72	261.37
24/12/01	9,050.40	1,311.90	10,879.20	1,580.08	2,667.87	172.57	3,193.83	192.07
27/12/01	10,834.20	1,219.68	11,010.60	1,259.60	3,250.26	228.11	3,303.18	292.72
sum	107,699.40	13,876.96	97,533.00	12,811.62	32,548.23	2,537.79	29,132.46	2,663.78
% Removal		87.12		86.86		92.20		90.86

Table C.3 Inflow and Outflow Rate of COD data of RUN III

Date	R31		R32		R33		R34	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
30/12/01	11,087.10	1,669.48	11,087.10	1,669.48	3,326.13	302.11	3,326.13	427.97
2/1/02	11,275.20	1,460.79	11,087.10	1,772.24	3,382.56	208.74	3,326.13	296.73
5/1/02	10,434.60	661.82	10,720.80	1,203.96	3,130.38	219.14	3,277.26	250.44
8/1/02	10,108.80	1,314.84	10,638.00	1,314.84	3,088.26	155.43	3,179.52	172.20
11/1/02	9,783.00	1,241.45	9,945.00	1,239.12	2,934.90	251.12	2,983.50	163.84
14/1/02	10,761.30	1,239.12	10,271.70	1,173.96	3,166.02	241.69	3,081.51	241.69
17/1/02	11,568.60	1,448.28	11,745.90	1,778.92	3,381.75	260.93	3,363.12	297.11
20/1/02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23/1/02	9,512.10	1,393.06	8,150.40	1,225.08	2,803.14	491.40	2,414.61	347.54
26/1/02	9,146.70	1,141.55	0.00	0.00	2,716.74	313.24	0.00	0.00
29/1/02	11,179.80	1,307.98	10,370.70	1,020.76	3,331.26	250.78	3,145.50	220.97
1/2/02	10,632.60	1,130.05	9,478.80	1,034.67	3,138.48	222.70	2,843.64	180.40
4/2/02	10,483.20	1,037.52	11,066.40	870.91	3,107.16	208.66	3,319.92	174.10
sum	125,973.00	15,045.94	114,561.90	14,303.92	37,506.78	3,125.93	34,260.84	2,772.98
% Removal		88.06		87.51		91.67		91.91

Table C.4 Inflow and Outflow Rate of COD data of RUN IV

Date	R41		R42		R43		R44	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
6/2/02	11,312.10	1,132.92	9,648.00	1,036.08	3,393.63	274.52	2,894.40	264.10
9/2/02	10,215.00	1,533.37	8,713.80	1,483.06	3,064.50	226.55	2,614.14	198.83
12/2/02	10,808.10	2,113.23	9,774.00	1,566.36	3,242.43	290.84	2,932.20	253.48
15/2/02	9,845.10	2,056.26	10,408.50	1,903.51	2,953.53	250.78	3,122.55	271.94
18/2/02	8,896.50	1,958.01	8,558.10	1,870.96	2,668.95	604.85	2,567.43	409.75
21/2/02	8,388.00	1,309.68	8,137.80	1,596.90	2,516.40	401.44	2,441.34	428.40
24/2/02	9,848.70	1,441.56	10,528.20	1,357.17	2,954.61	352.51	3,158.46	340.42
27/2/02	8,117.10	1,642.90	8,975.70	1,856.30	2,435.13	395.14	2,692.71	316.01
2/3/02	11,167.20	1,115.45	9,679.50	1,115.45	3,350.16	322.31	2,903.85	282.82
5/3/02	10,152.00	805.48	10,329.30	1,300.32	3,045.60	235.87	3,098.79	288.23
8/3/02	9,658.80	1,066.32	9,596.70	997.29	2,897.64	199.08	2,879.01	194.83
11/3/02	10,912.50	919.08	11,300.40	1,034.28	3,273.75	226.40	3,390.12	226.25
14/3/02	10,588.50	655.49	9,650.70	784.27	3,176.55	198.20	2,895.21	233.16
17/3/02	9,176.40	1,031.33	8,770.50	963.99	2,752.92	237.43	2,631.15	260.01
sum	139,086.00	18,781.07	134,071.20	18,865.94	41,725.80	4,215.90	40,221.36	3,968.22
% Removal		86.50		85.93		89.90		90.13

Table C.5 Inflow and Outflow Rate of TKN data of RUN I

Date	R11		R12		R13		R14	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
15/9/01	504.00	214.23	478.80	230.63	143.64	52.42	151.20	48.38
17/9/01	453.60	193.54	453.60	196.38	143.64	44.35	143.64	44.35
20/9/01	478.80	201.32	478.80	201.60	136.08	30.24	136.08	30.24
23/9/01	453.60	107.12	453.60	154.83	120.96	20.16	136.08	20.16
26/9/01	453.60	154.83	0.00	0.00	143.64	20.16	136.08	20.16
29/9/01	478.80	154.83	453.60	178.53	136.08	27.22	143.64	28.73
2/10/01	554.40	178.53	504.00	142.82	136.08	27.22	136.08	22.68
5/10/01	478.80	204.02	504.00	222.57	143.64	19.15	151.20	27.22
8/10/01	478.80	186.28	478.80	204.02	173.88	22.68	143.64	22.68
11/10/01	478.80	148.78	579.60	135.48	143.64	22.68	151.20	17.14
14/10/01	579.60	204.02	554.40	196.38	166.32	18.14	151.20	17.14
17/10/01	504.00	177.41	504.00	196.38	151.20	12.85	166.32	21.42
20/10/01	478.80	140.92	478.80	159.47	143.64	18.14	143.64	13.61
23/10/01	478.80	167.73	453.60	139.53	136.08	13.61	136.08	11.09
26/10/01	453.60	181.19	478.80	188.70	136.08	10.08	136.08	10.08
29/10/01	453.60	148.38	453.60	166.92	136.08	10.08	143.64	10.08
1/11/01	478.80	129.83	478.80	129.83	143.64	19.15	136.08	14.36
4/11/01	554.40	159.67	554.40	141.93	151.20	14.36	143.64	13.61
7/11/01	504.00	195.15	478.80	177.41	166.32	18.14	151.20	21.42
10/11/01	504.00	141.93	478.80	133.06	143.64	17.14	151.20	17.14
13/11/01	504.00	161.28	478.80	152.41	136.08	16.13	136.08	17.14
16/11/01	478.80	130.64	453.60	169.34	136.08	21.42	136.08	17.14
19/11/01	478.80	161.28	478.80	161.28	136.08	17.14	136.08	16.13
sum	11,264.40	3,842.89	10,710.00	3,779.49	3,303.72	492.66	3,296.16	482.08
% Removal		65.88		64.71		85.09		85.37

Table C.6 Inflow and Outflow Rate of TKN data of RUN II

Date	R21		R22		R23		R24	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
25/11/01	554.40	112.90	554.40	177.41	166.32	32.76	166.32	30.24
28/11/01	478.80	116.12	478.80	159.67	143.64	25.20	143.64	30.24
30/11/01	504.00	90.32	504.00	141.93	151.20	21.17	151.20	31.75
3/12/01	453.60	193.54	478.80	130.64	136.08	24.19	143.64	32.26
6/12/01	403.20	159.67	403.20	129.02	120.96	22.68	120.96	21.17
9/12/01	478.80	116.12	453.60	145.15	143.64	20.16	136.08	24.19
12/12/01	604.80	80.64	504.00	64.51	173.88	12.10	151.20	7.06
15/12/01	579.60	62.09	504.00	72.58	166.32	21.17	166.32	12.10
18/12/01	504.00	117.94	504.00	124.19	146.88	10.58	166.32	10.08
21/12/01	478.80	159.67	478.80	145.15	143.64	20.16	143.64	5.64
24/12/01	489.60	129.02	478.80	130.64	146.88	9.68	143.64	12.10
27/12/01	504.00	112.90	478.80	101.61	146.88	8.47	146.88	9.68
sum	6,033.60	1,450.92	5,821.20	1,522.48	1,786.32	228.31	1,779.84	226.50
% Removal		75.95		73.85		87.22		87.27

Table C.7 Inflow and Outflow Rate of TKN data of RUN III

Date	R31		R32		R33		R34	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
30/12/01	489.60	129.02	554.40	129.02	151.20	20.16	166.32	8.06
2/1/02	478.80	90.32	554.40	141.93	143.64	19.35	173.88	14.11
5/1/02	504.00	96.77	478.80	112.90	151.20	11.29	143.64	19.35
8/1/02	554.40	135.48	489.60	124.19	151.20	11.29	146.88	9.68
11/1/02	478.80	112.90	489.60	120.96	143.64	24.70	151.20	12.10
14/1/02	478.80	80.64	453.60	80.64	143.64	25.80	136.08	22.58
17/1/02	489.60	90.72	478.80	101.61	146.88	21.17	143.64	24.19
20/1/02	504.00	64.51	489.60	52.42	151.20	18.14	151.20	25.80
23/1/02	504.00	45.16	504.00	50.40	146.88	12.10	151.20	12.10
26/1/02	478.80	31.45	478.80	90.32	136.08	7.06	146.88	6.45
29/1/02	478.80	22.58	489.60	18.55	143.64	6.05	146.88	6.05
1/2/02	489.60	18.55	478.80	17.74	146.88	6.05	146.88	4.84
4/2/02	489.60	17.74	478.80	16.13	143.64	4.84	143.64	4.84
sum	6,418.80	935.83	6,418.80	1,056.79	1,899.72	187.99	1,948.32	170.15
% Removal		85.42		83.54		90.10		91.27

Table C.8 Inflow and Outflow Rate of TKN data of RUN IV

Date	R41		R42		R43		R44	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
6/2/02	489.60	30.24	478.80	80.64	146.88	8.04	143.64	7.06
9/2/02	478.80	33.87	478.80	60.48	143.64	7.06	143.64	7.06
12/2/02	504.00	25.79	489.60	30.24	151.20	6.05	146.88	6.05
15/2/02	453.60	35.08	453.60	33.87	136.08	6.05	136.08	15.12
18/2/02	489.60	103.17	453.60	103.17	146.88	45.31	136.08	21.17
21/2/02	478.80	80.64	453.60	93.54	143.64	17.64	136.08	20.16
24/2/02	453.60	116.93	489.60	112.90	136.08	16.13	146.88	16.13
27/2/02	478.80	120.96	478.80	145.15	143.64	12.10	143.64	17.64
2/3/02	453.60	88.70	478.80	79.83	136.08	10.58	143.64	16.13
5/3/02	453.60	58.06	489.60	90.72	136.08	24.19	146.88	9.68
8/3/02	453.60	90.72	453.60	88.70	136.08	11.29	136.08	24.19
11/3/02	453.60	100.80	453.60	100.80	136.08	22.58	136.08	12.90
14/3/02	453.60	70.96	453.60	78.62	136.08	31.75	136.08	12.90
17/3/02	453.60	80.64	453.60	86.49	136.08	25.80	136.08	25.80
sum	6,548.40	1,036.57	6,559.20	1,185.16	1,964.52	244.56	1,967.76	211.98
% Removal		84.17		81.93		87.55		89.23

Table C.9 Inflow and Outflow Rate of TP data of RUN I

Date	R11		R12		R13		R14	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
15/9/01	125.10	65.04	135.00	76.38	40.50	18.72	27.54	17.28
17/9/01	129.60	76.03	135.00	70.14	37.53	21.78	29.70	15.84
20/9/01	135.00	69.02	129.60	69.12	40.50	17.28	38.88	14.40
23/9/01	110.70	58.02	125.10	66.36	37.53	14.40	0.00	0.00
26/9/01	129.60	55.30	129.60	62.90	37.53	15.30	38.88	17.28
29/9/01	125.10	55.30	125.10	54.20	38.88	10.53	37.53	13.68
2/10/01	125.10	47.82	125.10	54.20	37.53	10.53	38.88	10.53
5/10/01	135.00	52.99	135.00	52.99	34.56	11.12	38.88	10.53
8/10/01	115.20	48.38	115.20	52.99	36.18	6.97	37.53	6.97
11/10/01	135.00	50.18	125.10	48.38	40.50	6.97	37.53	6.58
14/10/01	129.60	39.08	120.60	37.62	37.53	7.94	36.18	6.58
17/10/01	125.10	41.18	135.00	47.82	38.88	6.58	38.88	7.50
20/10/01	135.00	46.74	129.60	46.27	36.18	6.97	29.70	7.94
23/10/01	110.70	44.18	120.60	42.00	38.88	5.35	38.88	7.52
26/10/01	99.00	30.92	99.00	32.20	27.54	4.86	27.54	5.94
29/10/01	0.00	0.00	91.80	39.08	36.18	5.94	36.18	4.86
1/11/01	115.20	43.06	125.10	43.06	29.70	3.76	29.70	4.62
4/11/01	125.10	47.52	115.20	47.52	38.88	6.50	38.88	6.97
7/11/01	135.00	41.18	129.60	41.18	37.53	7.94	34.56	7.50
10/11/01	135.00	27.19	135.00	25.49	27.54	7.50	41.85	6.58
13/11/01	129.60	32.26	125.10	35.68	34.56	6.19	36.18	6.58
16/11/01	120.60	22.29	135.00	33.87	36.18	6.58	38.88	6.58
19/11/01	125.10	21.89	125.10	21.89	36.18	5.81	37.53	5.47
sum	2,750.40	1,015.56	2,866.50	1,101.33	837.00	215.50	790.29	197.71
% Removal		63.08		61.58		74.25		74.98

Table C.10 Inflow and Outflow Rate of TP data of RUN II

Date	R21		R22		R23		R24	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
25/11/01	91.80	33.98	129.60	32.26	27.54	10.06	38.88	7.74
28/11/01	129.60	29.03	118.80	30.59	38.88	4.86	35.64	12.10
30/11/01	129.60	17.34	129.60	35.48	38.88	4.16	38.88	9.56
3/12/01	135.00	33.98	129.60	48.73	38.88	6.19	40.50	5.47
6/12/01	120.60	35.48	116.10	37.44	37.53	7.94	37.53	2.77
9/12/01	116.10	33.70	120.60	33.98	34.83	3.89	37.53	3.89
12/12/01	153.90	15.55	135.00	12.44	44.82	2.33	37.53	2.77
15/12/01	153.00	8.67	144.90	16.99	45.90	4.16	43.47	3.89
18/12/01	135.00	15.44	149.40	15.32	38.88	5.42	44.82	5.94
21/12/01	116.10	22.29	149.40	22.29	37.53	5.47	46.17	2.72
24/12/01	129.60	25.80	135.00	22.29	37.53	2.53	40.50	3.28
27/12/01	129.60	21.77	118.80	17.34	37.53	2.72	38.88	2.53
sum	1,539.90	293.05	1,576.80	325.15	458.73	59.73	480.33	62.67
% Removal		80.97		79.38		86.98		86.95

Table C.11 Inflow and Outflow Rate of TP data of RUN III

Date	R31		R32		R33		R34	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
30/12/01	129.60	12.44	153.90	19.81	40.50	2.45	46.17	5.47
2/1/02	125.10	13.31	159.30	22.58	37.53	3.11	47.79	3.40
5/1/02	129.60	9.50	125.10	15.32	38.88	4.33	37.53	4.38
8/1/02	135.00	21.77	129.60	23.79	40.50	4.33	27.54	4.23
11/1/02	144.90	26.21	135.00	23.40	43.47	7.43	40.50	4.64
14/1/02	149.40	25.20	144.90	25.20	44.82	5.64	43.47	3.80
17/1/02	135.00	21.24	153.90	32.26	38.88	2.92	43.47	4.64
20/1/02	149.40	27.19	129.60	29.95	40.50	2.92	38.88	3.11
23/1/02	116.10	21.77	135.00	21.24	34.83	7.13	40.50	7.13
26/1/02	120.60	24.34	135.00	21.77	36.18	3.40	38.88	3.80
29/1/02	135.00	21.77	135.00	17.88	40.50	3.56	38.88	2.92
1/2/02	135.00	17.88	129.60	13.62	37.53	3.56	44.82	1.90
4/2/02	91.80	10.45	91.80	12.38	37.53	3.28	27.54	1.90
sum	1,696.50	253.08	1,757.70	279.22	511.65	54.08	515.97	51.33
% Removal		85.08		84.11		89.43		90.05

Table C.12 Inflow and Outflow Rate of TP data of RUN IV

Date	R41		R42		R43		R44	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
6/2/02	129.60	11.88	135.00	11.88	38.88	4.74	40.50	2.14
9/2/02	118.80	15.32	129.60	14.26	35.64	5.42	38.88	2.14
12/2/02	118.80	22.57	118.80	13.68	35.64	4.10	35.64	2.38
15/2/02	135.00	22.55	135.00	13.31	40.50	3.56	40.50	1.19
18/2/02	135.00	22.57	86.40	27.18	38.88	7.73	24.57	3.40
21/2/02	149.40	21.24	129.60	22.55	44.82	3.40	38.88	3.89
24/2/02	129.60	22.55	129.60	21.77	40.50	5.47	37.53	4.75
27/2/02	125.10	25.49	129.60	25.49	38.88	4.75	37.53	5.42
2/3/02	125.10	13.62	125.10	18.69	38.88	4.79	37.53	3.80
5/3/02	125.10	9.91	125.10	15.48	37.53	3.56	30.24	3.80
8/3/02	116.10	17.64	125.10	12.04	37.53	2.72	37.53	4.10
11/3/02	125.10	13.68	124.20	13.68	37.53	2.72	37.26	3.80
14/3/02	118.80	12.44	118.80	16.57	35.64	4.16	35.64	3.80
17/3/02	118.80	15.55	118.80	16.57	35.64	3.80	35.64	3.80
sum	1,770.30	247.01	1,730.70	243.13	536.49	60.93	507.87	48.42
% Removal		86.05		85.95		88.64		90.47

Table C.13 Inflow and Outflow Rate of TSS data of RUN I

Date	R11		R12		R13		R14	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
15/9/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17/9/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20/9/01	7,560.00	3,882.60	7,200.00	4,032.00	2,052.00	576.00	2,322.00	900.00
23/9/01	7,020.00	3,570.56	8,280.00	5,114.88	2,376.00	792.00	2,160.00	936.00
26/9/01	0.00	0.00	9,720.00	1,105.92	1,728.00	720.00	2,646.00	432.00
29/9/01	5,040.00	1,658.88	5,760.00	2,932.96	2,106.00	680.40	1,674.00	581.40
2/10/01	5,040.00	1,785.28	5,040.00	2,805.44	1,782.00	518.40	0.00	0.00
5/10/01	4,680.00	1,324.80	0.00	0.00	1,566.00	342.00	1,566.00	324.00
8/10/01	5,580.00	1,693.44	6,300.00	2,517.12	1,728.00	453.60	1,836.00	550.80
11/10/01	6,660.00	1,889.28	5,040.00	1,209.60	1,782.00	356.40	1,728.00	428.40
14/10/01	7,020.00	2,517.12	6,120.00	2,040.32	2,160.00	486.00	1,890.00	397.80
17/10/01	5,220.00	1,520.64	0.00	0.00	1,620.00	244.80	1,836.00	336.60
20/10/01	4,500.00	1,294.20	5,040.00	2,135.70	0.00	0.00	1,944.00	259.20
23/10/01	0.00	0.00	0.00	0.00	1,566.00	291.60	1,350.00	356.40
26/10/01	10,620.00	1,438.00	0.00	0.00	3,348.00	180.00	1,512.00	216.00
29/10/01	9,540.00	1,457.28	11,160.00	1,987.20	3,078.00	288.00	0.00	0.00
1/11/01	7,920.00	1,589.76	10,800.00	1,722.24	2,538.00	239.40	0.00	0.00
4/11/01	0.00	0.00	5,940.00	1,647.36	2,268.00	342.00	1,890.00	388.80
7/11/01	6,120.00	2,027.52	7,200.00	3,421.44	1,998.00	162.00	2,592.00	489.60
10/11/01	6,480.00	2,119.68	6,840.00	1,641.60	2,052.00	489.60	2,268.00	581.40
13/11/01	5,400.00	1,612.80	5,580.00	1,814.40	2,214.00	345.60	0.00	0.00
16/11/01	0.00	0.00	10,260.00	1,209.60	1,458.00	214.20	3,078.00	275.40
19/11/01	10,080.00	1,382.40	10,800.00	1,958.40	2,754.00	91.80	2,376.00	172.80
sum	114,480.00	32,764.24	127,080.00	39,296.18	42,174.00	7,813.80	34,668.00	7,626.60
% Removal		71.38		69.08		81.47		78.00

Table C.14 Inflow and Outflow Rate of TSS data of RUN II

Date	R21		R22		R23		R24	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
25/11/01	5,760.00	1,728.00	8,280.00	2,649.60	2,160.00	514.80	2,106.00	288.00
28/11/01	5,400.00	1,658.88	6,300.00	2,073.60	1,890.00	576.00	1,674.00	129.60
30/11/01	0.00	0.00	4,500.00	1,900.80	0.00	0.00	0.00	0.00
3/12/01	6,300.00	1,958.40	0.00	0.00	0.00	0.00	0.00	0.00
6/12/01	9,720.00	2,787.84	0.00	0.00	2,916.00	291.60	3,186.00	252.00
9/12/01	0.00	0.00	7,020.00	1,958.40	0.00	0.00	2,916.00	748.80
12/12/01	6,480.00	691.20	4,860.00	92.16	1,944.00	311.04	1,728.00	151.20
15/12/01	9,180.00	1,733.76	10,800.00	1,382.40	4,050.00	554.40	3,240.00	345.60
18/12/01	7,020.00	1,310.40	9,720.00	2,741.76	2,106.00	655.20	2,916.00	828.00
21/12/01	7,200.00	2,384.64	7,020.00	1,347.84	2,160.00	432.00	1,836.00	120.96
24/12/01	8,820.00	1,751.04	5,400.00	1,244.16	2,592.00	69.12	1,890.00	138.24
27/12/01	0.00	0.00	8,460.00	1,451.52	0.00	0.00	2,538.00	92.16
sum	65,880.00	16,004.16	72,360.00	16,842.24	19,818.00	3,404.16	22,194.00	3,094.56
% Removal		75.71		76.72		82.82		87.12

Table C.15 Inflow and Outflow Rate of TSS data of RUN III

Date	R31		R32		R33		R34	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
30/12/01	0.00	0.00	0.00	0.00	0.00	0.00	3,294.00	748.80
2/1/02	0.00	0.00	0.00	0.00	2,160.00	322.56	2,052.00	403.20
5/1/02	7,020.00	1,497.60	7,740.00	2,580.48	1,998.00	584.64	2,322.00	829.44
8/1/02	4,680.00	645.12	9,360.00	2,177.28	1,512.00	80.64	3,024.00	34.56
11/1/02	10,080.00	1,774.08	13,500.00	1,872.00	3,024.00	579.60	0.00	0.00
14/1/02	0.00	0.00	12,600.00	1,728.00	3,888.00	230.40	3,780.00	322.56
17/1/02	10,620.00	720.00	0.00	0.00	3,186.00	151.20	2,970.00	259.20
20/1/02	6,840.00	2,119.68	10,620.00	1,872.00	2,214.00	108.00	3,348.00	138.24
23/1/02	11,880.00	1,451.52	13,500.00	1,008.00	3,564.00	1,123.20	4,104.00	1,123.20
26/1/02	0.00	0.00	10,440.00	3,870.72	0.00	0.00	2,808.00	92.16
29/1/02	9,900.00	3,870.72	8,100.00	1,920.96	2,970.00	302.40	2,538.00	475.20
1/2/02	9,000.00	662.40	7,920.00	2,154.24	3,240.00	367.20	2,376.00	190.08
4/2/02	10,980.00	1,647.36	5,760.00	691.20	3,132.00	207.36	1,728.00	86.40
sum	81,000.00	14,388.48	99,540.00	19,874.88	30,888.00	4,057.20	34,344.00	4,703.04
% Removal		82.24		80.03		86.86		86.31

Table C.16 Inflow and Outflow Rate of TSS data of RUN IV

Date	R41		R42		R43		R44	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
6/2/02	10,620.00	1,512.00	9,540.00	1,584.00	3,186.00	200.90	2,862.00	302.40
9/2/02	11,160.00	645.12	0.00	0.00	3,348.00	327.60	0.00	0.00
12/2/02	8,640.00	2,487.24	12,960.00	2,808.00	2,592.00	367.20	3,888.00	518.40
15/2/02	4,680.00	1,336.32	7,920.00	2,096.64	0.00	0.00	2,376.00	410.40
18/2/02	11,700.00	3,132.08	0.00	0.00	0.00	0.00	0.00	0.00
21/2/02	10,080.00	3,600.00	12,960.00	1,002.24	3,240.00	504.00	0.00	0.00
24/2/02	10,620.00	2,171.52	11,520.00	1,935.36	3,186.00	460.80	3,564.00	144.00
27/2/02	6,480.00	1,900.80	0.00	0.00	1,944.00	288.00	3,078.00	151.20
2/3/02	8,820.00	380.16	9,720.00	2,724.48	2,646.00	176.40	2,916.00	69.12
5/3/02	7,200.00	967.68	8,460.00	1,296.00	2,160.00	172.80	2,538.00	253.44
8/3/02	10,080.00	1,800.00	6,480.00	633.60	3,024.00	80.64	1,944.00	129.60
11/3/02	10,800.00	2,088.00	10,800.00	1,584.00	3,240.00	181.44	3,240.00	368.64
14/3/02	10,080.00	737.28	10,080.00	1,628.64	3,024.00	352.80	3,024.00	161.28
17/3/02	11,160.00	1,382.40	11,160.00	1,965.60	3,348.00	253.44	3,348.00	299.52
sum	132,120.00	24,140.60	111,600.00	19,258.56	34,938.00	3,366.02	32,778.00	2,808.00
% Removal		81.73		82.74		90.37		91.43

Table C.17 Inflow and Outflow Rate of VSS data of RUN I

Date	R11		R12		R13		R14	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
15/9/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17/9/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20/9/01	9,720.00	5,320.60	9,900.00	5,760.00	2,700.00	1,116.00	2,916.00	1,404.00
23/9/01	0.00	0.00	0.00	0.00	2,862.00	1,440.00	2,754.00	1,512.00
26/9/01	7,020.00	3,732.48	9,360.00	5,806.08	2,646.00	1,404.00	2,322.00	1,044.00
29/9/01	8,640.00	4,423.68	9,720.00	4,973.28	0.00	0.00	2,538.00	1,094.40
2/10/01	7,920.00	3,953.12	8,820.00	4,718.24	2,484.00	1,101.60	2,106.00	842.40
5/10/01	8,280.00	4,106.88	8,280.00	4,504.32	2,592.00	1,026.00	2,754.00	939.60
8/10/01	9,180.00	4,475.52	10,080.00	4,504.32	2,808.00	1,036.80	3,132.00	1,198.80
11/10/01	10,260.00	4,250.88	7,560.00	3,386.88	2,916.00	1,036.80	2,808.00	1,071.00
14/10/01	11,520.00	5,299.20	11,160.00	4,973.28	3,186.00	1,263.60	2,808.00	887.40
17/10/01	8,640.00	4,688.64	0.00	0.00	2,970.00	979.20	2,754.00	948.60
20/10/01	8,100.00	4,457.80	7,200.00	3,986.64	2,322.00	777.60	2,484.00	842.40
23/10/01	7,920.00	4,043.52	7,740.00	3,559.50	2,862.00	1,069.20	2,970.00	1,326.60
26/10/01	8,280.00	5,033.00	9,000.00	4,642.56	3,132.00	936.00	2,646.00	1,008.00
29/10/01	7,380.00	4,504.32	9,540.00	4,504.32	2,592.00	1,224.00	2,268.00	864.00
1/11/01	10,260.00	2,649.60	7,020.00	3,576.96	2,430.00	957.60	2,538.00	923.40
4/11/01	9,540.00	4,055.04	8,820.00	4,561.92	2,592.00	1,197.00	2,754.00	648.00
7/11/01	9,540.00	5,068.80	11,340.00	5,575.68	2,862.00	842.40	3,240.00	1,071.00
10/11/01	10,080.00	4,331.52	10,260.00	3,542.40	3,078.00	1,346.40	3,402.00	1,621.80
13/11/01	7,920.00	3,801.60	9,720.00	4,717.44	3,456.00	979.20	2,322.00	642.60
16/11/01	7,200.00	3,214.08	8,820.00	4,475.52	2,808.00	550.80	2,538.00	734.40
19/11/01	8,640.00	3,801.60	9,720.00	5,068.80	2,322.00	336.60	2,700.00	864.00
sum	176,040.00	85,211.88	174,060.00	86,838.14	55,620.00	20,620.80	56,754.00	21,488.40
% Removal		51.60		50.11		62.93		62.14

Table C.18 Inflow and Outflow Rate of VSS data of RUN II

Date	R21		R22		R23		R24	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
25/11/01	0.00	0.00	14,400.00	5,529.60	0.00	0.00	3,996.00	1,440.00
28/11/01	11,880.00	5,806.08	7,920.00	3,421.44	3,888.00	2,340.00	3,672.00	2,116.80
30/11/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3/12/01	13,140.00	4,492.80	9,000.00	4,250.88	2,430.00	576.00	2,376.00	604.80
6/12/01	10,800.00	6,842.88	8,820.00	4,262.40	3,240.00	1,393.20	3,024.00	705.60
9/12/01	14,760.00	5,080.32	9,900.00	4,838.40	4,050.00	1,440.00	2,106.00	892.80
12/12/01	10,800.00	2,476.80	14,400.00	691.20	2,808.00	501.12	4,212.00	579.60
15/12/01	13,680.00	1,653.12	0.00	0.00	0.00	0.00	4,050.00	633.60
18/12/01	9,360.00	3,369.60	14,760.00	4,999.68	2,970.00	1,058.40	4,428.00	1,656.00
21/12/01	10,800.00	4,354.56	7,380.00	4,147.20	3,240.00	374.40	2,646.00	342.72
24/12/01	11,880.00	3,133.44	7,200.00	3,110.40	3,564.00	1,128.96	2,322.00	501.12
27/12/01	0.00	0.00	12,600.00	4,354.56	0.00	0.00	3,888.00	460.80
sum	107,100.00	37,209.60	106,380.00	39,605.76	26,190.00	8,812.08	36,720.00	9,933.84
% Removal		65.26		62.77		66.35		72.95

Table C.19 Inflow and Outflow Rate of VSS data of RUN III

Date	R31		R32		R33		R34	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
30/12/01	11,880.00	3,686.40	13,680.00	5,068.80	3,834.00	864.00	2,592.00	1,094.40
2/1/02	0.00	0.00	0.00	0.00	3,186.00	1,059.84	2,916.00	806.40
5/1/02	10,980.00	1,785.60	9,540.00	2,903.04	3,186.00	1,028.16	3,132.00	1,059.84
8/1/02	6,840.00	2,661.12	11,520.00	3,548.16	2,268.00	544.32	3,672.00	172.80
11/1/02	0.00	0.00	7,920.00	2,520.00	0.00	0.00	2,160.00	475.20
14/1/02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17/1/02	13,500.00	4,176.00	10,260.00	2,580.48	4,212.00	561.60	0.00	0.00
20/1/02	7,920.00	3,686.40	13,500.00	2,096.64	2,376.00	302.40	4,050.00	414.72
23/1/02	14,400.00	4,112.64	10,800.00	864.00	4,104.00	1,339.20	3,240.00	259.20
26/1/02	10,800.00	2,620.80	0.00	0.00	0.00	0.00	2,754.00	944.64
29/1/02	12,960.00	4,435.20	14,580.00	4,106.88	4,050.00	518.40	4,374.00	777.60
1/2/02	12,780.00	2,252.16	9,360.00	2,851.20	3,510.00	453.60	2,700.00	259.20
4/2/02	9,720.00	2,787.84	6,840.00	1,728.00	3,078.00	362.88	2,052.00	241.92
sum	111,780.00	32,204.16	108,000.00	28,267.20	33,804.00	7,034.40	33,642.00	6,505.92
% Removal		71.19		73.83		79.19		80.66

Table C.20 Inflow and Outflow Rate of VSS data of RUN IV

Date	R41		R42		R43		R44	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
6/2/02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9/2/02	14,580.00	4,354.56	11,160.00	3,024.00	4,374.00	604.80	3,348.00	478.80
12/2/02	9,000.00	4,145.40	8,460.00	3,240.00	2,700.00	583.20	2,538.00	648.00
15/2/02	7,740.00	2,839.68	9,000.00	3,306.24	2,322.00	216.00	2,700.00	583.20
18/2/02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21/2/02	0.00	0.00	0.00	0.00	0.00	0.00	2,376.00	806.40
24/2/02	11,700.00	3,257.28	9,900.00	2,419.20	3,510.00	777.60	2,160.00	633.60
27/2/02	8,280.00	2,937.60	9,000.00	3,456.00	2,484.00	604.80	3,240.00	428.40
2/3/02	10,620.00	950.40	11,160.00	3,484.80	3,186.00	529.20	3,348.00	322.56
5/3/02	9,540.00	1,612.80	10,080.00	2,232.00	2,862.00	410.40	3,024.00	460.80
8/3/02	11,880.00	2,664.00	8,100.00	1,520.64	3,564.00	342.72	2,430.00	626.40
11/3/02	13,500.00	3,600.00	13,500.00	2,592.00	4,050.00	302.40	4,050.00	599.04
14/3/02	10,260.00	1,474.56	10,260.00	1,684.80	3,078.00	529.20	3,078.00	737.28
17/3/02	8,100.00	1,900.80	8,100.00	1,404.00	2,430.00	737.28	2,430.00	622.08
sum	115,200.00	29,737.08	108,720.00	28,363.68	34,560.00	5,637.60	34,722.00	6,946.56
% Removal		74.19		73.91		83.69		79.99

Table C.21 Inflow and Outflow Rate of Cd data of RUN I

Date	R12		R14	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
15/9/01	80.25	2.21	25.57	0.38
17/9/01	77.33	4.52	26.31	0.52
20/9/01	74.74	5.09	27.43	0.48
23/9/01	79.09	1.49	26.31	0.52
26/9/01	88.11	1.18	24.33	0.00
29/9/01	84.60	0.86	23.36	0.16
2/10/01	83.97	0.78	22.65	0.13
5/10/01	106.38	0.67	29.51	0.10
8/10/01	92.61	0.71	25.62	0.27
11/10/01	85.23	1.09	27.78	0.13
14/10/01	96.48	0.52	28.08	0.13
17/10/01	94.77	0.77	28.97	0.12
20/10/01	83.14	0.92	25.77	0.14
23/10/01	84.71	0.84	26.50	0.15
26/10/01	83.07	0.93	23.97	0.14
29/10/01	80.26	0.65	24.19	0.14
1/11/01	77.60	0.71	26.23	0.11
4/11/01	84.74	0.73	24.94	0.09
7/11/01	87.64	0.72	25.43	0.16
10/11/01	86.05	0.34	24.87	0.13
13/11/01	84.84	0.61	25.85	0.09
16/11/01	82.03	0.44	23.66	0.03
19/11/01	79.85	0.43	24.92	0.03
sum	1,957.49	27.21	592.25	4.13
% Removal		98.61		99.30

Table C.22 Inflow and Outflow Rate of Cd data of RUN II

Date	R22		R24	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
25/11/01	448.92	4.50	134.68	0.24
28/11/01	453.87	5.52	136.16	0.33
30/11/01	429.75	7.68	128.93	0.65
3/12/01	431.19	3.96	129.36	0.61
6/12/01	435.42	1.22	130.63	0.41
9/12/01	449.37	1.46	134.81	0.35
12/12/01	506.34	0.64	151.90	0.29
15/12/01	429.75	0.78	128.93	0.38
18/12/01	428.58	0.76	128.57	0.26
21/12/01	438.75	0.53	131.63	0.17
24/12/01	449.46	0.75	134.84	0.17
27/12/01	448.29	0.62	134.49	0.18
sum	5,349.69	28.41	1,604.91	4.04
% Removal		99.47		99.75

Table C.23 Inflow and Outflow Rate of Cd data of RUN III

Date	R32		R34	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
30/12/01	1,080.90	1.17	324.27	0.38
2/1/02	1,035.90	8.75	310.77	0.37
5/1/02	803.43	8.70	241.03	1.02
8/1/02	1,052.10	7.76	315.63	0.60
11/1/02	1,057.50	7.11	317.25	0.71
14/1/02	1,000.80	11.37	300.24	0.33
17/1/02	1,050.30	9.21	315.09	0.11
20/1/02	1,155.60	8.57	346.68	0.22
23/1/02	1,076.40	3.41	322.92	1.53
26/1/02	832.87	2.42	249.86	0.30
29/1/02	1,089.00	1.19	326.70	0.32
1/2/02	1,066.50	2.36	319.95	0.17
4/2/02	916.20	2.30	274.86	0.16
sum	13,217.50	74.32	3,965.25	6.21
% Removal		99.44		99.84

Table C.24 Inflow and Outflow Rate of Cd data of RUN IV

Date	R42		R44	
	Influent (mg/d)	Effluent (mg/d)	Influent (mg/d)	Effluent (mg/d)
6/2/02	1,735.20	1.83	520.56	0.92
9/2/02	1,614.60	2.20	484.38	0.22
12/2/02	1,812.60	13.51	543.78	1.56
15/2/02	1,930.50	13.99	579.15	0.95
18/2/02	1,780.20	22.26	534.06	0.73
21/2/02	1,665.00	10.26	499.50	0.85
24/2/02	1,689.30	8.24	506.79	0.36
27/2/02	1,748.70	4.38	524.61	0.49
2/3/02	1,663.20	2.52	498.96	0.53
5/3/02	1,984.50	2.35	595.35	0.64
8/3/02	1,755.90	2.05	526.77	0.68
11/3/02	1,957.50	2.11	587.25	0.63
14/3/02	1,609.20	2.46	482.76	0.75
17/3/02	1,746.00	2.60	523.80	0.60
sum	24,692.40	90.76	7,407.72	9.92
% Removal		99.63		99.87

APPENDIX D

Calculation of coefficient of variation

Table D.1 Coefficient of variation of FWS

Comparison of the average removal efficiencies between control unit and experimental unit of free water surface wetland systems.

Parameters	RUN	Mean	Standard Deviation	Coefficient of variation
COD	I	79.19	1.17	1.47
	II	86.99	0.18	0.21
	III	87.79	0.39	0.44
	IV	86.22	0.40	0.47
TKN	I	65.30	0.83	1.27
	II	74.90	1.48	1.98
	III	84.48	1.33	1.57
	IV	83.05	1.58	1.91
TP	I	62.33	1.06	1.70
	II	80.18	1.12	1.40
	III	84.60	0.69	0.81
	IV	86.00	0.07	0.08
TSS	I	70.23	1.63	2.32
	II	76.22	0.71	0.94
	III	81.14	1.56	1.93
	IV	82.24	0.71	0.87
VSS	I	50.86	1.05	2.07
	II	64.02	1.76	2.75
	III	72.51	1.87	2.57
	IV	74.05	0.20	0.27

Table D.2 Coefficient of variation of SF

Comparison of the average removal efficiencies between control unit and experimental unit of free subsurface wetland systems.

Parameters	RUN	Mean	Standard Deviation	Coefficient of variation
COD	I	88.09	0.16	0.18
	II	91.35	1.20	1.32
	III	91.79	0.17	0.18
	IV	90.02	0.16	0.18
TKN	I	85.23	0.20	0.23
	II	87.25	0.04	0.04
	III	90.69	0.83	0.91
	IV	88.39	1.19	1.34
TP	I	74.62	0.52	0.69
	II	86.97	0.02	0.02
	III	89.74	0.44	0.49
	IV	89.56	1.29	1.44
TSS	I	79.74	2.45	3.08
	II	84.97	3.04	3.58
	III	86.59	0.39	0.45
	IV	90.90	0.75	0.82
VSS	I	62.54	0.56	0.89
	II	69.98	4.21	6.01
	III	79.93	1.04	1.30
	IV	81.84	2.62	3.20

APPENDIX E

Data of soil

Table E.1 Data of cadmium concentration in soil at the depth of 15 cm (RUNI)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R11	0.0008	0.0181	0.0053	0.0087
R12	0.0957	0.0398	0.0303	0.0056
R13	0.0022	0.0169	0.0000	0.0000
R14	0.0782	0.0490	0.0168	0.0113

Table E.2 Data of cadmium concentration in soil at the depth of 25 cm (RUNI)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R11	0.0092	0.0203	0.0129	0.0248
R12	0.0835	0.0297	0.0177	0.0131
R13	0.0145	0.0077	0.0000	0.0000
R14	0.0640	0.0379	0.0210	0.0143

Table E.3 Data of cadmium in soil at the depth of 15 cm (RUNI)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R11	0.0000	0.0009	0.0003	0.0004
R12	0.0048	0.0020	0.0015	0.0003
R13	0.0001	0.0008	0.0000	0.0000
R14	0.0039	0.0025	0.0008	0.0006

Table E.4 Data of cadmium in soil at the depth of 25 cm (RUNI)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R11	0.0005	0.0010	0.0006	0.0012
R12	0.0042	0.0015	0.0009	0.0007
R13	0.0007	0.0004	0.0000	0.0000
R14	0.0032	0.0019	0.0011	0.0007

Table E.5 Data of cadmium concentration in soil at the depth of 15 cm (RUNII)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R21	0.0019	0.0000	0.0005	0.0000
R22	0.8496	0.3556	0.2328	0.0832
R23	0.0034	0.0143	0.0079	0.0002
R24	0.3056	0.2614	0.1998	0.0446

Table E.6 Data of cadmium concentration in soil at the depth of 25 cm (RUNII)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R21	0.0190	0.0033	0.0107	0.0041
R22	0.5748	0.3778	0.1894	0.1252
R23	0.0077	0.0000	0.0051	0.0078
R24	0.2581	0.1223	0.0859	0.0725

Table E.7 Data of cadmium in soil at the depth of 15 cm (RUNII)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R21	0.0001	0.0000	0.0000	0.0000
R22	0.0425	0.0178	0.0116	0.0042
R23	0.0002	0.0007	0.0004	0.0000
R24	0.0153	0.0131	0.0100	0.0022

Table E.8 Data of cadmium in soil at the depth of 25 cm (RUNII)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R21	0.0010	0.0002	0.0005	0.0002
R22	0.0287	0.0189	0.0095	0.0063
R23	0.0004	0.0000	0.0003	0.0004
R24	0.0129	0.0061	0.0043	0.0036

Table E.9 Data of cadmium concentration in soil at the depth of 15 cm (RUNIII)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R31	0.0088	0.0081	0.0053	0.0048
R32	11.2480	9.4080	0.6910	0.1328
R33	0.0068	0.0050	0.0044	0.0023
R34	4.7440	3.7350	0.3247	0.0588

Table E.10 Data of cadmium concentration in soil at the depth of 25 cm (RUNIII)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R31	0.0077	0.0075	0.0043	0.0040
R32	10.0480	8.3180	0.3706	0.1426
R33	0.0032	0.0030	0.0020	0.0023
R34	3.1380	2.0100	0.3085	0.0553

Table E.11 Data of cadmium in soil at the depth of 15 cm (RUNIII)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R31	0.0004	0.0004	0.0003	0.0002
R32	0.5624	0.4704	0.0346	0.0066
R33	0.0003	0.0003	0.0002	0.0001
R34	0.2372	0.1868	0.0162	0.0029

Table E.12 Data of cadmium in soil at the depth of 25 cm (RUNIII)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R31	0.0004	0.0004	0.0002	0.0002
R32	0.5024	0.4159	0.0185	0.0071
R33	0.0002	0.0002	0.0001	0.0001
R34	0.1569	0.1005	0.0154	0.0028

Table E.13 Data of cadmium concentration in soil at the depth of 15 cm (RUNIV)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R41	0.0129	0.0067	0.0091	0.0054
R42	28.8700	20.9630	5.9220	2.4230
R43	0.0243	0.0161	0.0188	0.0123
R44	10.2000	7.0240	1.5186	0.6580

Table E.14 Data of cadmium concentration in soil at the depth of 25 cm (RUNIV)

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R41	0.0103	0.0122	0.0056	0.0099
R42	26.7740	17.8740	5.5829	1.3880
R43	0.0093	0.0077	0.0085	0.0064
R44	8.1870	6.0140	1.6100	0.3827

Table E.15 Data of cadmium in soil at the depth of 15 cm (RUNIV)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R41	0.0006	0.0003	0.0005	0.0003
R42	1.4435	1.0482	0.2961	0.1212
R43	0.0012	0.0008	0.0009	0.0006
R44	0.5100	0.3512	0.0759	0.0329

Table E.16 Data of cadmium in soil at the depth of 25 cm (RUNIV)

Reactors	Cadmium along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R41	0.0005	0.0006	0.0003	0.0005
R42	1.3387	0.8937	0.2791	0.0694
R43	0.0005	0.0004	0.0004	0.0003
R44	0.4094	0.3007	0.0805	0.0191

Table E.17 Total cadmium (g) in soil of free water surface wetland system

Reactors	Cadmium along the distance of channel bed (g)				sum
	0.5 m	1.5 m	2.5 m	3.5 m	
Run I	181.33	70.33	48.57	18.92	319.15
Run II	1,441.35	742.13	427.22	210.88	2,821.58
Run III	21,549.42	17,936.94	1,074.23	278.68	40,839.27
Run IV	56,306.16	39,299.16	11,641.81	3,856.35	111,103.48

Table E.18 Total cadmium (g) in soil of subsurface wetland system

Reactors	Cadmium along the distance of channel bed (g)				sum
	0.5 m	1.5 m	2.5 m	3.5 m	
Run I	143.89	87.93	38.25	25.90	295.98
Run II	570.41	388.27	289.10	118.49	1,366.27
Run III	7,975.80	5,813.37	640.74	115.46	14,545.35
Run IV	18,605.81	13,193.15	3,165.83	1,053.08	36,017.87

APPENDIX F

Data of cattail Plants

Table F.1 Data of cadmium concentration in leaves

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R1	0.0241	0.0239	0.0231	0.0266
R2	2.0840	0.5450	0.1006	0.0660
R3	0.0493	0.0354	0.0337	0.0294
R4	0.6326	0.4479	0.1427	0.2500

Table F.2 Data of cadmium in leaves

Reactors	Cadmium concentration along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R1	0.0024	0.0024	0.0023	0.0027
R2	0.2084	0.0545	0.0101	0.0066
R3	0.0049	0.0035	0.0034	0.0029
R4	0.0633	0.0448	0.0143	0.0250

Table F.3 Data of cadmium concentration in stems

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R1	0.0387	0.0368	0.0365	0.0379
R2	5.0480	2.0470	0.3760	0.1404
R3	0.0524	0.0480	0.0399	0.0291
R4	4.7200	1.0758	0.4470	0.3795

Table F.4 Data of cadmium in stems

Reactors	Cadmium concentration along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R1	0.0039	0.0037	0.0037	0.0038
R2	0.5048	0.2047	0.0376	0.0140
R3	0.0052	0.0048	0.0040	0.0029
R4	0.4720	0.1076	0.0447	0.0380

Table F.5 Data of cadmium concentration in roots

Reactors	Cadmium concentration along the distance of channel bed (mg/L)			
	0.5 m	1.5 m	2.5 m	3.5 m
R1	0.0418	0.0451	0.0339	0.0371
R2	24.8700	12.2600	3.0170	1.9680
R3	0.0499	0.0400	0.0286	0.0297
R4	23.3500	10.8000	1.9552	1.4480

Table F.6 Data of cadmium in roots

Reactors	Cadmium concentration along the distance of channel bed (mg/g)			
	0.5 m	1.5 m	2.5 m	3.5 m
R1	0.0042	0.0045	0.0034	0.0037
R2	2.4870	1.2260	0.3017	0.1968
R3	0.0050	0.0040	0.0029	0.0030
R4	2.3350	1.0800	0.1955	0.1448

Table F.7 Calculation the cadmium (g) in cattail plants for Free water surface and subsurface wetland

Reactors	Parts	Distance along the soil bed (m)				Total (g)
		0.5	1.5	2.5	3.5	
FWS	Roots	1,024.25	504.92	124.25	81.05	1,734.46
	Stems	694.10	281.46	51.70	19.31	1,046.57
	Leaves	268.21	70.14	12.95	8.49	359.79
SF	Roots	611.30	282.74	51.19	37.91	983.14
	Stems	354.66	80.84	33.59	28.52	497.60
	Leaves	48.93	34.65	11.04	19.34	113.95

Biography

Miss Nattavadee Samorkhom was born on December 20, 1978 in Nakhon Ratchasima. She studied in Suranaree Vitthaya School, Nakhon Ratchasima. She graduated from Suranaree University of Technology (SUT), in the School of Environmental Engineering in 1999. During the forth year, she was the trainee in the Co-Operative Education Program and worked at the University of Guelph, Canada. She started Master Degree Program since 1999.