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The Treatment of Landfill Leachate Using Natural Systems

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOL	DESCRIPTION
<	less than
>	more than
~	approximately
°C	degrees Celsius
µ	micro
Ø	diameter
±	plus/minus
BOD_5	5-day Biological Oxygen Demand
cm	centimetre
COD	Chemical Oxygen Demand
C/N	Carbon to Nitrogen ratio
DO	dissolved oxygen
g	grams
HF	Horizontal Flow (reed bed)
HLR	Hydraulic Loading Rate
HRT	Hydraulic Retention Time
kg	kilogram
l	litre
m	metre
m^3	cubic metre
max	maximum
min	minimum
mg/l	milligrams per litre

ml	millilitre
mS/cm	milli Siemens per centimetre
MSW	municipal solid waste
N_2	nitrogen
NH_3	ammonia
NH_4	ammonium
NO_2	nitrite
NOx	nitrate-plus-nitrite
NO_3	nitrate
pH	negative log [H+]
RBC	Rotating Biological Contactor
sd	standard deviation
SF	Surface Flow (constructed wetland)
SSF	Sub-Surface Flow (constructed wetland)
SBR	Sequencing Batch Reactor
SS	suspended solids
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
TON	Total Oxidised Nitrogen
VSS	Volatile Suspended Solids
VF	Vertical Flow (reed bed)

DECLARATION BY CANDIDATE

‘‘I hereby declare that the dissertation submitted for the degree of Doctor of Philosophy at the Division of Geology**,** School of Biological, Earth and Environmental Sciences, University College Cork, is my own original work and has not previously been submitted to any other institution of higher education.

I further declare that all sources cited or quoted are indicated and acknowledged by means of a comprehensive list of references’’.

Kevin Ryan

Kevin Ryan

ABSTRACT

Leachate may be defined as any liquid percolating through deposited waste and emitted from or contained within a landfill. If leachate is allowed to migrate from a site it may pose a severe threat to the surrounding environment and in particular to groundwater and surface water regimes.

Increasingly stringent environmental legislation both at European level and national level (Republic of Ireland) in the form of the Landfill Directive (1999/31/EC) and the Waste Management Act (1996) has brought about a highly regulated system for the operation of landfill sites, and management of associated emissions, as well as requirements for restoration and aftercare on completion of landfilling activities.

The landfill operator remains responsible for the maintenance, monitoring and control of the site in the aftercare phase for as long as may be required by the competent authority (current estimates for the aftercare phase is 30 years). This places an enormous environmental and economic liability on the operator during a period when there is no income from landfilling activities.

This onerous and potentially indefinite financial liability has prompted the research for this project into the design and development of a low cost, low maintenance, low technology trial system to treat landfill leachate.

A trial treatment plant incorporating varying alternative natural treatment processes, consisting of reed beds, compost units, timber chip units, compost-timber chip units, stratified sand filters and willow treatment plots, was constructed at Kinsale Road Landfill Site, on the outskirts of Cork city.

The facility was nearing closure and with rising energy prices and increasing costs associated with treating the effluent, Cork City Council was seeking new alternative methods of treatment.

In total, the trial plant consisted of 14 separate treatment units; 10 open top cylindrical cells (Ø 1.8 m x 2.0 high) and four reed beds, two vertical flow (VF) reed beds (5.0m x 5.0m x 1.0m) and two sub-surface horizontal flow (HF) reed beds (5.0m x 5.0m x 1.0m). The cells and the VF reed beds were intermittently dosed via a pump, and the HF reeds beds were gravity fed. The system was designed in such a way that all units could be operated both individually and in sequence.

Cost considerations were high on the agenda in the design stage, therefore locally available, off the shelf materials were chosen where possible, and specialised components were kept to a minimum.

A critical component of the design process was that it could be easily up-scaled and brought into full-scale operation if results so warranted. It was therefore imperative that the trial plant

mimicked as closely as possible the conditions that could be expected within an appropriately sized leachate treatment plant for the facility.

The trial plant operated successfully for a period of 43 months between July 2007 and December 2011.

A number of alterations were made to the system as the project progressed. Gravel filters were installed at the head of the system to assist in the removal of solids from the leachate, the HF reed beds were converted to vertical flow irrigated planes (VP units), and were planted with salt tolerant grass, denitrification units were added to the system, and numerous adjustments were made to the application rates and sequencing of treatment units to establish the most effective method of treatment.

High treatment efficiencies were achieved in units operating in sequence containing compost and timber chip media, vertical flow reed beds and vegetated planes.

Pollutant load removal rates of 99% for NH_4, 84% for BOD_5, 46% for COD, 63% for suspended solids, 94% for iron and 98% for manganese were recorded in the final effluent of successfully operated sequences at hydraulic loading rates of 2400 litres/unit/day, i.e. 945 l/m^2/day in the open top cylindrical cells and 96 l/m^2/day in the VF reed beds and irrigated planes (VP units). Almost total pathogen removal (*E. coli*) occurred in the final effluent of the same sequence.

Denitrification rates of 37% were achieved for a limited period.

Overall, when assessed against similar studies, operation of the vertical flow reed beds performed moderately well for all parameters at areal loading rates of 96 l/m^2/day.

Results achieved for NH_4 and COD treatment in units containing coarse grade compost and compost-timber chip mix are favourable when compared to other similar studies at areal loading rates of 945 l/m^2/day.

Interestingly, the leachate at Kinsale Road Landfill Site can be characterised as relatively low to moderate strength when compared to other methanogenic and acetogenic leachates. Heavy metals and List I and II substances were present in extremely low concentrations, at or below drinking water standards or not detected, and the raw untreated leachate was classed as being slightly toxic (3 - 10 Toxic Units).

Finally, a draft, up-scaled leachate treatment plant is presented, based on treatment performance of the trial plant.

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CHAPTER 1

1. INTRODUCTION

1.1 Preface

The practice of landfilling is the most common method of disposing of society's unwanted materials. These waste materials may be solid or liquid and can be hazardous or non-hazardous in nature. Irrespective of the classification of the waste, the final destination into which the waste material is deposited tends to be a hollow or ground depression, of natural or manmade origin, which may or may not contain elements of engineering design. The level of environmental engineering considered in the planning, design, operation and closure of landfill sites varies from site to site and from country to country. Landfilling of waste can generate nuisances, and pose long-term threats to the environment resulting from uncontrolled liquid and gaseous emissions from the site. The main sources of nuisances are odour, noise, vermin and flies, whereas the main sources of emissions are leachate and landfill gas, the latter comprising mainly methane and carbon dioxide.

The former emission, leachate, is the main concern of this thesis; namely its characterisation, description of its deleterious effects on the environment, and methods of control and treatment.

1.2 Landfill Leachate

Leachate may be defined as any liquid percolating through the deposited waste, which is emitted from or contained within a landfill. This leachate entrains suspended and soluble materials that originate from or are products of the degradation of the waste (EPA, 2003).

The composition of leachate is highly variable in terms of its constituents and potency, and depends on a number of factors including; the age of the landfill, the nature and composition of the waste, the rate of decomposition within the landfill, the amount of rainwater or groundwater infiltration, ambient temperature as well as heat generation within the waste body. Landfill leachates are typically characterised by high concentrations of organics that may be readily biodegradable or recalcitrant, ammonium, chlorides and suspended solids. Concentrations of heavy metals and other

hazardous substances (List I and List II substances) in the leachate stream are very much site specific and may fluctuate with time within a site.

The major environmental concern relating to landfill leachate is uncontrolled release to groundwater, surface water and soil. Such events can have significant impacts on water quality, resulting in impairment of ecosystem functions and services (algal blooms, increase in aquatic toxicity, fish kills etc.), closure of potable water sources, reduction in amenity value of an area, and damage to agriculture or commerce, and can cause major upset for residents in the surrounding community.

It is therefore essential that an appropriate system for collection, storage and treatment of leachate is in place, not only from the perspective of pollution prevention and control, but also from an economic viewpoint (Cortez, 2010).

1.3 Legislative Background

Waste management across the European Union and particularly in the Republic of Ireland has undergone a paradigm shift in both attitude and practice over the past two decades.

The operation of landfill sites has moved from an ad-hoc unregulated arrangement, where 'dump' sites were often poorly managed, and work practices were carried out with little or no concern for the environment, to highly regulated, engineered systems where protection of environmental services takes precedence.

In 1999, the European Commission adopted the Council Directive 1999/31/EC on the landfilling of waste, known as the Landfill Directive. Its overall objective is to prevent or reduce any negative effects on the environment or human health associated with the landfilling of waste. The Directive specifies the technical requirements for landfill design, operation, closure and aftercare, and sets deadlines for the diversion of biodegradable municipal waste from landfill.

Landfills in Ireland were brought under the regulatory control of the Environmental Protection Agency (EPA) with the introduction of the Environmental Protection Agency Act, (1992) and the Waste Management Act, (1996).

Licensing of landfill sites was introduced under the Waste Management Act. The Act (under the Waste Management (Licensing) Regulations S.I. 133/1997 (as amended)) entrusts the EPA with the power to award (and revoke) a waste licence to an operator. It is a powerful piece of environmental legislation and forms the cornerstone for waste management law, policy and activities in Ireland.

Enforcement of licensing regulations and the associated requirements for higher environmental standards resulted in the closure of many small-scale landfills. By 2009, only 30 municipal waste landfill sites were in operation in Ireland, down from 95 in 1995 (EPA, 2010).

A comparison of the standards pertaining at open municipal solid waste landfills (MSW) during the period 1995 - 1997 versus 2009 and the locations of landfill sites that remained in operation by 2009 are outlined below in Table 1.1 and Figure 1.1.

Table 1.1 Comparison of Standards Pertaining at Open MSW Landfills during the period 1995 - 1997 versus 2009

Indicator	1995-1997	2009
Number of open MSW landfills	95*	30
	%	
Records kept of waste accepted	71**	100
Weighbridge operating	10**	100
Landfilling in lined cells	26***	100
Collecting leachate	33***	100
Using daily cover	30***	97****
Flaring/utilising landfill gas	15***	97****
Monitoring surface water	42*	100
Monitoring groundwater	19*	100
Monitoring leachate	29*	100
Monitoring landfill gas	7*	100

Note:
*Based on a survey of standards at 95 local authority MSW landfills in 1995 and 1996
**Based on a survey of standards at 87 local authority MSW landfills in 1995
***Based on inspections of 27 local authority MSW landfills in 1997
****3% 'non-compliance' refers to one landfill
(after EPA, 2010)

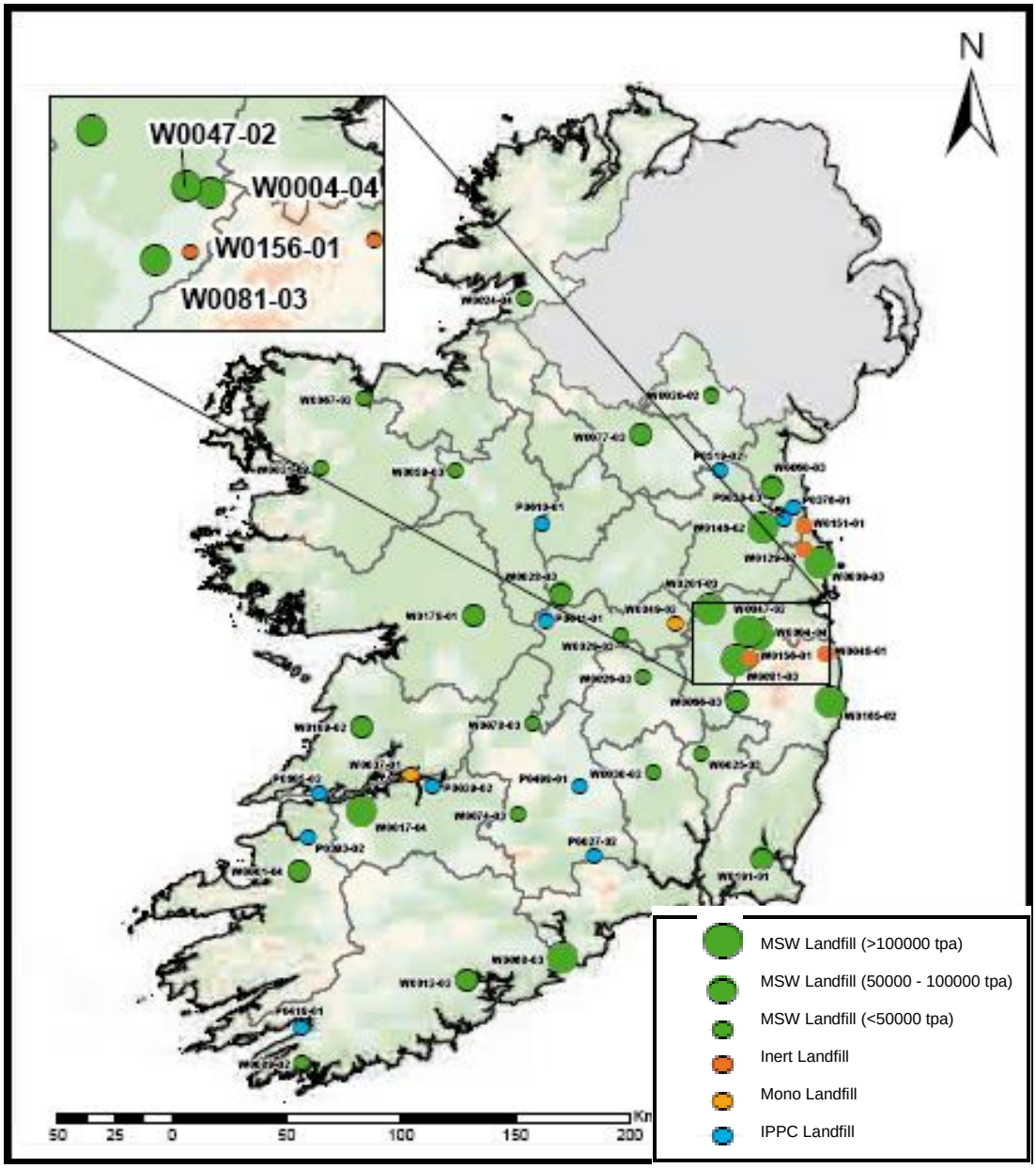


Figure 1.1 Open Landfill Sites in 2009 (after EPA, 2010)

The majority of landfill sites that closed later came under the umbrella of legacy landfills. This applies to Local Authority landfills that operated without a waste licence between 15/07/1977 and 27/03/1997; of which there are over 300; and these sites must now be controlled and managed under the Historic Unlicensed Waste Disposal and Recovery Activity Regulations (S.I. No. 524 of 2008) to ensure there is no environmental impact.

The EPA placed stringent conditions on the licensees of the 30 landfill sites that remained in operation with respect to environmental monitoring, leachate and gas management as well as restoration and aftercare.

Requirements for leachate management included the following where relevant (EPA, 2010):

- Provision and maintenance of leachate management infrastructure
- Enclosure of leachate storage/treatment structures
- Recirculation of leachate only to be undertaken with EPA agreement
- EPA approved agreements required for off-site removal and treatment
- Compliance with limit values for discharges of treated leachate to surface waters, and
- Monitoring of leachate levels and quality.

When final contours for a waste deposition area (cell) is achieved, the licensee is required to apply final capping following approximately one year of settlement. The design and function of the capping system aims to; limit the infiltration of water into the waste and thus minimise the generation of leachate, provide for the capture and management of landfill gas and create a physical barrier to the surrounding environment.

Perhaps the most stringent of all conditions in the licensing regime is the requirement for long term management and aftercare following closure of a landfill site.

The licensee remains responsible for the maintenance, monitoring and control in the after-care phase for as long as may be required by the competent authority (EPA), taking into account the time during which the landfill could present hazards to the environment.

This condition places an enormous environmental and financial liability on the licensee for an indefinite period post closure. Current estimates for the aftercare period are 30 years; however this is not based on hard facts as the active period for a lined and capped landfill site could extend well beyond this timeframe (perhaps up to a century or more post closure). To date no licence in Ireland has been successfully surrendered to the competent authority (EPA).

This onerous and potentially indefinite financial liability has prompted this investigation into the design and development of a low cost, low maintenance, low technological trial landfill leachate treatment system.

1.4 Project Aims and Reasoning

The overarching logic in developing and implementing this research project was based both on commercial and environmental principles. The landfill site, located at Kinsale Road on the outskirts of Cork city, was approaching the end of its operational life, with the filling capacity nearing agreed contour levels (as set out in the waste licence), and increasingly stringent environmental regulations demanded that all old landfill sites without artificial geo-membrane basal liners should close by July 2009. Consequently, the income stream from landfilling would no longer be available to the operator (Cork City Council) during the period of aftercare and management of landfill gas and leachate, which has provisionally been estimated to be of the order of 30 years at a minimum.

From an environmental perspective, Cork City Council had at the time spent over €32m on engineering infrastructure and remediation technologies to enhance environmental protection measures at the site (by 2015 the expected capital spend on site restoration is estimated at €40m). In addition, Cork City Council had (and continues to have) a positive disposition towards sponsoring environmental projects and research within its functional area.

To this end, it was proposed that the author should undertake a research project to examine the potential for treatment of landfill leachate using natural systems at the Kinsale Road Landfill Site.

The aim of the project was to design and build a demonstration scale leachate treatment system incorporating varying alternative natural treatment processes and media, with an emphasis on meeting leachate treatment discharge limits and regulations in the most cost effective manner (low technology, low maintenance, low cost) and mitigating the associated environmental impacts.

On commencement of the project, the following research questions were set:

1. Is it possible to treat leachate using natural systems and achieve the required standard for discharge to an aquatic receiving environment, river catchment or other?
2. What kind of natural systems and media are best suited to leachate treatment?
3. Is it possible to construct a full-scale treatment plant on site to accommodate leachate generated at the facility?

1.5 Thesis Structure

The remainder of this thesis is structured as follows:

Chapter 2 Background to the Kinsale Road Landfill Site

Outlines general background information on the Kinsale Road Landfill Site; where the trial project was constructed; and details the principles of the site geology, history, design and operation together with measures taken post closure to restore and remediate environmental hazards at the facility.

Chapter 3 Landfill Leachate Characterisation and Management

Typical characteristics of landfill leachate, its constituents and associated environmental hazards are discussed in this chapter, together with the management of leachate at Kinsale Road Landfill Site.

Chapter 4 Landfill Leachate Treatment Methods

Provides a systematic account of the project design and the selection criteria for including various treatment processes in the trial plant, together with a review of existing leachate treatment technologies.

Chapter 5 Trial Project Site Selection and Construction

Project construction and trial plant start-up phase are described.

Chapter 6 Trial Plant Commissioning and Operation

Describes commissioning of the trial plant and phased operation of the process units, together with problems encountered during plant operation and outlines trouble-shooting exercises.

Chapter 7 Leachate Analysis and Physical Examination of Treatment Units

Outlines the sampling methodology and the parameters measured in the leachate influent and effluent streams of the various treatment units, together with field testing of the media matrices of each treatment unit.

Chapter 8 Results and Interpretation

Outlines the results recorded throughout the project. Interpretation of results is organised by phase of operation and by parameter analysis of effluent from the respective treatment unit or sequences of units.

Chapter 9 Discussion

Sets out to integrate the main findings from the project and encompasses the initial idea and concept, trial plant construction and operation through to results and analysis of treated effluent. The findings are placed in a broader context in terms of final outcome of the trial project and comparisons with similar investigations cited in literature as well as its usefulness and applicability as a treatment system for landfill leachate.

Finally, a draft up-scaled treatment plant based on results attained is presented.

Chapter 10 Conclusions and Recommendations

Outlines the most significant conclusions drawn from the investigation, and sets out a number of recommendations for future research on this topic.

CHAPTER 2

2. BACKGROUND TO THE KINSALE ROAD LANDFILL SITE

2.1 Introduction

This chapter is a modification of the introductory section of the Kinsale Road Landfill Site's Environmental Management System (EMS), originally produced by environmental consultants Fehily Timoney & Co. (FTC, August 2001). It defines the service, commitment to the environment, the managerial responsibilities and a summary of the procedures relating to environmental standards at the Kinsale Road Landfill Site. The author revised the original EMS in June 2002 as part of Cork City Council's registration to the ISO 14001 Environmental Management Systems standard.

This section describes the general background information about the Kinsale Road Landfill Site and details the principles of the site design and operation. It includes a description of the site, current operations, measures for site drainage, groundwater and surface water management, leachate and landfill gas control, closure and restoration procedures and the environmental monitoring programme on site.

Kinsale Road Landfill Site is a municipal solid waste landfill site and Civic Amenity Site (recycling and waste timber and compost reprocessing centre). The site was issued with a Waste Licence by the Environmental Protection Agency (EPA) on the 2nd of February 2000 (Waste Licence No. 12-1). This licence was updated and renewed on the 29th November 2002 and again in 2009 and now operates under Waste Licence Number W0012-03 (granted May 2011).

Landfilling of waste has ceased at the facility as of 15th July 2009. Reclamation of timber waste, composting of green waste and recycling collection activities shall continue at the site for the foreseeable future.

The landfill site is owned and operated by Cork City Council, City Hall, Cork.

The address of the facility is as follows:

Kinsale Road Landfill Site,

South City Link,

Cork.

The National Grid Reference for the site is: 168033E 069658N.

2.2 Site Location and Description

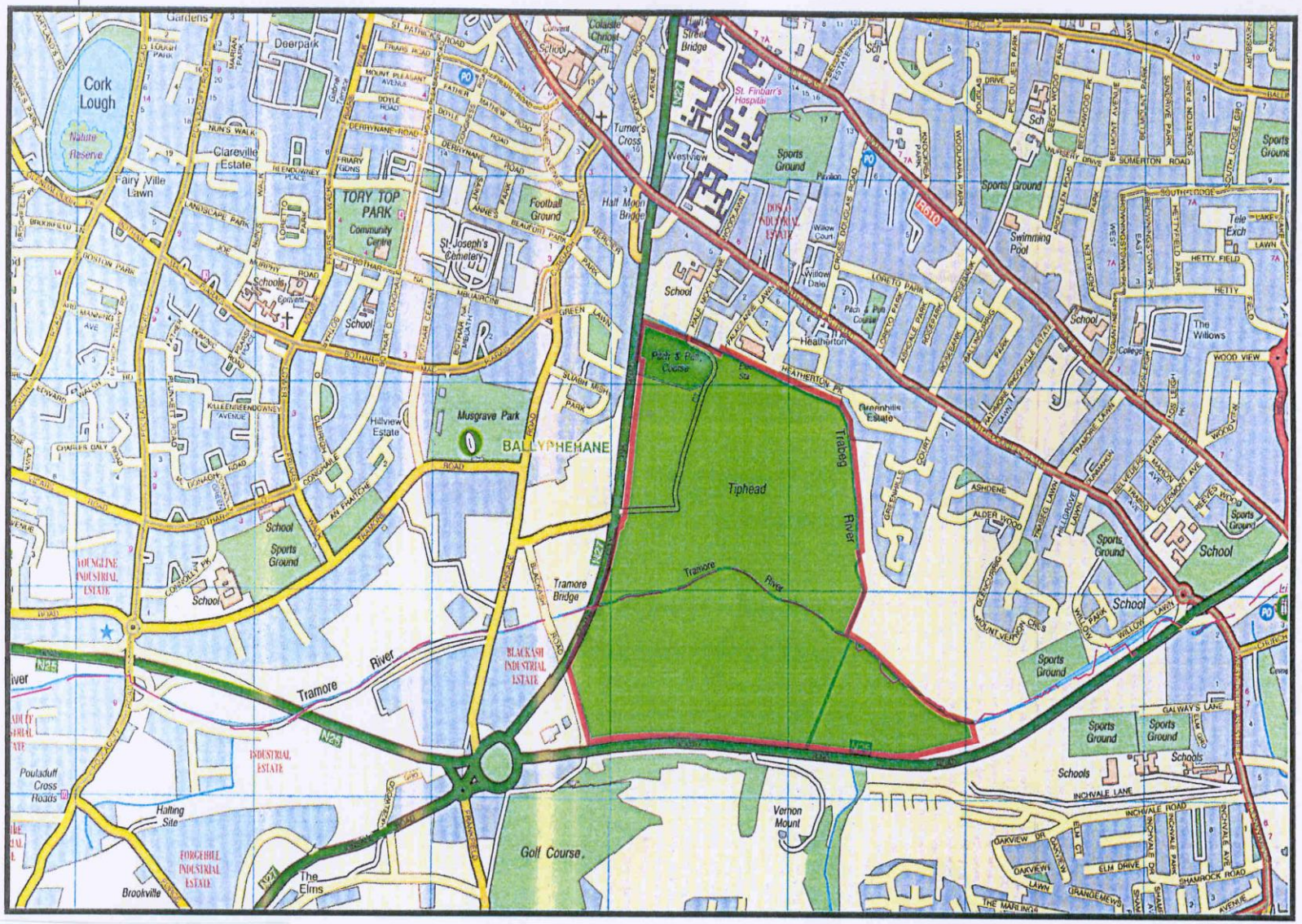
2.2.1 Location

The Kinsale Road Landfill Site is located at Ballyphehane, just off the South City Link Road along the southeastern suburbs of Cork. The site is surrounded by a 2.4 metre high palisade fence. The main site access for both public and Cork City Council vehicles is situated along the South City Link Road, 200 m north of the Kinsale Road Roundabout. The site is bounded by two rivers, the Tramore River to the southern section of the site with the Trabeg Stream flowing along the eastern site boundary. The environs of the site to the north and east and to the south of the South Ring Road are occupied by residential estates constructed mainly after landfilling commenced (circa 1960). Commercial development, including light engineering facilities, storage depots and retail outlets are situated to the south and west of the site.

There are a variety of public and private amenity and service facilities within 500m of the landfill boundaries. The amenities include a pitch and putt course, Musgrave Park and Turners Cross Football Ground, Frankfield Golf Course, Mount Vernon Motorcross Race Track, Nemo Rangers Football Grounds and Tramore Athletic FC. St. Finbarr's Hospital and Christ the King Girls Secondary School are located within 500m from the northern site boundary.

The location of the site is shown on Figure 2.1.

REVISION A
SK/DE
February 2001
2000/011/14/krl-emp_fig1
Ordnance Survey Ireland Licence no. EN 0001201 © Government of Ireland
Cork 1:15,000 Street Map



1:15,000 Site Location Map

Figure 2.1

2.3 Geology

The Kinsale Road Landfill Site is situated in the Tramore River valley. Much of the site is underlain by Waulsortian Limestone bedrock. The limestone is highly fractured and is infilled with alluvial silts in the mid to southern sections of the site. The southeastern section of the site is underlain by siltstone/mudstone which is weathered. This unit is considered to be part of the Kinsale Sandstone Formation which constitutes the high ground to the south of the site.

Geophysical surveys carried out at the site indicate the presence of a fault zone trending east-west in the southern section of the site. Within the fault zone the rock is highly fractured. To the south of the fault zone the rock is comprised of flags and grey slates of the Kinsale Sandstone Formation (Cuskinny Member). To the north of the fault the bedrock is comprised of blue-grey Waulsortian Limestone of varying degrees of competence.

The overburden varies in composition and thickness across the site. The Tramore River valley has been infilled by gravels, alluvial silts and peats. The overburden is thinnest in the northern portion of the site approximately 2-4m to bedrock and thickest in the southern portion where bedrock is encountered between 16.5 and 20 metres.

The water bearing zones beneath the site are the sands and gravels, the weathered and fractured limestones and the deeper unweathered bedrock. Above these units the peats, silts and clays (up to 5m thick) act as aquitards limiting the vertical migration of groundwater.

The sands and gravels are not continuous beneath the site and they appear to grade into gravelly clay beneath the central and southern part of the site but are of insignificant thickness moving towards the north. Where the sands and gravels are water bearing, they are considered to be only a locally important aquifer. The weathered and fractured bedrock are part of a Regionally Important Karst Limestone aquifer (Rkd) beneath the site (O' Callaghan Moran report, 2012).

The sands and gravels and the weathered bedrock are confined by the overlying clays and peats, on to which waste has been deposited, particularly in the southern section of the site. In the north-eastern section of the site, the peats thin out and the waste lies on the gravelly clays. The peats have a high organic content and are considered to have very low permeabilities (10^{-8} - 10^{-9}m/sec) throughout the site based on their composition. It is likely that the peats have been compacted due to the weight of the

overlying waste deposited through the years. The compressed peat has been squeezed dry in many places; as evidenced by the author during the drilling of boreholes in 2010; and has surged towards the periphery of the waste deposition area.

2.4 Hydrology and Hydrogeology

2.4.1 Hydrology

The Tramore River rises in the high ground to the south of Togher Village, close to Cork Airport in the townland of Lehenaghmore. The upper reaches of the Tramore River catchment are primarily steep sloped well draining agricultural lands. Much of the remaining area of the catchment has been developed for industrial and residential purposes.

Storm and surface water run-off from these areas are directed to the river along its length from Togher village to its discharge point at the Douglas Estuary. Two stormwater outfalls enter the river to the west and to the east of the Kinsale Road Landfill Site.

The Tramore River is also joined to the east of the landfill site by the Trabeg River, a tributary draining lands to the north and east of the landfill site. The Trabeg River receives surface water run-off from nearby residential estates.

The lands on the northern bank of the river running from the Kinsale Road Roundabout to the Douglas Estuary are primarily peat bog and are poorly draining. On the southern side of the river, the ground has been stabilised during development of the South Ring Road. Further south the lands rise steeply to Frankfield and Grange.

The Tramore and Trabeg Rivers are not used for supply of potable water or for livestock as the area is predominantly urban in nature.

The Tramore River was diverted in 1987 from its original route, which brought it through the centre of the area occupying the modern day landfill site, to flow along the southern and western perimeters of the licensed facility. The new course of the river has been stabilised and supported by hard-core fill comprising the northern and southern banks of the channel along the southwestern margins of the landfill site.

2.4.2 Hydrogeology

Outcropping bedrock occurs to the north and south of the landfill site, while the valley floor is underlain by peats, alluvial silts and clays. The geology of South Cork is structurally complex and is dominated by Devonian and Carboniferous clastic sediments.

The bedrock geology is characterised by a series of east to west trending fold structures which run from Midleton in the east to Macroom in the west. The anticlinal limbs of the folds are composed of Devonian rocks of the Old Red Sandstone facies, whilst the cores of the synclines are composed of Carboniferous clastic sediments.

Folding occurred as a result of the Variscan Orogeny. The structural picture was further complicated by north–northwest/south-southwest faulting of the original folded sequence during later deformation events.

The unconsolidated subsoil deposits are primarily concentrated above the Carboniferous limestone bedrock. The high ground comprising the anticlinal limbs of the Devonian sandstones have much thinner soil cover and are comprised of free draining sandy clay soils.

The subsoil and unconsolidated deposits above the Carboniferous bedrock vary greatly in thickness and composition. In particular, the river valleys are comprised of vast thickness of alluvium, sands and gravels. Many of the sand and gravel sequences are extensive enough to be considered as valuable groundwater resources.

Groundwater flow direction in the overburden is from the northwest to the southeast.

Groundwater movement in the bedrock is similar to that in the overburden. Based on the Geological Survey of Ireland (GSI) Guidelines on Aquifer Classification and Vulnerability, the bedrock beneath the site would be considered to be a regionally important aquifer. This classification is based on a review of the site investigation data and the availability of 500m^3/day of groundwater removed from the site of the former CMP Dairies well 250m to the west of the landfill site boundary.

The vulnerability rating of the aquifer is considered to be moderate to low. This rating is based on the thickness of peat and clay overlying the bedrock at the site.

CMP Dairies was the only abstractor of groundwater in the vicinity up gradient of the site. The dairy processing factory closed in 2010 and there is currently no known extraction from the aquifer upstream or downstream of the landfill site.

2.5 Climate

Data for localised conditions, or microclimate, are derived from meteorological measurements at Cork Airport located 4km to the south of the site and University College Cork (UCC) located 2.2km northwest of the site.

Average monthly rainfall data from the UCC Meteorological Station which is at a slightly elevated ordnance datum level to the facility are set out in the Table 2.1 below.

Table 2.1 Monthly Average Rainfall at UCC Meteorological Station

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Rainfall
Rainfall (mm)	131	94	91	61	74	54	61	75	98	104	102	119	1064

Wind direction measurements taken at Cork Airport show that the prevailing wind direction is westerly. Average wind speed is 10.7 knots.

2.6 Design Principles of the Landfill

The basic design principles of the landfill site are set out below and discussed in more detail in relevant sections of this thesis.

2.6.1 Containment and Leachate Treatment

While the site is not designed as an engineered contained landfill, the geology of the site acts as an effective natural barrier to vertical migration of potential contaminants i.e. the thick sequence of peats and underlying silts and clays which thicken from approx 5m in the NW to 15 m in the SE. The existing ground conditions mitigate the environmental impacts of waste disposal to a certain degree although recent geophysical surveys and an assessment of the hydrogeology have highlighted a plume of leachate discharging to the underlying aquifer. Engineering measures have been put in place to control leachate and landfill gas.

The physical, chemical and biological properties of the peat underneath the site help attenuate the impact of leachate. The silts and boulder clays underlying the peats form an effective barrier to vertical movement of leachate across the majority of the site.

Lateral leachate movement is controlled via a leachate collection trench which has been constructed along 80% of the site, along the western, southwestern and southern perimeters. The trench is 3m deep and has been backfilled with non-carbonaceous cobble-size stone. The trench also serves as a barrier to lateral landfill gas migration. Leachate makes its way to the stone filled trench via gravity flow and is extracted by sequential operation of ten pump sumps evenly dispersed along the length of the trench. The leachate is directed towards a covered containment lagoon, is fed to a methane stripping plant for pre-treatment prior to discharge to the Tramore valley sewer, which runs along the southern boundary of the site. The leachate receives final treatment at Carrigrennan Waste Water Treatment Plant, located across Cork Inner Harbour at Little Island, approximately 5 km from the site.

The maximum quantity of leachate that can be discharged to sewer from the landfill site is 25m^3/hour (600m^3/day) with a further allowance of 73m^3/hour from an additional temporary pre-treatment plant (methane stripping) for contaminated storm water.

A detailed description and layout of the leachate treatment is outlined in Chapter 3.

2.6.2 Surface Water

A surface water swale (rain water collection ditch) has been installed around the restored (capped) areas of the site. The collected surface water flows by gravity into a stormwater retention pond. Surface water from the pond then discharges into a reed bed system and ultimately into the Tramore River. In the event that the surface water quality is not adequate, it can be diverted to the leachate management infrastructure prior to discharge to the sewer.

Landfill activities have ceased at the facility as of 15th July 2009. Restoration and rehabilitation of the site is ongoing and at the time of writing (September 2013) over 200,000m^2 (~ 80%) of the facility has been capped to the required engineering standards in agreement with the EPA.

2.6.3 Landfill Gas

Landfill gas is generated as a result of the biodegradation of the organic component of the wastes. The composition of landfill gas varies depending on the nature of the waste, age, and landfill operations. Typically, the major constituents of landfill gas are

methane (CH_4) and carbon dioxide (CO_2) both of which are colourless and odourless. Minor constituents such as hydrogen sulphide (H_2S) and organo-sulphur compounds give landfill gas its characteristic odour.

Methane is flammable at certain concentrations (5-15% v/v). In the absence of adequate control measures, landfill gas could migrate from the site presenting a potential hazard to on-site offices and off-site properties. Landfill gas produced at the site is controlled by active gas abstraction. This system draws gas under negative pressure from the numerous gas wells (180 gas extraction wells approx.) that have been drilled throughout the site. The gas makes its way via a series of gas manifolds to a central utilisation unit.

A combined heat-power plant was commissioned in 1997 and operated until 2012, generating 1 Megawatt of electricity. Two landfill flares are also in operation at the site with capacities of 2500m^3/hour and 1250m^3/hour respectively. In the absence of a combined heat-power engine, the larger flare is currently used for destruction of volatiles within the gas stream. The 1250m^3/hour flare is used as a duty stand by in the event of breakdown or overhaul of the main flare.

Landfill Gas Monitoring

A series of landfill gas monitoring boreholes have been installed outside the waste fill areas.

The monitoring boreholes are constructed to permit monitoring in the overburden materials.

The boreholes are located between the fill areas and off site structures. Landfill gas monitoring is carried out in the boreholes to determine the efficiency of the landfill gas control measures and to assess fugitive emissions. Monitoring is also carried out in all onsite structures.

2.7 Site Infrastructure

2.7.1 Site Access and Internal Access Roads

Access to the site is off the South City Link Road via a controlled entry gate. This access is used by all traffic associated with the operation of the landfill and recycling activities.

2.7.2 Site Facilities

Site facilities include administrative offices, laboratory, kitchen and showering facilities, a gate house, site control office, a store, a weighbridge, a wheel wash facility, a gas utilisation plant, a leachate conditioning plant, a contaminated stormwater treatment plant, a bunded fuel storage area, a waste inspection/waste quarantine area, a car park and civic amenity area. The timber reclamation area and the composting facility are located either side of the civic amenity site.

2.8 Waste Inputs and Reception

2.8.1 Waste Composition

Wastes that were formerly deposited at the facility as set out in the Waste Licence included municipal solid waste, commercial waste and non-hazardous industrial waste, including non-hazardous industrial sludges. Liquid wastes were not accepted at the site.

Construction and demolition timber waste is accepted at the landfill site for reclamation purposes. Clean, non-contaminated timber is accepted from commercial and domestic sources for shredding prior to transportation to another facility for reprocessing and production of timber products (chipboard etc.).

Green waste (garden waste) is accepted for composting on site (open windrow method).

2.8.2 Waste Acceptance

All waste is subjected to the acceptance/rejection procedures which are outlined in a series of Standard Operational Procedures set out in the site's Environmental Management System (EMS).

2.8.3 Waste Volumes

This is included in the Annual Environmental Report.

The last AER which included waste that was accepted for landfilling on site was for January–December 2009. 76,000 tonnes were landfilled during this period.

It is estimated that 2.78 million tonnes have been deposited at the Kinsale Road Landfill Site, which was in operation since the early 1960's. During landfilling operations, the maximum quantity (tonnes per annum) of wastes that was permitted for deposition at the site was 98,000 tonnes**.**

2.8.4 Waste Records

A record is kept of the origin, type, nature and quantities of waste disposed/reclaimed at the site.

2.8.5 Waste Inspection

During the period of landfilling, waste contractors using the facility were issued with waste transfer forms.

All waste loads entering the site were checked to ensure that only waste permitted for landfilling (as set out in the waste licence) was accepted.

Non-conforming waste was quarantined and sent to a suitable facility for destruction/disposal.

2.9 Closure and Aftercare

2.9.1 Site Restoration

The site is undergoing restoration to a profile as submitted to the Environmental Protection Agency in February 2009.

Final fill levels have now been achieved and as of September 2013, the site has been 80% capped to the required engineering standard.

In the restored areas, the waste has been capped with a low permeability lining system. Details of the cap are as per Condition 10.5 of the Waste Licence:

Condition 10.5 Final Capping

The final capping shall consist of the following:

(i) Top soil (150 -300mm).

(ii) Subsoils, such that total thickness of top soil and subsoils is at least 1m.

(iii) Drainage layer of 0.5m thickness having a minimum hydraulic conductivity of $1x10^{-4}$ m/s or an equivalent geosynthetic material (e.g. LLDPE).

(iv) Compacted mineral layer of a minimum 0.6m thickness with a permeability of less than $1x10^{-9}$ m/s or a geosynthetic material (e.g. LLDPE) or similar that provides equivalent protection.

(v) Gas collection layer of natural material (minimum 0.3m) or a geosynthetic layer.

(vi) Where tree planting is to be carried out above waste-filled areas, a synthetic barrier shall be used to augment the clay cap.

The site has been capped and restored in phases since 2001. Final restoration of the site is due for completion by 2015.

2.9.2 Landscaping

A programme of planting and landscaping of restored areas will be implemented by Cork City Council.

Grasses and shallow rooting trees and shrubs will be established at the earliest opportunity to provide protection to the capping layer. The precise mix of vegetation and the phasing of the landscaping will be agreed with the EPA prior to the restoration of each phase. Where tree planting is proposed above waste filled areas, an additional synthetic barrier will be used to augment the soil cap.

It is considered that shallow rooting perennial grasses and shrubs (rye-grass, clover, honeysuckle, oxeye daisy and bush vetches) indigenous to the area are the optimum plant types.

2.9.3 Aftercare

An aftercare environmental monitoring programme will be implemented following advanced agreement with the Agency. At the time of writing, a Closure Restoration and Aftercare Management Plan (CRAMP) was being developed for Cork City Council by FTC Consulting Engineers.

Cork City Council will be responsible for maintenance of the landscaped and re-vegetated areas. Cork City Council will be also responsible for the operation and maintenance of the surface water retention lagoons, landfill gas management and leachate treatment system in the aftercare phase.

2.10 Environmental Monitoring

Environmental monitoring at the site is carried out in accordance with the numerous conditions of the waste licence.

The following environmental parameters are monitored:

- Landfill gas;
- Leachate;
- Surface water;
- Groundwater;
- Meteorology;
- Noise and Dust;
- Odour and PM_{10};
- Sewer emissions.

CHAPTER 3

3. LANDFILL LEACHATE CHARACTERISATION AND MANAGEMENT

3.1 Leachate – what is it?

Leachate may be defined as any liquid percolating through the deposited waste and emitted from or contained within a landfill. This leachate picks up suspended and soluble materials that originate from or are products of the degradation of the waste (EPA, 2003).

The composition of leachate is variable and depends on a number of factors including:

• age of the landfill,
• composition of the waste,
• the rate of decomposition within the landfill,
• the amount of rainwater infiltration, and
• temperature.

3.2 Why treat leachate?

Leachate needs to be controlled in a landfill for the following reasons (HRB, 2003):

- to reduce the potential for seepage out of the landfill through the sides or the base either by exploiting weaknesses in the liner or by flow through its matrix;
- to prevent liquid levels rising to such an extent that they can spill over and cause uncontrolled pollution to ditches, drains, watercourses etc.;
- to influence the processes leading to the formation of landfill gas, chemical and biological stabilisation of the landfill;
- to minimise the interaction between the leachate and the liner; and in the case of above ground landfills, to ensure the stability of the waste.

If leachate is allowed to migrate from a site, it may pose a severe threat to the surrounding environment and in particular to the groundwater and surface water regimes. This in turn can pose serious human health issues if polluted potable water sources are consumed.

3.3 Main Constituents

The principal organic content of leachate is formed during the breakdown processes summarised in Figure 3.1. It is normally measured in terms of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) or Total Organic Carbon (TOC). The quality of municipal landfill leachate changes with time as the degradation of the waste continues inside the body of the waste. The degradation process is generally divided into five successive phases (EPA, 2000), namely:

- *Phase I - Hydrolysis and Aerobic Degradation*

The initial stage of organic decomposition occurs during the emplacement of the waste in the landfill and for the period of time after, when oxygen is available within the waste. Chemical processes are initiated and facilitated by the presence of aerobic micro-biota, which metabolise a fraction of the organic waste to produce simple hydrocarbons, water, carbon dioxide and, as this is an exothermic reaction, heat. In these reactions, water and carbon dioxide are produced in the greatest concentrations. The carbon dioxide can dissolve in the water, forming a leachate that is rich in carbonic acid, which, in turn, lowers the pH of the surroundings. This stage generally lasts for a matter of days or weeks and terminates when the available oxygen within the waste is utilised.

- *Phase II - Hydrolysis and Fermentation*

The removal of oxygen in Phase I facilitates a change in conditions within the landfill, whereby the activities of anaerobic and facultative organisms (involving acetogenic bacteria) are initiated. These organisms hydrolyse and ferment cellulose and other putrescible materials, producing simple soluble compounds such as Volatile Fatty Acids (VFAs), which in turn give rise to a high BOD value. Phase II can last for years or even decades, and the leachates produced at this stage are characterised by high BOD values (> 10,000mg/l), high BOD:COD ratios (typically greater than 0.7), acidic pH levels (5 – 6), strong unpleasant odours and high concentrations of ammonia (500-1000mg/l). The aggressive chemical nature of this leachate assists in the dissolution of high levels of iron, manganese, zinc, calcium and magnesium (usually occurring as sulphides) (McBean *et al*., 1999).

- *Phase III – Acetogenesis*

In this phase, anaerobic conditions are still present and the organic acids that were formed in the hydrolysis and fermentation phase are now converted via specific microorganisms to acetic acid, acetic acid derivatives, carbon dioxide and hydrogen. Other microorganisms convert carbohydrates directly to acetic acid in the presence of carbon dioxide and nitrogen. Hydrogen and carbon dioxide levels begin to diminish towards the end of this stage, with the lower hydrogen concentrations promoting the methane-generating microorganisms (methanogens), which subsequently generate methane and carbon dioxide from the organic acids (and their derivatives) generated in the earlier stages. A summary compositional analysis of acetogenic leachates is outlined in Table 3.1.

- *Phase IV – Methanogenesis*

This phase encompasses the main processes that lead to the production of methane. At this point, the chemical processes involved are comparatively slow and can take many years to complete. Oxygen-depleted, anaerobic conditions remain as in the previous two phases. Low levels of hydrogen are required to promote the methanogenic organisms, which generate carbon dioxide and methane from the organic acids and their derivatives such as acetates and formates produced in the earlier stages. Methane generation may also occur from the direct conversion of hydrogen and carbon dioxide (via microorganisms) to methane and water. Hydrogen ions concentrations, produced during Phases II and III, fall to low levels during this fourth phase, raising the pH of the leachate. A summary compositional analysis of methanogenic leachates is outlined in Table 3.2.

- *Phase V - Oxidation*

Oxidation processes mark the final stage of the reactions involved in the biodegradation of waste. As the acids are used up in the production of landfill gas (as seen in Phase IV), new aerobic microorganisms slowly replace the anaerobic forms and re-introduce oxygen to the system. Microorganisms that convert methane to carbon dioxide and water may also become established (Whittleton, 2004).

These biodegradation processes are dynamic, with each stage being dependent on the creation of a suitable environment by the preceding stage. Phase III leachate is characterised by a high organic material content with a BOD:COD ratio of greater than 0.4, and a low pH. After the transition to the methanogenic phase (Phase IV), the organic materials concentration and the BOD:COD ratio of the leachate decrease rapidly, whilst the pH value increases. A BOD:COD ratio of less than 0.25 is typical of a methanogenic phase leachate. The concentration of certain compounds such as nitrogen, ammonium, phosphorus and chloride do not change significantly between these phases. Ammonia is probably the most important inorganic contaminant with the greatest potential to adversely impact on surface and groundwaters. However, other components such as heavy metals and sulphides may be significant in certain circumstances. Iron and calcium are particularly important with respect to the precipitation of solids, whilst elevated salinity levels are ubiquitous.

It is important to recognise that landfills are created over periods of many years. Wastes deposited at one time are later covered with more waste, creating a layered structure that may extend over large areas and to depths of several tens of metres. Thus, at any given time the different vertical and spatial zones within the landfill may be experiencing different decompositional phases. Also, many factors associated with the heterogeneity of the waste environment, such as the moisture content, waste density, and the availability of nutrients, will affect the duration and character of each phase. Microbial communities should likewise be expected to differ within the structure of the landfill. A graph detailing some of the changes in leachate composition with time can be seen in Figure 3.2.

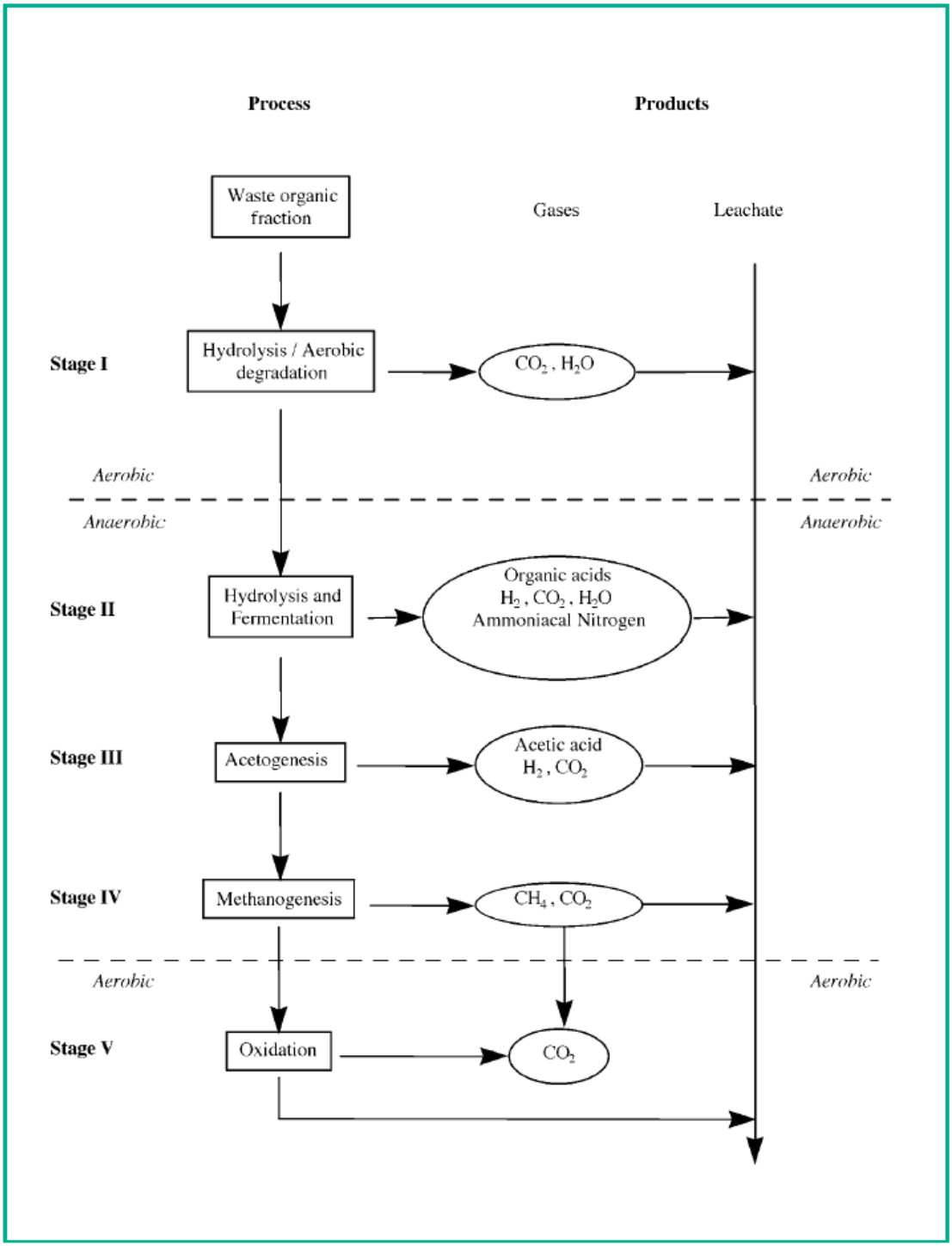


Figure 3.1 The Major Stages of Waste Degradation (after EPA, 2000)

3.4 Significance of Constituents of Leachate

The composition of leachate is an indication of the state of the biological processes occurring within the waste body and the solubility of the ions. If leachate is to be removed and treated, certain parameters will have particular environmental and economic significance. This significance will alter with the route for treatment/disposal chosen.

The most significant parameters are (UK DOE, 1995):

Ammonia

Ammoniacal-N is the contaminant with the greatest potential to adversely impact upon surface and groundwater in the vicinity of landfills. It will be several decades before concentrations of ammoniacal nitrogen will fall to values where direct release to a watercourse becomes a viable option.

Organic Loading

This refers to the organic compounds present in the leachate. The main significance of organic loading is its effect on watercourses where the compounds are broken down aerobically causing dissolved oxygen levels in the watercourses to fall and so threaten aquatic life. The organic loading can be measured by a number of analytical methods, e.g. Total Organic Carbon (TOC), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). The amount of organic carbon present in leachate will affect the method of treatment and the suitability of the leachate for discharge to a watercourse.

Chloride

Leachate contains the final soluble degradation products of waste which are in the main simple ions. The major contributor to this ionic strength is chloride and this can again cause major problems to aquatic fauna. For sewer discharges, restrictions are less likely due to dilution by other effluents.

Phosphorus

The levels of total phosphorus in leachates are low. The treatment of leachates at wastewater treatment plants may require the addition of phosphorus as a nutrient for bacterial growth. However, one must be cognisant of the applicable regulations

(namely The Urban Waste Water Treatment Regulations (S.I. No. 419 of 1994) and The Local Government (Water Pollution) Act, 1977 (Water Quality Standards for Phosphorus) Regulations, 1998 (S.I. No. 258 of 1998)) when discharges from leachate treatment/Waste Water Treatment (WWT) plants are being examined. Consideration must be given to the assimilative capacity and the dilution available in the receiving water.

Metals

Conditions within the landfill during the acetogenic phase are such that the liquid can be chemically aggressive and the resulting leachate may contain high concentrations of iron, manganese, calcium and magnesium. During the methanogenic phase, the heavy metals are rendered insoluble and levels of dissolved metals tend to be low. Where high concentrations do occur, they will need to be reduced during treatment as both sewer and surface water discharge consents will contain limits for these parameters. However, metal concentrations in leachate tend to be below those routinely determined in urban wastewater.

Sulphate

Sulphate levels may be restricted in discharge consents. Methanogenic leachate generally contains low concentrations (mean of 67mg/l) whereas on average acetogenic leachate contains up to 10-fold higher sulphate concentrations. Sulphates if present are likely to cause a problem due to reduction to hydrogen sulphide which gives rise to odour problems. Leachates will therefore often receive some form of treatment via carbon scrubbers prior to discharge offsite.

Dissolved gases

For discharge to sewer, prior physical treatment to remove methane, carbon dioxide, and hydrogen sulphide may be necessary to prevent buildup of explosive, asphyxiating or toxic gases in the sewer system.

Discharges to surface water will require aeration and as such should only contain atmospheric gases.

Other compounds

It is important that the List I and List II substances, referred to in the EU Directives on Dangerous Substances (76/464/EEC) and Groundwater (80/68/EC) and associated amendments, are prevented from being discharged or limited so that surface water or groundwater pollution is prevented.

Certain substances, both organic and inorganic are highly restricted by virtue of their toxicity and persistence in the aquatic environment. Some of these materials are present in leachates in trace quantities and may significantly restrict any discharge to surface water and/or sewer networks (EPA, 2000).

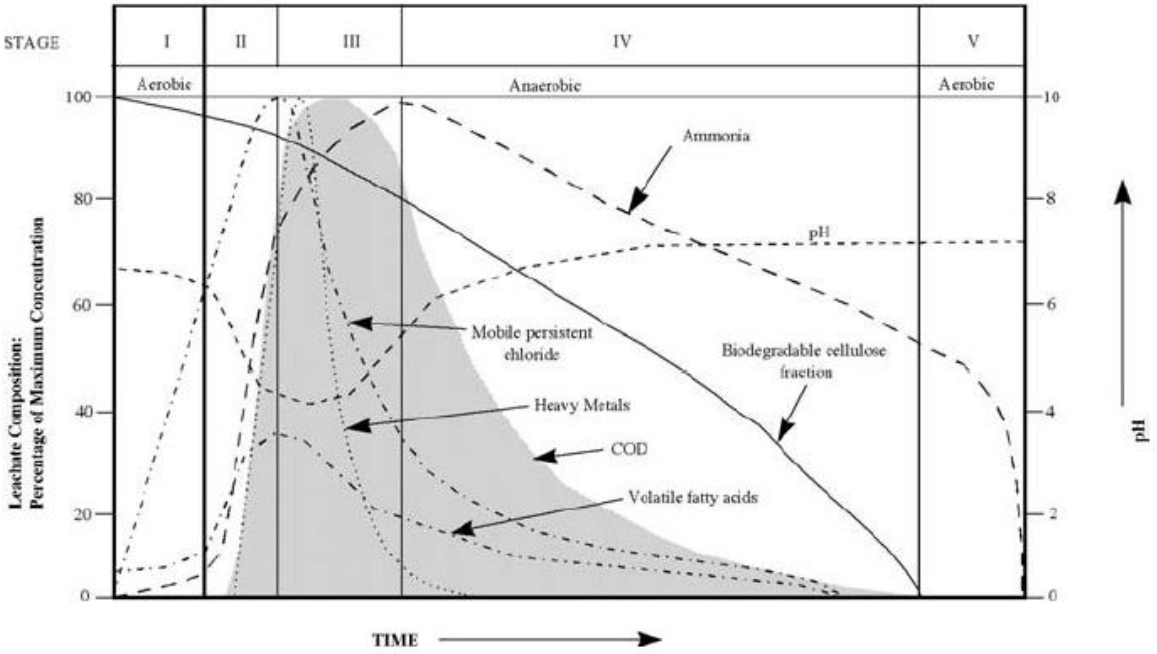


Figure 3.2 Changes of Leachate Composition with Time (after UK DOE, 1991)

Table 3.1 Summary of Composition of Acetogenic Leachates sampled from large landfills with a relatively dry high waste input rate

	Overall Range		Overall Values	
Determinant	Minimum	Maximum	Median	Mean
pH-value	5.12	7.8	6.0	6.73
conductivity (µS/cm)	5,800	52,000	13,195	16,921
alkalinity (as $CaCO_3$)	2,720	15,870	5,155	7,251
COD	2,740	152,000	23,600	36,817
BOD_{20}	2,000	125,000	14,900	25,108
BOD_5	2,000	68,000	14,600	18,632
TOC	1,010	29,000	7,800	12,217
fatty acids (as C)	963	22,414	5,144	8,197
ammmoniacal-N	194	3,610	582	922
nitrate-N	<0.2	18.0	0.7	1.8
nitrite-N	0.01	1.4	0.1	0.2
sulphate (as SO_4)	<5	1,560	608	676
phosphate (as P)	0.6	22.6	3.3	5.0
chloride	659	4,670	1,490	1,805
sodium	474	2,400	1,270	1,371
magnesium	25	820	400	384
potassium	350	3,100	900	1,143
calcium	270	6,240	1,600	2,241
chromium	0.03	0.3	0.12	0.13
manganese	1.40	164.0	22.95	32.94
iron	48.3	2,300	475	653.8
nickel	<0.03	1.87	0.23	0.42
copper	0.02	1.1	0.075	0.13
zinc	0.09	140.0	6.85	17.37
arsenic	<0.001	0.148	0.010	0.024
cadmium	<0.01	0.1	0.01	0.02
mercury	<0.0001	0.0015	0.0003	0.0004
lead	<0.04	0.65	0.3	0.28

Note: All results in mg/l except pH and conductivity (µS/cm)

(after UK DOE, 1995)

Table 3.2 Summary of Composition of Methanogenic Leachates sampled from large landfills with a relatively dry high waste input rate

	Overall Range		Overall Values	
Determinant	Minimum	Maximum	Median	Mean
pH-value	6.8	8.2	7.35	7.52
conductivity (µS/cm)	5,990	19,300	10,000	11,502
alkalinity (as $CaCO_3$)	3,000	9,130	5,000	5,376
COD	622	8,000	1,770	2,307
BOD_{20}	110	1,900	391	544
BOD5	97	1,770	253	374
TOC	184	2,270	555	733
fatty acids (as C)	<5	146	5	18
ammmoniacal-N	283	2,040	902	889
nitrate-N	0.2	2.1	0.7	0.86
nitrite-N	<0.01	1.3	0.09	0.17
sulphate (as SO_4)	<5	322	35	67
phosphate (as P)	0.3	18.4	2.7	4.3
chloride	570	4,710	1,950	2,074
sodium	474	3,650	1,400	1,480
magnesium	40	1,580	166	250
potassium	100	1,580	791	854
calcium	23	501	117	151
chromium	<0.03	0.56	0.07	0.09
manganese	0.04	3.59	0.30	0.46
iron	1.6	160	15.3	27.4
nickel	<0.03	0.6	0.14	0.17
copper	<0.02	0.62	0.07	0.13
zinc	0.03	6.7	0.78	1.14
arsenic	<0.001	0.485	0.009	0.034
cadmium	<0.01	0.08	<0.01	0.015
mercury	<0.0001	0.0008	<0.0001	0.0002
lead	<0.04	1.9	0.13	0.20

Note: All results in mg/l except pH and conductivity (µS/cm)
(after UK DOE, 1995)

When the data from the Kinsale Road Landfill Site (KRLF) (see Table 3.3) and data presented in the above tables are compared, it can be seen that the leachate emissions from the KRLF do not fit into Phase III – Acetogenic Leachates or Phase IV - Methanogenic Leachates. Based on the monitoring data available, the KRLF is most likely somewhere between Phases IV and V – the Oxidation Phase.

Table 3.3 **ANNUAL VALUES for LEACHATE PUMPING STATIONS - KINSALE ROAD LANDFILL SITE - 2004 (mg/l)**

	Frequency	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	Min	Max	Mean Conc. (PS 1 - 9)	Mean Conc. (Highlighted)
Vis/Odour	q	Fair/Nil	Fair/Nil	Fair/Nil	Fair/Nil	Fair/Nil	Fair/Nil	Fair/Nil	Fair/Nil	Good/Nil				
Ammonium	a	450	400	1.2	400	450	510	550	370	120	1.2	550	361	447
B.O.D.	a	30	37	12	27	42	47	35	43	7	7	43	31	37
C.O.D.	a	447	494	21	415	413	476	509	317	29	21	509	347	439
Chloride	a	533	531	35	638	602	687	710	496	212	35	710	494	600
Cond µs/cm	a	5390	5350	627	5870	5750	6600	6520	4900	2250	627	6600	4806	5769
pH	a	7.74	7.4	7.1	7.56	7.43	7.39	7.44	7.4	7.32	7.1	7.74	7.42	7.48
Sus.Sols	a	26	116	32	97	98	113	82	69	14	14	116	72	86
Temp	a	15.4	13	14.4	13.5	15	15.5	13	12.4	12.1	12.1	15.5	13.81	13.97
Boron	a	1.5	1.5	0.2	1.5	2.1	1.9	1.4	0.3	0.1	0.1	2.1	1.17	1.46
Cadmium	a	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Calcium	a	28	24	70	56	40	24	24	120	46	24	120	48	45
Chromium	a	0.01	0.001	0.01	0.01	0.04	0.01	0.007	0.06	0.01	0.001	0.06	0.02	0.02
Tot Phos	a	0.6	0.4	0.5	0.3	0.3	0.4	0.2	0.3	0.1	0.1	0.6	0.3	0.4
T.O.N.	q	4	6	11	15	4.5	5.1	7	23	6	4	23	9.1	9.2
Ratio BOD:COD		0.07	0.07	0.57	0.07	0.10	0.10	0.07	0.14	0.24	0.33	0.08	0.09	0.08

Note: Pumping Stations (PS) are individual pump sumps where leachate is extracted from a gravel-filled trench that surrounds the landfill area.

Analysis of the leachate from the individual pump sumps can display quite a range in values of particular parameters. This is likely associated with leachate from different parts of the site (emanating from wastes of varying age) exploiting preferential flow paths within the waste body. Dilution due to surface water runoff and groundwater intrusion will also act to lower concentrations at certain pumping stations.

Mean Concentration of measured parameters from pump sumps highlighted in yellow are more typically representative of leachate generated on site.

Table 3.3 (continued) **ANNUAL VALUES for LEACHATE PUMPING STATIONS 2004 (mg/l)**

	Frequency	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	Min	Max	Mean Conc. (PS 1 - 9)	Mean Conc. (Highlighted)
Copper	a	0.002	0.002	0.01	0.02	0.008	0.005	0.03	0.008	0.005	0.002	0.02	0.010	0.011
Cyanide	a	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Fluoride	a	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.2	0.2	0.4	0.4	0.4
Iron	q	0.3	0.5	0.03	0.5	0.6	0.65	0.7	0.4	0.08	0.03	0.7	0.42	0.52
Lead	a	0.001	0.001	0.005	0.001	0.002	0.001	0.001	0.001	0.001	0.001	0.005	0.002	0.001
Magnesium	a	63	65	12	75	70	85	100	85	50	12	100	67	78
Manganese	a	0.001	0.004	0.002	0.01	0.02	0.008	0.2	0.07	0.17	0.001	0.17	0.054	0.045
Mercury	a	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Potassium	q	210	245	30	275	260	295	310	230	85	30	310	216	261
Sulphate	a	12	15	40	18	16	20	16	10	40	10	40	21	15
Sodium	q	270	335	38	410	405	485	440	310	108	38	485	311	379
Zinc	a	0.002	0.001	0.001	0.002	0.002	0.003	0.002	0.001	0.001	0.001	0.003	0.002	0.002
Ni	a	0.02	0.008	0.05	0.05	0.06	0.06	0.04	0.004	0.001	0.001	0.06	0.033	0.035

Note: Frequency, a = annual; q = quarterly

3.5 Leachate Treatment Methods

The main constituents of leachate requiring treatment are the ammoniacal-N content and organics.

Treatment methods may be divided into four categories (HRB, 2003):

- Physical/chemical pre-treatment (e.g. air stripping of methane or ammonia and precipitation or flocculation)
- Biological treatment (e.g. activated sludge, sequencing batch reactors, rotating biological contactors, combined leachate and urban wastewater treatment, anaerobic treatment, and biological nitrogen removal)
- Combination of physical-chemical and biological treatment (e.g. membrane bioreactors, powdered activated carbon, or filtration)
- Advanced treatment (activated carbon adsorption, reverse osmosis, chemical oxidation, evaporation, and reed bed treatment).

Methane air stripping is the leachate treatment process in operation at the KRLF.

Air stripping removes dissolved methane prior to discharge to the sewer.

Raw leachate can be saturated with methane, containing up to 15mg/l. Concentrations of methane as low as 1.4mg/l in leachate can give rise to explosive concentrations of methane gas (14% by volume) under certain conditions. Removal of dissolved methane is therefore necessary to avoid the possibility of forming an explosive atmosphere in the sewer system. A detailed description of the Leachate Management Infrastructure at the Kinsale Road Landfill Site is detailed in Section 3.6.

3.6 Leachate Management Infrastructure at Kinsale Road Landfill Site

3.6.1 Introduction

The following section outlines the current management of leachate at Kinsale Road landfill site. The management of leachate is based on preventing leachate contamination from entering the local environment.

The text is reproduced with modifications from reports by environmental consultants Fehily Timoney & Company (FTC, August 2004 and FTC, October 2011).

Modifications made by the author are in underlined *ITALICS*.

3.6.2 Leachate Collection Infrastructure

The leachate collection system consists of a primary and a secondary system. The primary system is a 1,750m long, 3m deep cut off trench. The trench consists of a 200 mm diameter slotted HDPE pipe in a stone surround and geotextile wrap. At ground level the trench is capped with clay. The main function of the trench is to prevent subsurface leachate from entering the Tramore and Trabeg Rivers. The *leachate captured in the* deep trench *can be* discharged to the leachate storage lagoon *or can be sent directly to the balancing tank at the treatment plant. Pumping is achieved* via 10 pump sumps located at intervals along the length of the *cut off* trench. The pumps run in batch sequences of three, i.e. pumps 1 - 3 run for 4 hours, then pumps 4 - 6 run for 4 hours, *and so on until* the cycle repeats. *The system can also be controlled via leachate level within each pump sump set against ordinance datum across the collection trench.* Each individual pump sump can also be manually controlled with the SCADA PC – *a computer management system for logging and recording data as well as providing for remote control of pumps and valves associated with the leachate collection and treatment network.*

The secondary collection system consists of four cell pumps situated in the old waste disposal area. Four leachate wells were installed within the waste body as part of the Phase 4 Capping Project (2010). At the time of writing this report, the borehole wells had been drilled but the pumps were yet to be installed and commissioned.

The base of the wells is at approx +5.0 m AOD (each leachate well is approximately 20m deep from ground level). When commissioned, leachate will be pumped from the main body of the waste directly to the leachate collection lagoon.

When operational, the pumps will run on an automated sequence controlled by the SCADA PC.

3.6.3 Leachate Storage, Treatment and Disposal

3.6.3.1 Leachate Lagoon

The leachate/stormwater lagoon provides storage for leachate and additional storage for contaminated stormwater. The lagoon is divided into three cells, where cells 1 and 3 are for the storage of potentially contaminated stormwater and cell 2 is for leachate storage. Cell 2 has a floating cover, which acts as an odour barrier *and prevents rainwater infiltration*. *Stormwater from lagoons 1 and 3 can be diverted to a reed bed treatment system via a stormwater storage pond. Dosing of the reed beds is achieved by means of a floating decanting arm, thus ensuring a steady flow.*

Stormwater from the lagoons and/or from the stormwater pond that is deemed unsuitable for treatment within the reed beds (i.e. high in ammonia, chloride etc.) can be (a) discharged directly to the Tramore Valley sewer or (b) may be directed to the leachate treatment plant for air sparging prior to discharge to the sewer.

Leachate collected in Cell 2 discharges to the leachate treatment plant by gravity feed.

3.6.3.2 Leachate Treatment Plant

The leachate treatment plant is designed to strip dissolved methane from leachate prior to discharge to the Tramore Valley sewer. *For reasons of safety, there is a sewer discharge limit of 0.2mg/l dissolved methane in the leachate.*

A layout of the plant is shown in *Figure 3.3*. The leachate stored in cell 2 of the lagoon is discharged to the balancing tank, which has an operating capacity of 55m^3. The leachate is then transferred from the balancing tank to the methane stripping lanes (x2) at an approximate rate of 5.0 l/s. The stripping lanes consist of four chambers divided by baffled weirs. As the leachate flows through the chambers, it is aerated by disc

membranes powered by two air blowers, one blower per lane. An anti-foaming agent is added at the *start of the process* to prevent foaming of the leachate *and premature triggering of the level sensors (which would result in plant shutdown)*. The pH level can be adjusted by acid dosing *although this has not been necessary since commissioning of the plant*. The discharge from the lanes enters a gravel trap to prevent calcium and iron precipitation adhering to the discharge pumps and pipework. The precipitation *has the potential to* completely block the pumps and pipework within a matter of weeks thus preventing nominal discharge. *Effluent from the* gravel trap then flows to a discharge chamber and is pumped to the sewer through either the 100mm (4") or the 160mm (6") HDPE line. The discharge line must be manually selected. The current EPA waste licence allows for a discharge to sewer of 25 l/s *with a maximum daily discharge of 600m^3 per day. There is an additional discharge permit from Cork County Council which allows for sewer discharge of contaminated stormwater from the temporary leachate plant (see below) at a rate of 73 l/s.*



Temporary Leachate Treatment Plant

The temporary leachate treatment plant is based on the main treatment plant design but with 4 times the capacity of the main plant and was originally fed with surface leachate as well as stormwater run-off from *former active areas of waste disposal*. Its construction is similar to that of the storage lagoon of cell 2, consisting of a HDPE lined pond with a concrete base containing 3 x 4 rows of 12 *air* diffusers and a discharge pump with a 20 l/s capacity. The plant is fully automated and is controlled by a level float switch near the discharge pump. The *discharge permit from Cork County Council allows for a discharge to sewer at a rate of 73 l/s.*

3.6.4 Leachate Volumes

The volume of leachate discharged from the site to the public sewer from 2005 to 2011 is presented in Table 3.4 and Figure 3.4 below.

Table 3.4 Annual Volume of Leachate Discharged to the Public Sewer

Year	Leachate Discharged to Sewer (m^3/year)	Mean discharge Volume (m^3/ day)	Mean Discharge (litres/second)
2005	121,454	333	3.85
2006	122,627	336	3.89
2007	104,243	286	3.31
2008	68,000	186	2.16
2009	55,000	151	1.74
2010	79,857	219	2.53
2011	78,114* (projected 12 month total based on Jan –Aug results)	214	2.48
Mean (05-11)	89,899	246	2.85

(after FTC, 2011)



Figure 3.4 Graph Showing Leachate Discharge Volumes (after FTC, 2011)

3.6.5 SCADA PLC

The SCADA PLC (Programme Logic Control) monitors and records all sensor and pump data from the treatment plants as well as pump chambers and probes on-site. It is situated in the administration building and records the following:

- *Pump sumps:*

  Operational status, green – on, red – off

  Pump sump level
- *Leachate lagoon:*

  Levels within each of the cells

- *Treatment plant readings:*

  pH levels both lanes

  Head space methane levels

  Dissolved methane using a CAPSUM probe

  Flow rates through the lanes

  Discharge flow rates to the Tramore sewer

  Leachate levels within the balancing tank and the discharge pump sump, and

  Operational status of all the plant, green – on, red – off.

- *Tramore sewer discharge:*

  pH levels both lines (100/160mm HDPE)

  Head space methane levels

  Dissolved methane using two CAPSUM probes, both lines (100/160mm HDPE).

  Flow rates.

A typical schematic display of the SCADA system can be seen in Figure 3.5.

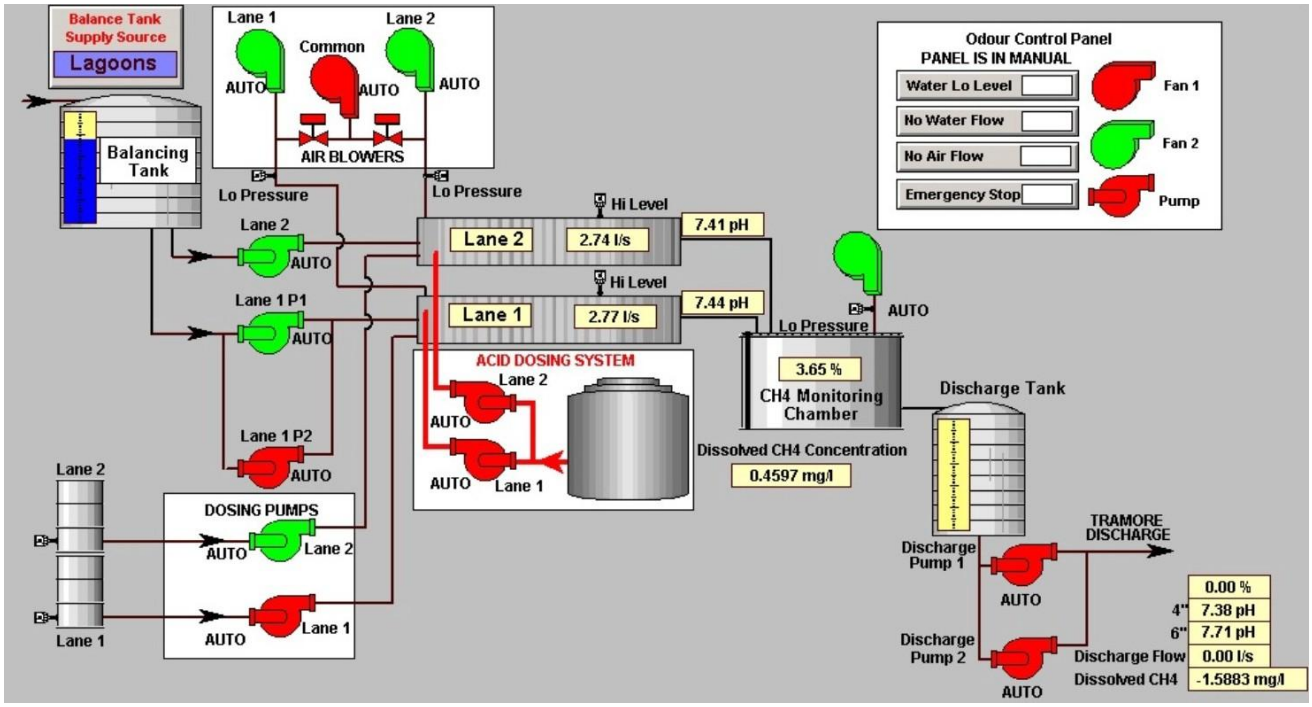


Figure 3.5 SCADA Display of Leachate Treatment Plant (after FTC, 2011)

It should be noted that although the dissolved methane reading from the CAPSUM probes provide a constant readout on the SCADA PLC of dissolved methane levels within the leachate sent to sewer, the readings are in fact in error. The probes were installed at the request of the EPA as part of the licence agreement and trialled over a two year period. However due to constant fouling and clogging of the membrane (with iron calcite build-up and the formation of a bio-film) the probe never functioned properly and gave continuous inaccurate readings.

The results of a GC analysis for a weekly grab sample for methane is now used as a measure of compliance with emission limit standard. This change to the sampling method and frequency is in agreement with the EPA.

Along with the above, the SCADA PLC also monitors the met station, emissions from the combined heat–power generator/flares and the stormwater entering the stormwater pond.

An aerial view of the leachate management infrastructure at KRLF is outlined in Figures 3.6 and 3.7 below.

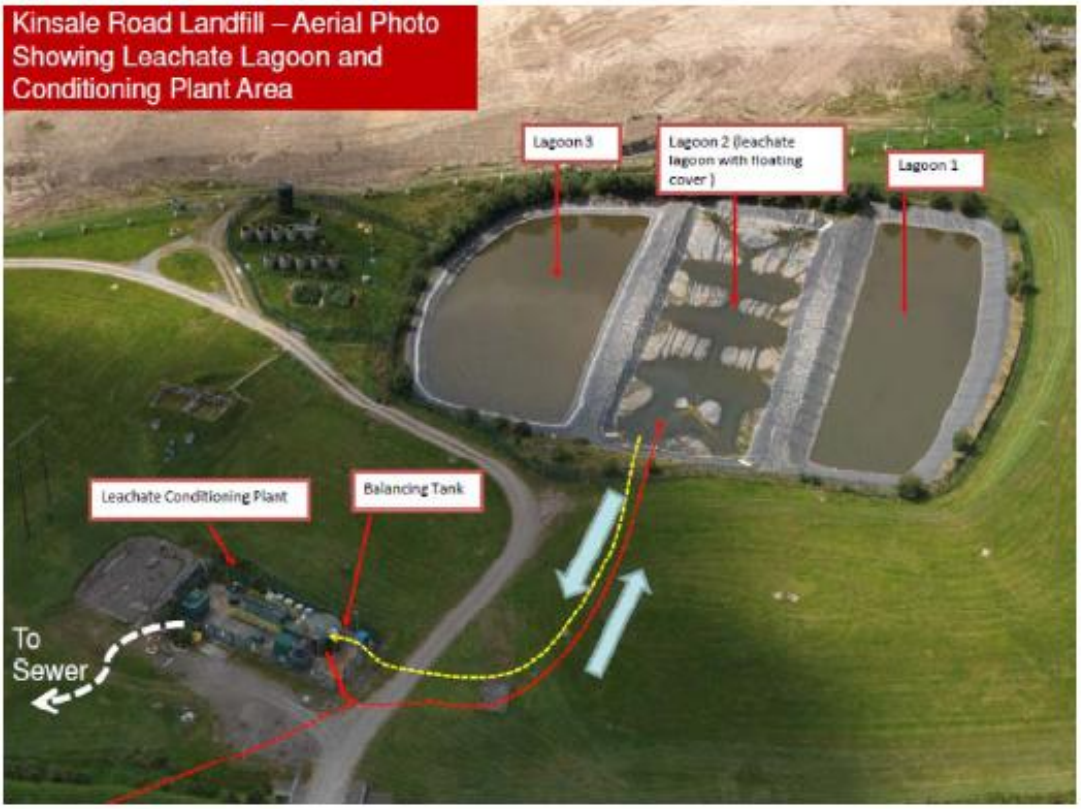


Figure 3.6 Aerial View of Leachate Lagoon and Conditioning Plant (after FTC, 2011)



Figure 3.7 Aerial View of Leachate Management Infrastructure (after FTC, 2011)

CHAPTER 4

4. LANDFILL LEACHATE TREATMENT METHODS

4.1 Introduction to Project Design and Treatment Process Selection

This chapter details a step by step account of the project design and process selection criteria.

Initial Idea – Project Concepts and Aims

The initial idea for a project entailing the treatment of landfill leachate at the Kinsale Road Landfill Site using natural systems came from Dr A.R. Allen of the Department of Geology, University College Cork (joint project supervisor) who approached Mr Michael O' Brien, Senior Engineer within the Environment Section of Cork City Council. Following a number of meetings, it was agreed that the author, who at the time was working at the landfill site as an environmental scientist, would undertake the project as a M.Sc. with the Department of Geology, University College Cork. The project was later extended to a Ph.D.

The aim of the project was to design and build a demonstration scale wastewater treatment system incorporating varying alternative natural treatment processes with an emphasis on meeting leachate treatment discharge limits and regulations in the most cost effective manner (''low tech'', low maintenance, low cost) and mitigating the associated environmental impacts.

4.1.1 Analysis of Treatment Process Options

The original treatment process considered was the use of compost as a medium contained within a vessel which would then be dosed with leachate. Compost is readily available and free of charge at the Kinsale Road Landfill Site (KRLF). Cork City Council operates a compost facility at the landfill site in conjunction with a private operator (CTO Environmental Ltd.), where green waste, instead of being landfilled is composted using the open windrow/aerated static pile method. The compost is then used on site as a top

soil improver for areas undergoing permanent engineering capping and along the site periphery where trees are planted to prevent soil erosion and flooding.

Following an initial desktop survey, other additional treatment options were put forward, namely:

- Use of peat as a treatment medium
- Percolating sand filters
- Soil filters
- Timber chip percolating filters
- Treatment using willow trees
- Use of composite media – i.e. varying percentage mixtures of sand/compost/peat/soil etc.
- Reed bed treatment systems – two types, Vertical Flow (VF) and Horizontal Flow (HF), as discussed in section 4.7.

Each of these treatment options will be discussed in further detail below.

4.1.2 Wastewater Characterisation

In order to design a wastewater treatment system it is necessary to examine the characteristics of the wastewater to be treated. The appropriate wastewater treatment design and process can then be selected bearing in mind the effluent discharge standard required. The more important characteristics of landfill leachate are listed in Chapter 3.

4.1.3 Selection of Treatment-Process Flow Diagrams

Process flow diagrams are graphical representations of combinations of unit operations and processes used to achieve specific treatment objectives. They are used to describe the major elements of the treatment process. The process flow diagram for this project and the stages of development can be seen in Chapter 5, Figure 5.17.

4.1.4 System Hydraulics

This involves the determination of the major components of the treatment system's hydraulics and is critical during the early planning and design stage of major projects (Metcalf and Eddy, 1991). Flow rates, (max, min, average, dry weather flow etc.) will

determine the sizing of the pipework and the hydraulic head losses to be allowed for between each unit stage. The calculation of head loss through the system is essential to ensure unimpeded flow. Head losses through a treatment unit include, head loss at the inflow structure, at the outflow structure, head loss through the unit and miscellaneous losses through pipework, fittings, valves, flow-splitters etc. (EPA, 1999).

After careful consideration, discussions with hydraulic engineers in Cork City Council's Water and Drainage Departments and a review of the relevant literature, it was decided that the hydraulic dynamics of this project did not require attention at the micro–meso level as opposed to the requirements of larger, perhaps city-wide drainage schemes. Pumping distances and head requirements would be no more than several metres (up to seven metres); therefore head loss due to friction etc. would be negligible and could easily be overcome through the correct choice of pump. In addition, the section of the site selected for the trial plant is situated on a mild gradient, which was deemed adequate for gravity flow for effluent discharge and flow between units. Decisions on the sizing of pipework etc. were made in conjunction with the mechanical and electrical contractors chosen to carry out the works.

4.1.5 Hydraulic Profile

The hydraulic profile for the system was calculated using a scaled site contour map. A maximum head of 5 m (0.5 bar) was available from the influent (header tank) to the final effluent point (stone trap). However due to the site topography; which is a gentle convex slope for the most part, with sharp concave hollows over the last 20 metres; and spacing requirements between the process units, the pressure head available did not allow for dosing each unit under gravity flow alone. To compound this, due to the fact that the system was to be built on an engineered capped area, the units and associated pipework could not be buried to increase the hydraulic gradient.

Sufficient spacing and gradient between the units was assigned during the planning stage to allow for effluent flow under gravity to the pump sumps at the upstream end of each treatment unit.

4.2 Past Experience

Past experience in the design and operation of wastewater treatment systems is important in process selection so that the capabilities and limitations of various processes and their support systems can be realistically assessed.

A study of the known performance criteria of existing systems can help eliminate many of the design uncertainties and avoid miscalculations in terms of expected treatment efficiencies, costing estimates and adaptability to on-site conditions.

To this end, the author made a number of site visits to similar facilities where varying types of treatment processes were in operation as well as in-depth studies of available literature, conference symposia etc. and conversations with field experts.

A site visit in April 2004 to Laois County Council's Landfill Site at Kyletalesha, approximately 5km from the town of Portlaoise, provided some valuable insights into the design and operation of an alternative leachate treatment process.

As part of a European Union LIFE funded project in 1997, Laois County Council constructed an onsite leachate treatment system using peat as the treatment medium. Four 19.2m diameter galvanised tanks were constructed and filled with peat to a depth of 1.5m. The peat was harvested in blocks (300 x 300 x 300mm), placed in the tanks and intermittently dosed with leachate on an hourly basis using automatically controlled pumps.

The plant has proven to be extremely successful in terms of treatment efficiencies of contaminants such as NH_4-N, BOD_5, suspended solids and conductivity. So much so that the EPA Waste Licence allows for the direct discharge of the treated leachate to the nearby river Triogue. In the event of the effluent not achieving the discharge limits set (e.g. during frosts and cold spells when the *Nitrosomonas* and the *Nitrobacter* bacteria become less active), the leachate is recirculated through the system (personal communication with the facility manager).

Other sites visited included Cork County Council's Sewage Treatment Works at Boherbue near the town of Millstreet, Co. Cork, where a horizontal surface flow constructed wetland is utilised to treat incoming sewage effluent. This was coupled with a

day visit to Cork City Council's Water Treatment Works located on the Lee Road to the west of the city.

At each of the plants visited, essential information was gathered through observations and conversations with on site personnel with respect to the operation and maintenance of the various unit processes, influent flow rates, dosing applications, potential costs involved as well as sourcing of equipment and materials.

Further information on past experiences was gleaned from referenced material (Mulamoottil *et al.,* 1999 ''Constructed Wetlands for the Treatment of Landfill Leachates'' was particularly useful), attendance at a conference in Dublin City University in June 2004 on Reed Beds and Constructed Wetlands, conversations with field experts in constructed wetlands as well as water and drainage engineers in Cork City Council.

4.3 Regulatory Requirements for a Waste Licence

A waste licence is required for the operation of a landfill site. The licensing system is controlled and operated by the Environmental Protection Agency (EPA). The Agency is a statutory body set up under the Environmental Protection Agency Act (1992) and has responsibility for protecting the environment in the Republic of Ireland. They regulate and police activities that might otherwise cause pollution and ensure that solid information on environmental trends is available so that the necessary actions may be taken (EPA, 2007). The power to award (and revoke) a waste licence to an operator is provided to the Agency via the Waste Management Act (1996) (as amended). This is a powerful piece of environmental legislation and forms the cornerstone for waste management law, policy and activities in Ireland. The Act stems from overarching European Community Directives and Regulations on Waste (1975, 1979) and Landfill (1999).

Under the provisions of the Act, the Agency inserts a series of conditions in the waste licence relating to the control of emissions from the activity/facility concerned in an integrated manner.

The parameters to be monitored, the methods of monitoring and frequency at which they will be recorded are detailed in a list of Schedules usually towards the end of a waste

licence. The schedules will also detail the emission limit values for certain parameters, depending on the situation i.e. type of waste licence (hazardous versus non-hazardous), waste activities carried out at the facility (landfilling versus reclamation activities), site location (proximity to environmental receptors), discharges from the facility (quality and quantity of discharges), receiving environment (river, sewer), protection status/special circumstances relating to the receptor (Special Protection Area [SPA], Special Area of Conservation [SAC], Area of Special Scientific Interest [ASSI] etc.), facility legacy and past experiences (old historical pollution).

Before granting a licence, the Agency will have to be satisfied that the Best Available Technology (BAT) will be used to prevent, limit or reduce emissions for the activity so that such emissions will comply with appropriate environmental standards and that the activity will not cause environmental pollution.

The licensee must be a ‘’fit and proper person’’ to carry out the activity concerned. The criteria applied by the Agency in making this determination includes the absence of convictions for relevant offences under the Act, the availability of appropriate technical knowledge or qualifications, and the ability to meet any financial commitments or liabilities arising out of compliance with the licence. The Agency may require the licensee to provide a bond or security to ensure the discharge of anticipated financial commitments or other liabilities that may arise (DOELG, 1998).

This bond may be drawn down in the event of licensee bankruptcy or failure to rehabilitate and restore the facility to the required post-closure standard.

Failure of a licensee to abide by the conditions of a waste licence or to report incidents, environmental or otherwise, to the relevant authority can lead to censure by way of the Agency issuing a non-compliance and or instruction to initiate mitigation measures. In the event of a serious breach, continuous breaching of emission limit values (ELVs) or failure to act on instruction, the Agency may initiate court proceedings which can result in a fine, imprisonment or both for the operator.

4.4 Leachate Treatment Options

4.4.1 Introduction

Leachate Treatment Options

The leachate treatment options available to the operator of Kinsale Road Landfill Site are set out in Figure 4.1 below.

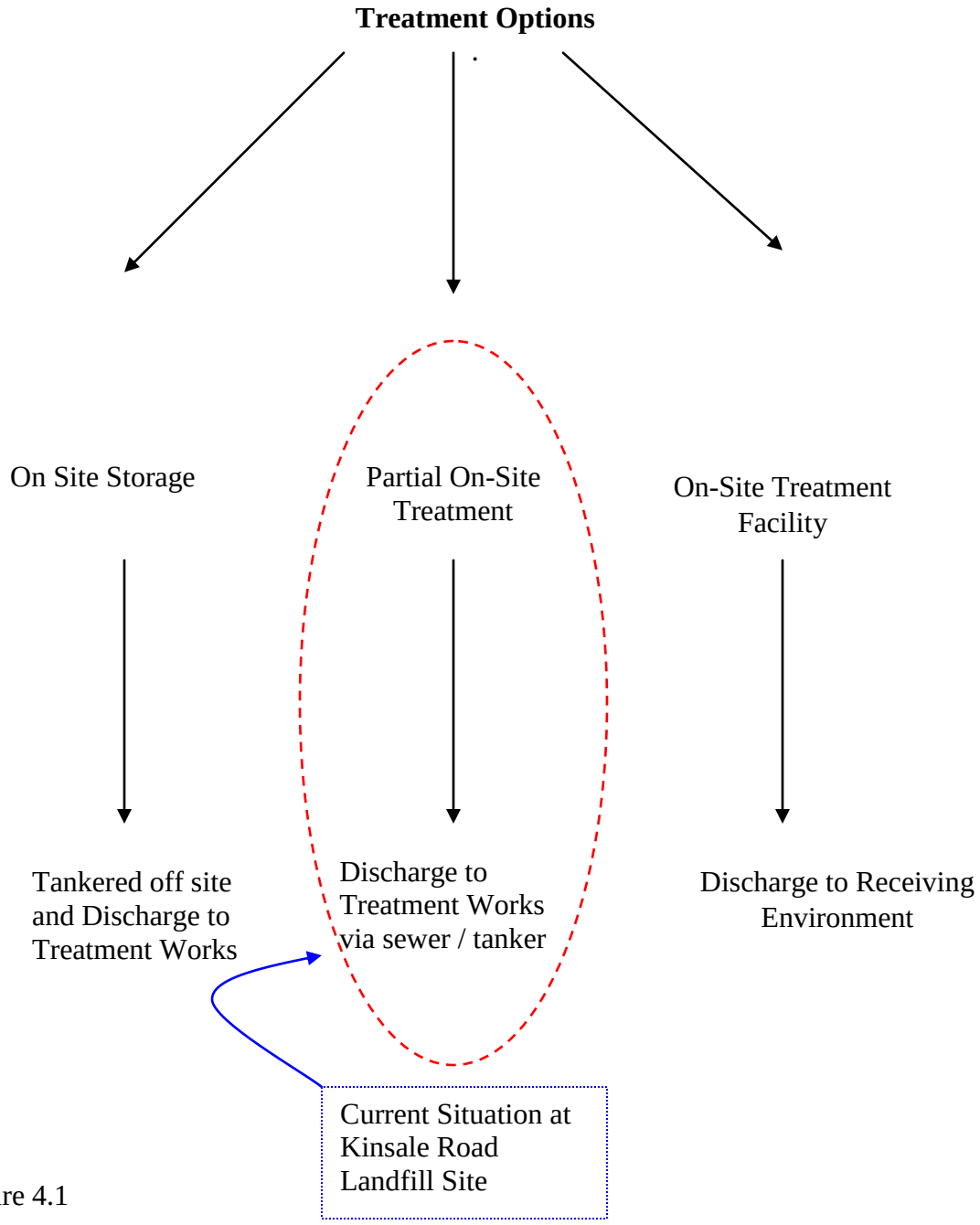


Figure 4.1

Leachate Treatment Options Available

A detailed description of the current leachate treatment technology deployed at the Kinsale Road Landfill Site is outlined in Chapter 3.

4.4.2 On-Site Storage and Tankering to Waste Water Treatment Works

This is one of the traditional methods for dealing with leachate from landfill sites. It entails exactly as the headline title states – the leachate is stored in a holding compound, usually a lined lagoon or a tank(s). The storage vessels may be covered or uncovered and the leachate may be aerated, passively or actively (by way of air blowers or stirrers) as a form of pre-treatment prior to tankering offsite for treatment and final disposal.

Transfer of the leachate offsite is usually achieved by tanker trucks, typically using trucks for drain and sewer cleaning and effluent disposal. The standard capacity of these trucks is 27m^3. The quantity of leachate produced at the facility and the onsite storage capacity will feed in to the cost of tankering, which over the life of a landfill site can have significant cost implications. The cost of leachate transfer at the state of the art landfill site at Bottlehill, Co. Cork is estimated at €50,000 per annum for the early phases of infilling (personal communication with landfill manager). At the time of writing (September 2013), the landfill site at Bottlehill was not open for receiving waste due to overcapacity in the landfill market.

An issue that may arise with the storage and tankering of landfill leachate is the potential for overloading the receiving sewage treatment works. This is more likely to occur at small-scale plants designed for a small town where the limiting factor may be the high ammonia content in the leachate. At larger facilities accommodating more densely populated urban areas (≥ 20,000 population equivalent (PE)), this is less likely to be an issue due to the factors of dilution available.

Other problems associated with tankering and leachate transfer is the potential presence of recalcitrant organics and heavy metals within the leachate stream. These are compounds for which the treatment processes employed at the wastewater treatment works may never have been designed. The operator of the treatment works may encounter problems with regulators in light of increasingly strict discharge limits placed on these facilities.

In spite of the above, it is likely that on site storage and tankering will continue to play a role in leachate control at landfill sites.

4.4.3 Partial on Site Treatment and Discharge to Sewer / Tankered Off Site

This involves air stripping of ammonia and/or methane from the wastewater prior to discharge to the public sewer or prior to tankering to the wastewater treatment works.

This is the situation at the Kinsale Road Landfill Site where dissolved methane is stripped from the leachate before discharge to the public sewer. This process is described in detail in the following sections.

4.5 Wastewater Treatment Technologies

4.5.1 Introduction

Since the implementation of the Waste Management Act 1996, and the associated Waste Management (Licensing) Regulations, 1997 (as amended), local authorities in the Ireland have had to seriously address the issue of historic, usually unlined landfills (as has happened at the KRLF). This had led to a demand and subsequent rapid development of leachate treatment technologies. The market for such treatment technologies has been characterised by the entry of companies who bring to it heavily marketed systems, which, while derived from other treatment industries, often have no track record of application to landfill leachate. In several instances, systems have been adopted that have not provided a complete solution.

Various wastewater treatment technologies have been applied to landfill leachates with varying degrees of success. These have included (Robinson *et al*., 1999):

1. Aerobic biological treatment
    a. Attached growth (trickling filters)
    b. Non attached growth
2. Anaerobic biological treatment
3. Spray irrigation to media (grassland, peatland or woodlands etc.)
4. Ammonia and Methane stripping
5. Reverse osmosis

6. Ozonation
7. Reed bed treatment – constructed wetland technology.

Of the above treatment technologies, options 1, 3 and 7 were deemed suitable for inclusion in this project. An explanation of each is detailed below.

4.5.2 Aerobic Biological Treatment

4.5.2.1 Attached Growth Biological Treatment Systems

In an attached growth, or fixed film, system of aerobic biological treatment, bacteria grow attached to the surface of an inert medium – generally plastic support material, or the rotating arm of a Rotating Biological Contactor (RBC) system. A number of alternative processes, each with specific benefits and disadvantages are available.

Bacteria which effect nitrification can become strongly fixed to a suitable medium, provided that high concentrations of degradable COD are not present. Stable nitrification can then be achieved under optimal conditions. However, a common problem with attached growth systems is that they are not completely mixed reactors and do not have the same capacity to rapidly dilute high incoming concentrations of ammoniacal-N in particular.

Since free ammonia is toxic to nitrifying bacteria, and is a function of pH value and concentration of total ammoniacal-N, if high concentrations of ammoniacal-N come into direct contact with the bacteria, then rates of nitrification will fall rapidly. This failure will move at pace through the full depth of the attached growth system and result in poor treatment efficiencies within the treatment unit.

Percolating Filters

A Percolating Filter or Trickle Filter is an aerobic, fixed film biological treatment system, which comprises a fixed bed medium, to which bacterial films are attached, and over which wastewater to be treated, percolates downwards under gravity.

Media may typically be between 2-4m deep, and can comprise a variety of materials, from blast furnace slags, or gravels, to specialised plastic units designed to have a high

ratio of surface area to volume. The medium itself plays no part in treatment, acting only as a surface to which the biological films that effect treatment are attached.

Wastewater is irrigated evenly onto the surface of the percolating filter to achieve maximum surface area contact. Treated effluent that emerges from the base of the bed can be passed through a clarifier, to remove excess biological solids that slough off from the media surfaces before final effluent is discharged.

Process Overview

Although a limited number of very weak leachates (ammoniacal-N < 50mg/l) have been treated with some success (often on a seasonal basis) using simple percolating filters, application of this technology to stronger leachates has failed on many occasions. Typical reasons for failure have included (Environment Agency, 2007):

- Scaling/clogging of filter material with organic and inorganic sludges
- Short hydraulic retention times leading to vulnerability to short-term shock loading of the system
- Inhibition of nitrification due to colder temperatures, either diurnally (at night) or seasonally (in winter)
- Inability to provide additional alkalinity required for sustainable nitrification evenly through the filter, leading to either local scale formation, or unstable pH-volumes in the filter causing process inhibition
- Direct bacterial inhibition of nitrifiers, as the top layers of the filter receive leachate feed containing concentrations of ammoniacal-N well in excess of those at which significant inhibition will take place (e.g. typically >80mg/l)
- Inability to supply adequate oxygen to the medium.

4.5.2.2 Non Attached Growth Biological Treatment Systems

In a non-attached growth biological treatment system the process is based on suspended-growth biomass. Typical suspended growth systems include aerated lagoons, activated sludge processes and sequencing batch reactors (SBR) (Renou *et al*., 2008).

Aerated Lagoons

Aerated lagoons are one of the most basic types of suspended growth systems. They involve an upper aerated zone where oxidation of the wastewater occurs. Effluent is discharged via a weir or overflow system and is usually diverted to a secondary treatment system. The lagoon can either be passively or actively aerated (using stirrers or mixers) and the system is considered to be a low cost, low technological treatment system. However they suffer from a number of limitations, mainly due to the length of the residence time required to achieve suitable treatment efficiencies (up to several weeks), requirement for a large footprint for the lagoon, sensitivity of the system to temperature (below 15°C microbial activity is limited) as well as issues related to lagoon de-sludging. Aerated lagoons are most suited as a pre-treatment process for the treatment of leachate.

Activated Sludge

Activated sludge processes are extensively applied for the treatment of domestic wastewater and for the co-treatment of leachate and sewage (Renou *et al*., 2008). The process depends on the use of a concentration of microorganisms present as a floc kept in suspension by mechanical agitation and vigorous aeration (via compressed air) leading to high oxygen transfer rates throughout the liquor (Tebbutt, 1992).

It is a two-stage system where the wastewater is fed into an aerated mixing tank that has been pre-seeded with microbial biomass. The mixed liquor is constantly tapped off to a clarifying tank via an overflow mechanism. Here the sludge and liquid portion are separated out. The biomass is first settled out and later returned to the aeration unit and the clarified effluent is decanted and discharged or returned for further treatment.

Disadvantages relating to the activated sludge process include the requirement for high energy inputs for aeration and mixing, requirement for high chemical input for feedstock

and pH balancing of the system (phosphoric acid and sodium hydroxide) and difficulties in maintaining microbial populations due to ammonia levels in high strength leachates.

Sequencing Batch Reactor

A sequencing batch reactor (SBR) is a cyclically operated suspended growth, activated sludge process. It operates in a similar fashion to the activated sludge process mentioned above with the exception that the entire process occurs within the same tank and runs on a time sequence for each phase of wastewater treatment instead of utilising two or more separate units (Environment Agency, 2007). It is generally a four phase process:

Phase 1 – Fill: leachate is fed to the system

Phase 2 – React: reactor aeration and contaminant breakdown occurs with pH stabilisation as required

Phase 3 – Settle: Aeration stopped and liquid is clarified

Phase 4 – Decant: Effluent is decanted and sent for discharge.

SBRs may be lagoon or tank based systems. They are highly automated and are usually controlled using a Supervisory Control And Data Acquisition (SCADA) system.

SBRs are very reliable, provide a good degree of wastewater treatment (particularly ammoniacal-N nitrification) and are widely used on landfill sites throughout the UK, a small number of plants are also based on landfill sites in Ireland (Arthurstown Landfill, Co. Dublin).

4.5.3 Anaerobic Biological Treatment

Anaerobic biological treatment is a process employed for stabilisation of wastewaters containing high levels of COD (≥ 10,000 mg/l). It is an 'in vessel' process that occurs in the absence of oxygen with organic matter degradation occurring at an optimum temperature of 30-35˚C (Environment Agency, 2007). The reactor vessels may have a fixed media on to which the anaerobic bacteria attach or may be a fluidised bed type, using sand or activated carbon to provide a surface for biofilm formation. A common type of anaerobic reactor is the 'Upflow Anaerobic Sludge Blanket' or UASB reactor. The liquid waste is forced up through the sludge blanket within the reactor where mixing and contact between the liquid and anaerobic bacteria occurs. Degradation of the organic

matter will result in the production of gases, mainly methane and sulphur dioxide, the former being captured for heat-power production to assist in heating the incoming liquid and the latter being captured for odour abatement.

Anaerobic biological treatment is typically employed as a pre-treatment process for effluents containing high levels of COD that in their primary state would be unsuitable for discharge to sewer or for aerobic biological treatment. Post treatment, when the wastewater has been biologically degraded and stabilised, the effluent may be either discharged to sewer or further treated aerobically.

4.5.4 Spray Irrigation to Media

4.5.4.1 Introduction

This involves dosing the treatment medium with effluent intermittently via a spray nozzle or similar. Dosing may be achieved via gravity feed, provided sufficient hydraulic head is available; however, the majority of spray irrigation dosing is accomplished by use of a suitably sized pump.

Spray irrigation as a treatment option for leachate typically utilises grass planes, willow/poplar trees and peat as the treatment medium.

4.5.4.2 Spray Irrigation to Grass Planes

Grass treatment planes are areas of vegetated sloping land, usually constructed using low permeability soils on to which leachate is applied from a storage lagoon or tank (Tyrrel *et al*., 2002).

They may be employed as a temporary measure during the startup phase of a landfill site and are often incorporated with recirculation of leachate and return to the storage lagoon.

Treatment occurs as the leachate flows over land and interacts with the upper soil horizons and the vegetation (usually grass). Leachate is intermittently dosed across the plane via irrigation pipes, perforated at set intervals to achieve maximum effluent dispersal across the system. Other simpler forms of irrigation may be via a weir or slotted pipe at the head of the slope. The effluent will flow down slope through the plane

to the collection apparatus at the toe where it is collected for recirculation or final disposal.

Treatment mechanisms are highly complex and involve a series of physio-chemical exchanges (cation exchange, adsorption and absorption) as well as microbial interactions.

The process will require considerable surface area; up to several hectares of treatment plane; to achieve the desired treatment efficiency. Past experience has shown that leachate treatment using irrigated planes, when sized appropriately and dosed to correct loading capacity, are most effective at oxidising ammonia and organic matter content (BOD_5 and COD) within the effluent (Justin *et al.*, 2009), (Zang *et al*., 2010). Nitrate uptake by the vegetation used for the production of biomass will mostly be limited to the growing season; however, N uptake may be enhanced through mowing of the plane coupled with collection of the excess biomass.

Drawbacks of the system include; dependence on weather conditions, precipitation and temperature, where low temperatures will result in reduced pollutant removal rates; development of preferential flow paths leading to system bypass (partial or otherwise); decrease in soil permeability due to the development of an iron pan and partial soil cementation associated with iron and calcite oxidation. Also, depending on the nature of the site and associated soil properties, the treatment plane may have to be lined at the base to prevent migration and escape of the leachate.

4.5.4.3 Spray Irrigation to Willlow/Poplar Tree Plantations

Willow (*Salix sp.*) and Poplar (*Populus sp.)* can be used for producing a biomass energy crop when harvested on a short rotation. Termed ‘short rotation coppice’ (SRC), the plants are relatively cheap to establish, grow quickly and can be harvested on a 3–5 year cycle. The fact that SRC is a non-food, non-fodder crop also makes it an ideal candidate for ecological engineering purposes (Aronsson *et al*., 2010).

The process has been used at several facilities for leachate treatment in Sweden and to a lesser extent in the UK and in the USA (Aronsson *et al*., 2010). More commonly utilised in the treatment of urban wastewater and food processing wastewater, an early land application system involving leachate dosing on to forested land was trialled on an

abandoned landfill site at State College Sanitary Landfill in Centre County, Pennsylvania, USA. Described in a paper by Cohen (1983), this seems to be one of the earliest in depth studies involving spray irrigation of leachate on to forested land. Although the overstory vegetation of mixed hardwoods (white and black oak, red maple, quaking aspen, bitternut hickory and blank willow) within the irrigated plots was not coppiced, the data analysis within the study period (April–September 1981) provided a solid baseline for future studies to work off.

Considering that an SRC system is a relatively simple system to establish, and given the favourable growing conditions, it is surprising that it has not been widely used in Ireland for leachate treatment, at least as a partial pre-treatment process for reducing organic content and oxidation of ammonia.

Potential problems associated with the use of SRC for ameliorating landfill leachate include; seasonality of treatment potential, plant die back (especially with willows) associated with salt intolerance, establishing the willow or poplar copse may have to be planned several years in advance of irrigation with leachate, tree saplings during early development may require protection from grazing animals and insects, and as with the vegetated plane, the SRC process will require considerable surface area to achieve the desired treatment efficiency.

4.5.4.4 Spray Irrigation to Peat Filters

Peat filter systems tend to be operated as stand alone, small to medium scale wastewater treatment units for households, schools, retail outlets and restaurants, often situated in isolated areas distant from conventional urban wastewater treatment plants. Designed as secondary treatment systems for treating effluent emanating from septic tanks, they have been shown to provide a reliable and high degree of contaminant breakdown for parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, ammoniacal-N as well as bacteriological parameters (total coliforms and *E. coli*).

Treatment is provided as effluent is distributed via perforated pipe laterals across the surface of the peat filter bed (either by gravity or by pumping) and percolates vertically downwards through the peat to the base of the system. The peat acts as a host medium

providing a carbon source for microorganisms, which accomplish treatment in an aerobic environment. Depending on the regulatory setting, the final effluent may be collected and discharged to the environment, local water course, soak away or groundwater, or may require further treatment via a polishing medium (McKee, 1998).

High contaminant removal rates for peat filter systems have been reported for BOD (up to 90% removal), suspended solids (up to 99%), ammoniacal-N (up to 99%) and faecal and total coliforms (up to 90%) (www.barnstablecountyhealth.org). Package peat filter systems have been marketed in the USA and Canada under the trade name Enviro-Pure^{TM} by American Concrete Industries, Maine and similar type systems have been marketed by Bord Na Mona in Ireland and in the UK using the Puraflo system.

In terms of treating landfill leachate using peat filter systems, there seems to be a limited amount of available literature on the subject when compared to the use of peat filters for ameliorating sewage wastewater. However, the author has come across a number of examples from Scotland, Canada and Ireland, and has visited one particular site where peat filter systems were in operation for treating landfill leachate.
At Gairloch Landfill Site, Ross-Shire in northern Scotland, aerobically treated leachate was sprayed over an area of prepared peat moorland prior to discharge to a high quality stream. Up to 30m^3 of leachate per day was treated using the *in situ* peat as a polishing medium. High treatment efficiencies for iron (90%), manganese (95%), COD (85%), BOD_5 (99%) and ammoniacal-N (99%) were achieved using the combined aerobic (SBR) and peat polishing system (Enviros-Aspinwall – Leachate Treatment, 1997 (http://website.lineone.net/~steve.last/profiles-Gairloch.htm) and Novella *et al*., 1998).

At Red Pine sanitary landfill site in New Brunswick, Canada, Roy Consultants Group developed a peat bed polishing system for biologically pre-treated leachate. Treating up to 15,000m^3 of leachate per annum, the system provided for up to 90% reduction in effluent COD and BOD at loading rates up to 40mm/m^2/day. Costs associated with installation and operation of the tertiary peat treatment beds were approximately

$140,000 for plant construction and set up with operation costs estimated at $80,000 per annum (costs refer to the year 2000) (www.enviroaccess.ca).

As mentioned previously in Section 4.2, the author visited Laois County Council's landfill site at Kyletalesha in April 2004, where a full-scale leachate treatment plant using peat filters was in operation. Following successful laboratory trials (circa 1989), Laois County Council were successful in their application for funding through the EU LIFE Programme to upscale the plant from the laboratory, to treat the entire amount of leachate produced at the site (approx 30,000m^3 per annum). Upon construction and after a period of trouble shooting and fine tuning leachate dosing applications, the up-scaled treatment plant achieved almost 100% removal of ammonia and BOD_5 (Heavey, 2003). In all, there was in excess of 1150m^2 of surface area available for treatment (4 galvanised tanks, 19.2m in diameter). Maximum treatment efficiency and plant performance was achieved using naturally air-dried harvested blocks of raised bog peat (300 x 300 x 300mm), placed in the tanks to a depth of 1.5m and intermittently dosed with leachate on an hourly basis using automatically controlled pumps (pers. comm. C. Tweeney, Laois County Council, April 2004). At the time of the site visit, the licensee (Laois County Council) were permitted to discharge the treated leachate direct to the nearby river Triogue once the relevant emission limit values for the various parameters set in the conditions of the waste licence were achieved.

Running in parallel to the above project, a similar set up was trialled at Dingle Landfill site, Dingle, Co. Kerry. The peat treatment bed constructed at Dingle Landfill site formed part of the closure and after care management plan. A single peat bed was constructed using soil bunds lined with high density polyethylene sheeting. The peat was sourced from a nearby blanket bog and placed in the confining receptacle to a depth of two metres. The peat bed was then intermittently dosed with leachate (EPA, 1998).
The author is unsure as to the degree of success of the peat filter system trialled at Dingle Landfill Site, but in personal communications with officials from the Environmental Protection Agency, the peat filter system did not perform as expected and the project did not progress beyond the pilot plant stage.

Advantages of Peat Filter Systems

Peat filters are low cost, low energy use systems that provide a high degree of wastewater treatment. The treatment units are very robust and adaptable and do not require highly skilled personnel for plant operation. Often the only mechanically operated component is a simple effluent pump.

Disadvantages of Peat Filter Systems

Disadvantages of peat filters include the fact that they are frequently considered an unproven technology in engineering terms and very often long-term operating data on system treatment efficiencies are unavailable. Replacement of the treatment medium material may become an issue due to lack of locally available peat and or the absence of specialised machinery to harvest and process the peat to the plant specifications. The surface area of the filter material will require regular inspection to avoid clogging (iron pan, surface cementation etc.). This can lead to infiltration rates falling below effluent dosing rates, resulting in surface ponding and poor treatment efficiencies (US EPA, 2000(a)).

Since commencing this project in 2004, it has been noted that very little new literature relating to peat filter systems for wastewater treatment has been published (at least within Europe). This is probably due to the fact that peatlands have acquired a high level of protection under the EU Habitats Directive (EEC No. 43 of 1993) and legislation protecting peatlands has been transposed into national law throughout the European Union. In Ireland this has been achieved under the EC, Natural Habitats Regulations; Statutory Instrument 94 of 1997. Peat harvesting has been severely curtailed (peat being a non-renewable resource) and many peatlands have been designated Special Protection Areas (SPA) and Special Areas of Conservation (SAC).

4.5.5 Air Stripping

4.5.5.1 Introduction

This is a common method for elimination of high concentrations of ammonia and can be used as a pre-treatment method for ammonia reduction from leachate prior to discharge to sewer or other treatment systems. The ammonia is removed as a gas (ammonia gas).

High pH levels are required to achieve maximum efficiency (pH 10 or 11) and the process necessitates the control of the released gases by use of hydrochloric acid (HCl) or sulphuric acid (H_2SO_4) in order to avoid health hazards associated with high concentrations of ammonia gas.

Drawbacks of the air stripping process include the requirement for maintenance of high pH levels to afford maximum treatment efficiency; scaling of the vessels with calcium carbonate and iron precipitate due to changes in pH; high costs associated with chemicals required as anti-foaming agents during the air stripping phase, and reagents required for pH adjustment. There will also be costs associated with safe disposal of chemical by-products produced during the acid dosing phase. Temperature adjustment of the influent may also be required as the process operates most efficiently (and economically) at temperatures of 60-70˚C (achieving up to 80% ammonia reduction).

4.5.5.2 Treatment System at Kinsale Road Landfill Site

The current leachate treatment plant in operation at Kinsale Road Landfill Site is a methane stripping plant. The process is described in detail in section 3.6. In brief, the removal of dissolved methane from the leachate is effected by the diffusion of air bubbles through the liquid as it passes horizontally along baffled chambers. The exhaust gases in the headspace of the plant are collected and passed through an odour control unit containing a calcium carbonate medium. The treated gas is then vented to the atmosphere. Treatment of the leachate is deemed to be successful if the dissolved methane as measured at the sewer discharge is $\leq$ 0.2mg/l, reduced from an original value of 5–10mg/l in the raw, untreated effluent.

4.5.5.3 Previous Proposed Solutions

Tenders for proposals for construction and operation of an ammonia stripping plant at Kinsale Road Landfill Site were sought in 2003–2004. This was to comply with a proposed ammonia sewer discharge limit of 20mg/l on receipt at Carrigrennan Wastewater Treatment Works at Little Island, Co. Cork. Four tender submissions were received and two companies were recommended to conduct onsite trials, namely EPS Water Treatment Systems and P & IDC Consultants Ltd.

EPS offered two solutions using caustic soda for ammonia reduction:

- Option 1 - Elevated pH levels and air stripping
- Option 2 - Activated Sludge incorporating an anoxic zone followed by a bio-tower.

The proposal put forward by P & IDC Consultants Ltd. entailed the following (FTC, 2003):

- Air stripping of ammonia, methane, VOCs and odours
- Thermal oxidation of the ammonia and organic compounds to NO_x, CO_2, H_2O etc.
- Conversion of NO_X to N_2
- Efficient removal of odour from the leachate
- Control of carbonate precipitation and disposal.

Whilst the trials were carried out and the best available technology approach was applied to each process, an ammonia stripping plant was not commissioned at the facility. Post commissioning of the wastewater treatment plant at Carrigrennan; the receiving plant for the leachate; the initial proposed sewer discharge limit of 20mg/l for ammonia was relaxed to a more manageable 600mg/l ammonia discharge measured at the sewer outfall.

4.5.6 Reverse Osmosis

Reverse osmosis (RO) operates on the reversal of the principle of osmosis in which a solvent (usually water) passes through a semi-permeable barrier from the side with a lower solute concentration to the side with the higher solute concentration. Water flow continues until chemical potential of the solute is established. At equilibrium, the pressure difference between the two sides of the membrane is equal to the osmotic pressure of the solution. To reverse the flow of water (the solvent), a pressure difference greater that the osmotic pressure difference is applied; as a result, separation of the water from the solution occurs as pure water flows from the high concentration side to the low concentration side (Williams, 2003).

The physical filtration process is a pressure driven membrane separation technique with the majority of the contaminants (solutes) remaining to form the concentrate. The properties and structure of the membrane are essential to the success of RO as a treatment process. The membranes must be resistant to chemical and microbial attack, mechanically and structurally stable over long periods of time and have the required separation characteristics suitable to the type of effluent the plant receives.

Reverse osmosis leachate treatment plants are widely operated throughout Europe, with plants in France, Holland, Germany and Spain (www.leachate.co.uk). RO plants usually employ a pre-treatment filtration stage (sand filters or other fine filters) to prevent clogging of the membrane. Most RO plants treating leachate are multi-stage systems and can treat the leachate to a high degree producing a quality effluent (permeate) that can usually be discharged to the local watercourse without further treatment.

Disadvantages of the RO process include; the high initial capital costs for set up as well as high running costs due to energy demand; costs associated with disposal of concentrate; the requirement for constant backwashing due to membrane fouling and due to the fact that it is a physical filtration technique; the biological contaminants (ammonia etc.) remain active within the concentrate after the process is complete, thus requiring a further stage of biological treatment.

4.5.7 Ozonation

Ozonation is a well established treatment technology for drinking water and swimming pools, where it is used as a disinfectant technique and as a degradation process for substances such as recalcitrant organics to remove colour, taste and odour.

The process involves the diffusion of ozone (O_3) through the liquid in a batch reactor column. Ozone, being a powerful oxidizing agent has the potential to breakdown certain contaminants within the wastewater not otherwise amenable to biological oxidation. Ozonation is rarely used as a stand-alone technology to treat leachate (www.leachate.co.uk) and there is only one example of a full-scale leachate treatment plant in the UK where ozonation has been applied (Buckden Landfill Site, Huntingdon, Cambridgeshire (Robinson *et al*., 2002).

Drawbacks of ozonation include the high capital costs, high demand of energy to create ozone and the requirement for biological pre-treatment to remove readily degradable organic compounds.

Ozonation as a treatment process is generally only appropriate as a polishing step following extensive biological pre-treatment of landfill leachates.

4.5.8 Reed Bed Treatment Systems

General Information

Constructed Wetlands and Reed Beds are designed as man-made systems which attempt to simulate treatment that has been observed to take place when polluted water passes through natural wetlands. These systems may be called “Reed Beds” or “Reed Bed Treatment Systems” (RBTS), but internationally they are usually referred to as Constructed Wetlands (CW).

Reed Bed Treatment Systems are able to treat wastewaters by degrading organic matter (BOD and COD) and oxidising ammoniacal-N, removing suspended solids, and to a lesser extent reducing concentrations of nitrate and phosphorus. Treatment mechanisms are complex and involve bacterial oxidation, filtration, nitrification and chemical precipitation.

Constructed Wetlands have become popular across Europe because they are seen to have the following advantages:

- Relatively low capital and operating costs
- Simplicity of operation (low requirement for operator supervision)
- Suitable treatment for low flows, previously untreated
- Seen as a natural and therefore "green" process
- They are attractive and provide wildlife habitat
- As a polishing stage, they can improve and enhance performance of initial treatment processes.

A full description of RBTS, types, treatment mechanisms and their uses is detailed in section 4.6 and the actual RBTS design for this project can be seen in Chapter 5.

4.5.9 Other Treatment Technologies

The above list of leachate treatment technologies should not be considered exhaustive and new and improved systems are being trialled continually. The field of membrane technology processes provides an area of exciting new opportunities, especially where a combination of membranes, namely nanofiltration, microfiltration and ultrafiltration, are used for removal of recalcitrant contaminants.

However, further discussion of these technologies lies outside the remit of this thesis.

4.6 Wetland Systems

4.6.1 Introduction

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the surface, or where the land is covered by shallow water.

The Ramsar Convention (1971) takes a broad approach in determining the wetlands which come under its aegis. Under the text of the Convention (Article 1.1), wetlands are defined as:

"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres".

In addition, the Convention (Article 2.1) provides that wetlands:

"may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands".

Wetlands often border open water systems and in many cases form a zone of continuous transition between dry land and open water.

4.6.2 Types of Wetland

In Ireland, the following types of wetlands can be found (Otte, 2003):

- Coastal and estuarine salt marshes, dune slacks and saline wet meadows
- Lagoons
- Fens and bogs
- Canal, river and lake edges and reed swamps
- Callows and flood plains and fresh water meadows
- Turloughs
- Wetland woods.

4.6.3 The Value of Wetlands

It is extremely difficult to ascribe a monetary value to natural systems such as wetlands. Estimates of their value may reflect the assessor's needs and background than any intrinsic quality of the land.

For instance, a wetland could be seen as an invaluable resource, if one is to take into account the often hidden "free-services" that they can provide to the larger community. Some of these "free services" include flood prevention, erosion and sedimentation control, purification of groundwater and surface water as well as the production of commercially and recreationally important species of fish and waterfowl. Wetlands thus provide a vital 'ecosystem service' especially in terms of cleaning and purifying anthropogenically generated wastewaters.

However, these functions, services and attributes can only be maintained if the ecological processes of wetlands are allowed to continue to operate. Unfortunately, and in spite of important progress made in recent decades, wetlands continue to be among the world's most threatened ecosystems, owing mainly to ongoing drainage, conversion, pollution, and over-exploitation of their resources (Cheng Hua, 2003).

4.6.4 The Wise Use of Wetlands

As mentioned above, wetlands can have a wide range of uses and benefits, among which are (http://ramsar.org):

- Sediment and erosion control

  Wetlands slow the passage of water and encourage the deposition of nutrients and sediments carried in water.

  Nutrient retention in wetlands makes them among the most productive recorded, rivalling even intensive agricultural systems (Ramsar 1).

- Flood control

  This is especially critical in areas that experience seasonal flooding. Inland floodplains and coastal deltas act as natural "overflow" areas that slow the velocity of the floodwaters, allowing the nutrients and sediments to settle (Ramsar 2).

- Maintenance of surface and underground water supply

  Wetlands can play a major role both in irrigation and in recharging aquifers that are used as domestic water supplies (Ramsar 3).

- Support for fisheries, grazing and agriculture

  Wetlands provide numerous benefits to people in the form of products that can be exploited for use. These range from foodstuffs (fruit, fish, shellfish, meat, and rice), resins, timber for building, fuel, reeds for thatching and weaving, fodder for animals, etc. (Ramsar 4).

- Outdoor recreation and education for human society

  Many wetlands are prime locations for tourism and some of the finest are protected as National Parks, World Heritage Sites, Ramsar sites, or Biosphere Reserves. Tourism associated with wetland sites may also generate considerable income locally and nationally.

  Recreational activities such as fishing, hunting and boating, etc. may be carried out at or on wetland sites.

  Wetlands may also have a significant cultural and heritage attachment (religious, historical, archaeological or other) and form an integral part or a community's/nation's identity (Ramsar 5).

- Provision of habitat for wildlife, especially waterfowl

  Wetlands in general are home to a great diversity of species. Although freshwater ecosystems cover only 1% of the Earth's surface, they hold more than 40% of the world's species and 12% of all animal species. On the marine front, coral reefs are among the most biologically diverse ecosystems on the planet, rivalling tropical rainforests (Ramsar 6).

- Contribution to climatic stability

  In terms of management of greenhouse gases (especially CO_2) and in physically buffering climate change impacts, wetlands act as significant carbon sinks and may account for as much as 40% of global terrestrial carbon (Ramsar 7).

- Maintenance of water quality and abatement of pollution

  Plants and soils in wetlands play a significant role in purifying water. High levels of nutrients such as phosphorous and nitrogen, commonly associated with agricultural

run-off, are effectively removed by wetlands. This is important in preventing eutrophication further downstream. It can also be important in preventing high concentrations of these nutrients reaching groundwater supplies or other water sources that may be used as a potable supply for drinking water (Ramsar 8).

Indeed wetlands have been so successful in treating anthropologically generated wastewater that a large proportion of this research project is dedicated to the subject.

4.7 Constructed Wetlands

4.7.1 Introduction:

Constructed wetlands (CW), in contrast to natural wetlands, are man-made systems or engineered wetlands that are designed, built and operated to emulate functions of natural wetlands for human desires and needs. They are created from a non-wetland ecosystem or a former terrestrial environment, mainly for the purpose of contaminant or pollutant removal from wastewater (Hammer, 1994).

4.7.2 Typical Effluents Treated by Constructed Wetlands

Constructed wetlands can accommodate a wide range of effluent type. These include municipal and domestic wastewater, urban storm water runoff, agricultural wastewater, industrial effluents and polluted surface waters in rivers and lakes.

In Ireland, their principal application has been in the treatment of sewage effluent at varying scales from single house systems to small to medium-scale municipal facilities. These systems have proven to be an economically attractive (low cost, ‘‘low tech’’) and energy efficient means of providing a high standard of wastewater treatment.

4.7.3 Types of Constructed Wetland Treatment Systems

Constructed wetland systems are classified into two general categories:

- Horizontal Flow Systems (HFS)
- Vertical Flow Systems (VFS).

4.7.3.1 Horizontal Flow Systems

Horizontal Flow Systems (HFS) have two general types: Surface Flow (SF) and Sub-Surface Flow (SSF) systems. They are called HFS because wastewater is fed at the inlet and flows horizontally through the bed to the outlet (see Figure 4.2). Vertical Flow Systems (VFS) are fed intermittently and the effluent drains vertically through the bed filter media and exits via a network of drainage pipes.

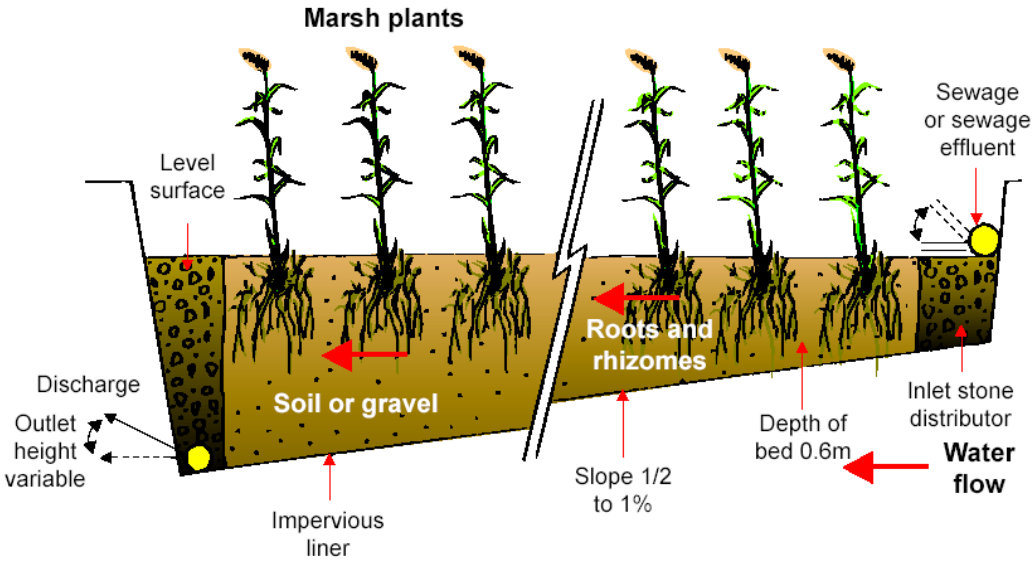


Figure 4.2 Typical Configuration of a Horizontal-Flow Wetland System (after Cheng Hua, 2003, modified from Cooper *et al.*, 1996)

Surface Flow (SF) Systems

Surface Flow systems consist of shallow basins in soil or any other medium that will support plant roots.

This type of system has been characterised as most closely mimicking natural marshes (Reed and Brown., 1992).

A SF wetland generally has a soil base, emergent vegetation, and a water surface exposed to the atmosphere. The water surface moves through the wetland above the substrate at low velocities in a quiescent manner. Areas of open water may or may not be incorporated into the design.

Plants in these SF systems are able to withstand continuously saturated soil conditions and corresponding anaerobic soils. SF wetlands have variable oxygen levels depending

on atmospheric diffusion, wind action, and the amount of algae or macrophytes available to introduce oxygen to the system. Dissolved oxygen levels are at their highest at the air/water interface and decrease with depth. Depending upon the depth of the water and its quiescence, dissolved oxygen levels may be quite low at the bottom of the water column and even anaerobic just a few millimetres below the water/sediment interface (www.itrcweb.org, 2003). A typical configuration for a surface flow wetland is outlined in Figure 4.3.

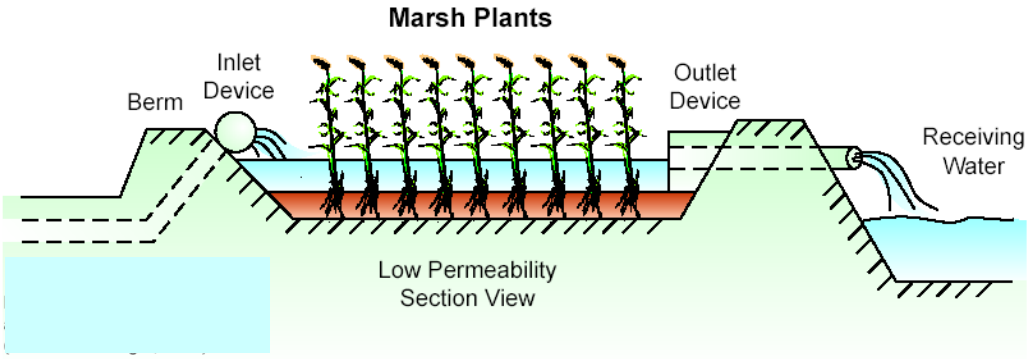


Figure 4.3 Typical Configuration of a Surface Flow Wetland (after Kadlec and Knight, 1996)

Sub-Surface Flow (SSF) Systems

These systems are essentially horizontal trickling filters when a rock medium is utilised. They have the added component of emergent plants with extensive root systems within the medium. Systems using sand and gravels or soil media are also used. Soil based systems designated as the Root-Zone-Method (RZM) were developed in Germany (US EPA, 1988).

The size for most gravel substrate beds will range from 5–10mm and 6–12mm. The base of the bed is sloped, usually 1%, to the outlet point.

The advantages of SSF systems include increased treatment efficiencies, fewer pest problems, reduced risk of exposing humans or wildlife to toxins and increased accessibility for upkeep (no standing water). The substrate provides more surface area for bacterial biofilm growth over an SF wetland, such that increased treatment effectiveness may require smaller land areas (IRTC, 2003).

A typical configuration for a sub-surface flow wetland is outlined in Figure 4.4.

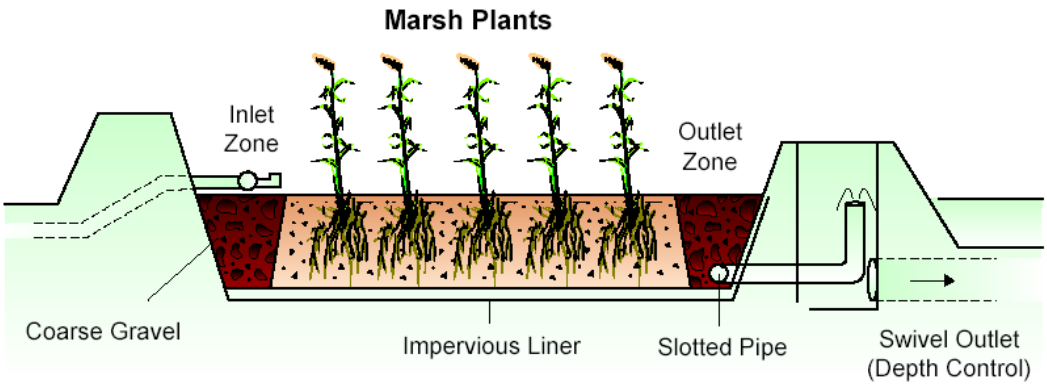


Figure 4.4 Typical Configuration of a Sub-Surface Flow Wetland (after Kadlec and Knight, 1996)

4.7.3.2 Vertical Flow (VF) Systems

Vertical Flow (VF) systems are free draining reed beds. The reeds are set in a graded sand–gravel substrate. The effluent is sprayed intermittently onto the sand surface matrix and then drains vertically to a pipe in the outlet zone.

Dosing of the VF system can be via gravity (via a dosing siphon) or mechanically using pumps. Dosing volume, frequency and duration will depend on the effluent quality and type applied to the system and the level of treatment required.

A typical arrangement of a VF System can be seen in Figure 4.5.

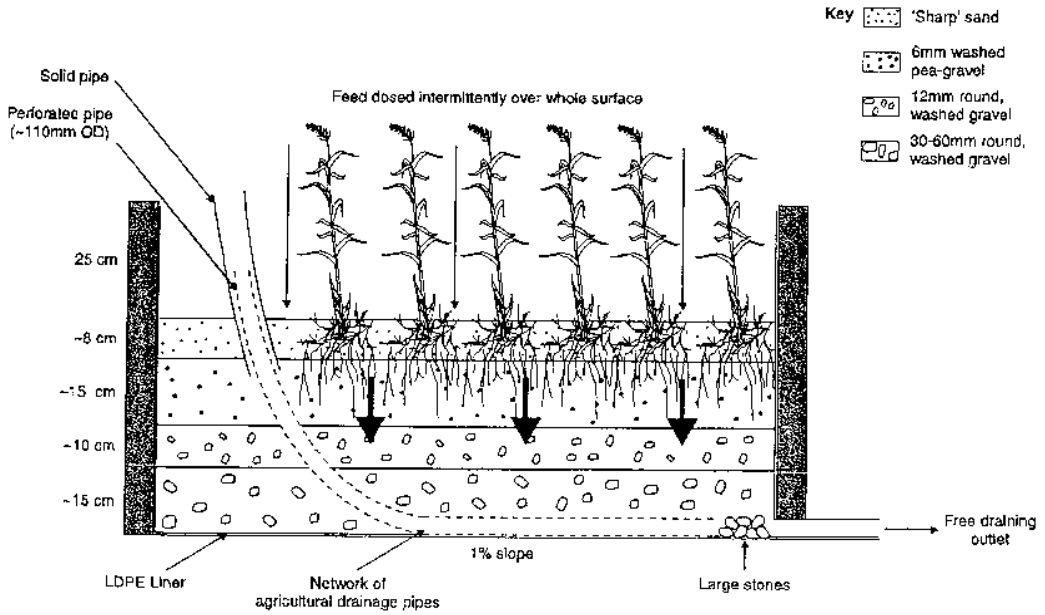


Figure 4.5 Typical Arrangement of a Vertical-Flow Reed Bed System (after @qua enviro Technology Transfer, 2004)

The effluent feed is dosed intermittently over the entire surface area of the bed through a series of spray nozzles or feeder channels. The 'sharp sand' layer at the surface acts as the diffusing mechanism and aids in achieving maximum surface contact area for the effluent.

The effluent will pass through the rhizosphere, where the majority of the treatment/purification will occur, and will finally drain freely through the graded gravels to the outlet pipe.

In general, VF beds tend to be small and more compact than SF and SSF systems and provide a more efficient treatment due to an increased rate of oxygen transfer.

4.8 The Role of Wetland Plants in Wastewater Treatment

4.8.1 Introduction

The plants (reeds in this case) provide a large surface area for microbial growth and the development of a biofilm. The rhizosphere and extensive root network provides stability for the media material and assists in effluent sediment filtration.

A range of wetland plants have shown their ability to assist in the breakdown of wastewater. The common reed *Phragmites australis,* bulrush (cattails), *Typha latifolia*, *Typha angustifolia* and *Iris pseudacorus* (yellow flag) are good examples of marsh species that can effectively uptake nutrients and as such are most commonly used in constructed wetlands. These plants have a large biomass both above (leaves and stalks) and below (underground stem and roots - rhizomes) the surface of the substrate (Cheng Hua, 2003).

The role of wetland plants in constructed wetland systems can be divided into a number of categories:

4.8.2 Physical

The presence of vegetation in wetlands helps to distribute and reduce influent velocities (Pettecrew and Kalff, 1992). The extensive root zone network assists in stabilising the substrate and creates conditions for sedimentation of suspended solids and the development of attached microbial growth. Plant litter and trapped suspended solids helps increase the contact time with the wastewater.

4.8.3 Soil Hydraulic Conductivity

In constructed wetlands, the hydraulic conductivity through the supporting matrix is increased via water flow through and along the root system. As roots and rhizomes dieback and decay, they leave behind tubular pores and channels (macropores), which in turn are thought to stabilise and increase hydraulic conductivity through the supporting media (Kikuth, 1977).

4.8.4 Organic Compound Release

Reed plants have been shown to release a wide variety of organic compounds through their root systems. This carbon release may act as a source of food for denitrifying microbes (Brix, 1997). Decomposing plant biomass also provides a readily available carbon source for the microbial populations.

4.8.5 Microbial Growth

Macrophytes have biomass above and below ground to provide a large surface area for growth of microbial biofilms. These biofilms are responsible for the majority of microbial processes in a constructed wetland system, including nitrogen reduction (Brix, 1997). Plant dieback and the creation of a humus layer provide additional surfaces for attached growth processes thus adding to the system's ability to treat the influent wastewater.

4.8.6 Creation of Aerobic Media

It is well documented that aquatic macrophytes release oxygen from their roots into the rhizosphere. This influences biogeochemical cycling of sediments through the effects on the redox status of the sediments (Barko *et al*., 1991). Oxygen release rates from the roots depend on the internal oxygen concentration, the oxygen demand of the surrounding medium and the permeability of the cell walls (Sorrell and Armstrong 1994).

The extensive root system of marsh plants and their role in oxygen transfer is depicted in Figure 4.6.

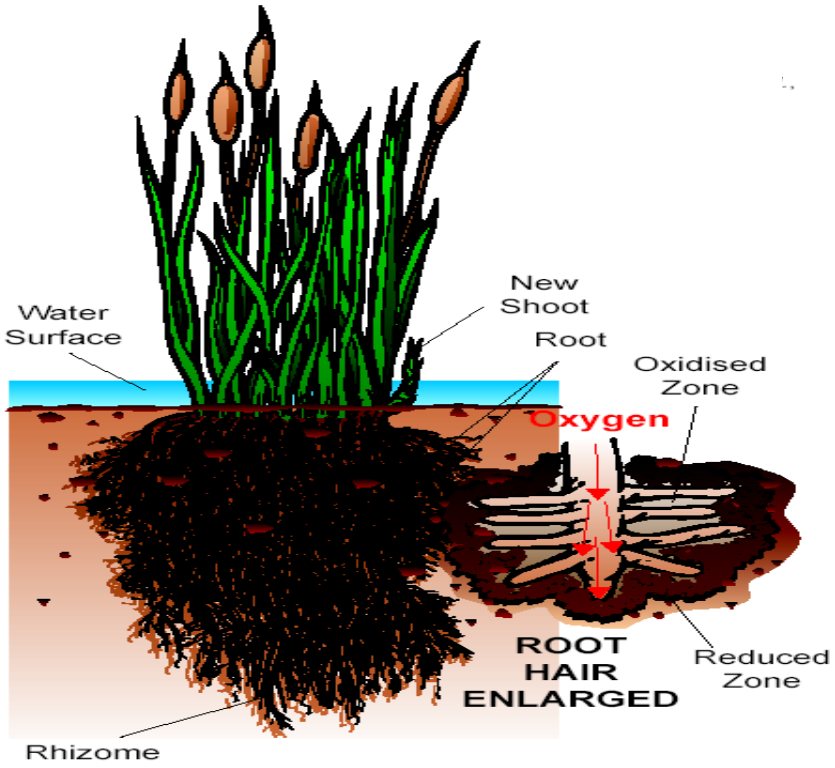


Figure 4.6 The Extensive Root System of Marsh Plants
(after Cheng Hua, 2003 - modified from Cooper *et al.*, 1996)

4.8.7 Selection of Wetland Plants

The system needs to be closely monitored to prevent attack from nuisance / invasive species and to ensure the system is not overloaded or as the case may be under loaded, thus not receiving an adequate supply of nutrients.

Either of the above scenarios can result in the partial loss of plant cover, which will impair treatment effectiveness. Ineffectual effluent treatment can occur through scouring, streaming and channelisation of the effluent along preferential flow paths, thus bypassing the purifying medium i.e. the rhizosphere.

4.9 Constructed Wetland Treatment Mechanisms

4.9.1 Introduction

Constructed wetlands have the ability to attenuate a range of potential pollutants including biological oxygen demand (BOD), organic compounds, total suspended solids (TSS), nitrogen and nitrogen compounds (NH_4) and pathogens, as well as entraining within the media and the rhizosphere, metals and other inorganic constituents contained within the wastewater.

4.9.2 Nitrogen Removal Mechanisms

Nitrogen in the form of nitric oxide, nitrite or ammonia/ammonium is soluble in water and can reach waterways from a variety of sources, including non-point sources (agricultural runoff), and point sources (wastewater treatment plant discharges) (Yalcuk and Ugurlu, 2009).

The removal of nitrogen from landfill leachate is particularly important as excessive levels of nitrogen will cause serious water quality problems.

Nitrogen removal in a constructed wetland system is achieved via the following mechanisms (Yang *et al*., 2001):

- Uptake by plants and other living organisms
- Nitrification
- Denitrification
- Matrix adsorption
- Ammonia volatilization
- Cation exchange of ammonium.

Plant rhizosphere aeration may also stimulate aerobic decomposition processes, increasing nitrification and subsequent gaseous losses of N via denitrification and decreasing relative levels of dissimilatory nitrate reduction to ammonium (Tanner *et al*., 1995).

The process of denitrification can be limited by temperature, pH, redox potential, carbon availability and nitrate availability (Johnston, 1991).

The range of nitrogen transformations in a constructed wetland treatment system is depicted in Figure 4.7.

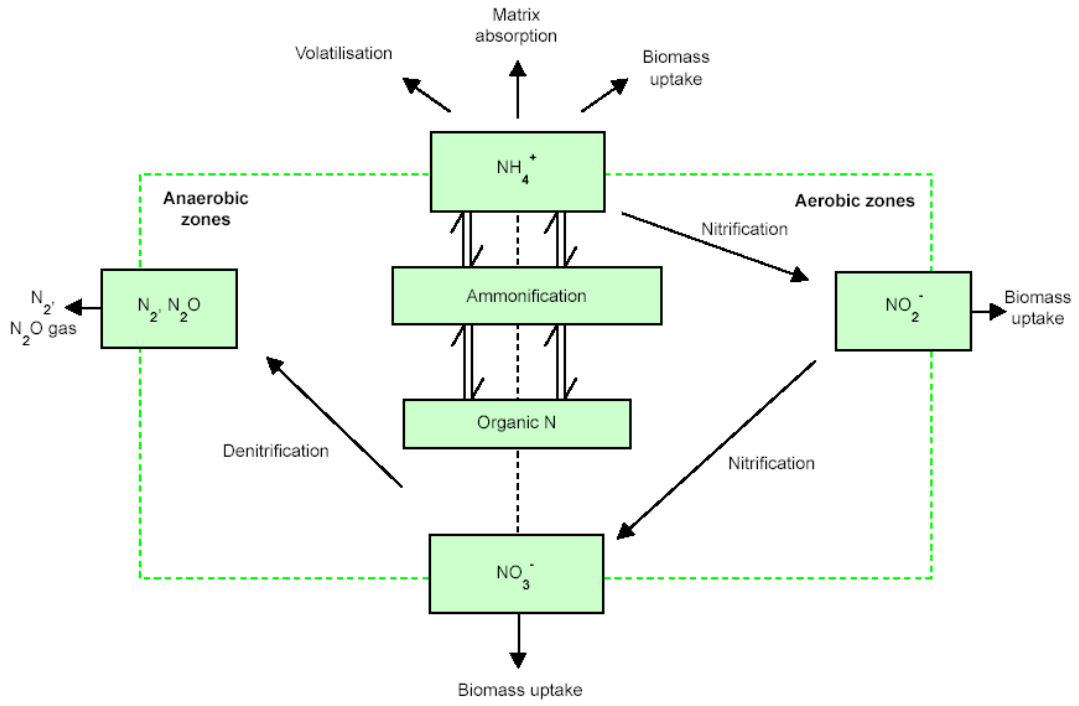


Figure 4.7 Nitrogen Transformations in a Constructed Wetland Treatment System (after Cooper *et al*., 1996)

4.9.3 Phosphorous Removal Mechanisms

Phosphate removal is governed by physical (sedimentation and precipitation) and chemical (adsorption and complexation) process and biological transformations. Phosphorus can also be removed directly by plant uptake or chemical storage in the sediments (Bonomo *et al*., 1997). Sakadevan and Bavor (1998) suggest that the principal long-term P removal mechanism in constructed wetland systems is via substratum, litter and Al/Fe component reactions, with the role of plant uptake of lesser importance.

4.9.4 Metals

The metal removal processes in constructed wetlands is very complex. These processes include a combination of biotic and abiotic reactions such as sedimentation, flocculation, adsorption, precipitation, co-precipitation, cation and anion exchange, complexation, oxidation and reduction, microbial activity and plant up-take (Kosopolov *et al*., 2004;

Ujang *et al*., 2005). The metals are not destroyed but their chemical and physical characteristics are simply modified (Ujang *et al*., 2005).

4.9.5 Pathogens

The removal of pathogens is achieved by sedimentation, filtration and absorption as well as by natural die-off and predation.

4.9.6 Other Pollutant Removal Mechanisms

Other physio-chemical processes that are responsible for contaminant removal are (ITRC, 2003):

- sorption
- chemical oxidation/reduction-precipitation
- photo-degradation/oxidation
- volatilization
- evapotranspiration

Sorption includes the combined processes of adsorption and absorption. Chemical precipitation involves the conversion of metals in the influent stream to an insoluble solid form that settles out. These reactions represent an effective means for immobilizing toxic metals in the wetland.

Photo-degradation involves the degradation/oxidation of compounds in the presence of sunlight. Volatilization occurs when compounds with significant vapour pressures partition to the gaseous state.

4.10 Establishment of a Constructed Wetland Treatment System

4.10.1 Introduction

The establishment of a constructed wetland system involves the building of bunds and lining of same (usually with a geotextile (LLDPE)) for the creation of an impermeable pond layer into which the substrate and associated drainage pipe network are placed. Once complete, the media material is ready for the planting stage. This may involve the planting of mature vegetation or seedlings.

4.10.2 Design and Principles of Constructed Wetland Systems

The principal design criteria for a constructed wetland system include choosing the substrate types, plant species, pollutant loading rate and retention time.

4.10.3 Choice of Wetland Plant Species

The wetland species chosen for a specific project should ideally be native to the area. They should be perennials with a lifecycle of more than one or two growing seasons to ensure the continuity of operation and treatment. The plants should be readily available and harvested locally as transportation over distance can lead to plant damage. The species chosen for this project were *Phragmites* and *Typha sp.* as well as *Sparganium erectum* all of which were available on site.

4.10.4 Substrates

Substrates may remove wastewater constituents by ion exchange/non-specific adsorption, specific adsorption/precipitation and complexation.

The choice of substrate is determined in terms of their hydraulic permeability and their capacity to absorb nutrients and pollutants. The substrate must provide a suitable medium for successful plant growth and allow even infiltration and movement of wastewater. Poor hydraulic conductivity will result in surface flow and channelling of wastewater, severely reducing the effectiveness of the system.

The chemical composition of the substrate will also affect the efficiency of the system. Soils with low nutrient content will encourage direct plant uptake of nutrients from the

wastewater. Substrates with high Al or Fe content will be most effective at lowering phosphate concentrations.

Gravel Substrates

Gravels will need to be washed to reduce clogging (increase void spaces) and enhance filtration. Fluvio-glacial sandstone gravels are the ideal media for such reed beds, being naturally rounded and washed.

Reed bed media gravel sizes tend to range between (O' Hogain, 2004):

- ∅ 3 – 6 mm,
- ∅ 5 – 10 mm, and
- ∅ 6 – 12 mm.

Historical analysis of gravel based reed bed systems show that they tend to achieve better nitrification rates, whilst denitrification tends to be higher in soil-based reed systems (Markantonatos *et al*., 1996).

A mixture of organic clay soils, sand, gravels and crushed stones could be used to provide support for plant growth. These substrates are ideal reactive surfaces for ion complexation and microbial attachment. They also provide a sufficiently high hydraulic conductivity to avoid short-circuiting within the system (i.e. along preferential flow paths or as surface sheet flow).

4.10.5 Area of Reed Bed

The required area for the constructed wetland will depend on the type of bed used (Sub-surface/Surface Flow as against Vertical Flow), the pollutant of significance, system loading, discharge consents as well as emission limit values.

In a European Union Funded project carried out at the Institute of Wastewater Management, Hamburg University of Technology; Wendland and Chiarawatchai *(cgi.tuharburg.de/~awwweb/wbt/emwater/documents/lesson_b4.pdf)* compiled data from a range of sources on the sizing of constructed wetlands for treating municipal wastewater (Tables 4.1 and 4.2).

Table 4.1 Design Criteria for Sub-Surface Flow Reed Beds Treating Municipal Wastewater

Criteria	Germany, DWA 2004	US EPA 2000	EC Guidelines CEMAGREF	United Kingdom, Cooper 1996
Surface area	5 m^2/pe minimum size 20 m^2		5 m^2/pe for BOD > 300 mg/l, otherwise 10 m^2/pe	5 m^2/pe** 0.5-1 m^2/pe***
Hydraulic surface load	40 mm/d			< 50 mm/d** < 200 mm/d***
Max organic load	*BOD: 8 g/(m^2*d)**	BOD: 6 g/(m^2*d)		
Depth	0.5 m			0.6 m

* calculated with 40 g BOD/(PE*d)

** for secondary treatment

*** for tertiary treatment

(after Wendland and Chiarawatchai)
(*cgi.tuharburg.de/~awwweb/wbt/emwater/documents/lesson_b4.pdf*)

Table 4.2 Design Criteria for Vertical Flow Reed Beds Treating Municipal Wastewater

Criteria	Germany, ATV 2004,	Lange & Otterpohl 1998	EC Guidelines CEMAGREF	United Kingdom, Cooper 1996
Surface area	4 m^2/pe minimum size 16 m^2	1-2 m^2/pe for greywater	5 m^2/pe for BOD > 300 mg/l, otherwise 10 m^2/pe	5 m^2/pe** 0.5-1 m^2/pe***
Hydraulic surface load	80 mm/d			< 50 mm/d** < 200 mm/d***
Max organic load	COD: 20 g/(m^2*d)			
Depth	0.5 m			0.6 m

** for secondary treatment

*** for tertiary treatment

(after Wendland and Chiarawatchai)
(*cgi.tuharburg.de/~awwweb/wbt/emwater/documents/lesson_b4.pdf*)

These data can be used for the design of SSF, and VF reed beds for use in urban wastewater (sewage) treatment. However, it may not be applicable for other forms of

effluent, e.g. industrial wastes, mining wastes, landfill leachate etc. due to their varying nature.

In landfill leachate, for example, effluent concentrations of BOD_5 may not be the limiting factor. Dissolved ammonium concentrations are more likely to stress the system and an adequate supply of BOD for effective treatment may be lacking.

This can be demonstrated by comparing the concentrations typical of sewage effluent and leachate from the Kinsale Road Landfill Site where the ammonium nitrogen concentrations of the effluents vary by a factor of 12 (see Tables 4.3 and 4.4).

Table 4.3 Typical Sewage Effluent Values

Typical Sewage Effluent Values (UK Population Equivalent - pe):			
			Concentration (mg/l)
BOD_5	60g/person/day (UK)	→	300 mg/l
	65g/person/day (EU)	→	325 mg/l
TSS	75g/person/day	→	375 mg/l
Flow	200 litres/person/day		
COD	155g/person/day	→	775 mg/l
Total N	12g/person/day	→	60 mg/l
	(of which 7g/pe/day of AN)	→	35 mg/l
Total P	2g/person/day	→	10 mg/l

(after O' Hogain, 2004)

Table 4.4 Typical Leachate Values at Kinsale Road Landfill Site

Typical Leachate Values (Kinsale Road Landfill Site)		
		Concentration (mg/l)
BOD_5	→	37 mg/l
TSS	→	86 mg/l
COD	→	439 mg/l
TON	→	9 mg/l
Ammonium	→	447 mg/l
Total P	→	0.36 mg/l

(Annual Environmental Report, Kinsale Road Landfill Site, 2004)

In light of these differences in ammonium concentrations, the author has compiled two tables (Tables 4.5 and 4.6) from referenced literature for the design of vertical flow and horizontal flow constructed wetlands for the treatment of landfill leachate based on hydraulic loading rate (HLR) and ammonium loading data.

Table 4.5 Loading Design for Horizontal Flow Constructed Wetlands Treating Landfill Leachate

Criteria	Nivala *et al.*, 2007	Lin *et al.*, 2003	Lin *et al.*, 2003	Lin *et al.*, 2003	Eckhardt *et al.*, 1999	Eckhardt *et al.*, 1999	DeBusk, 1999	Robinson *et al.*, 1999
CW Type	SSF	SSF	SSF	SSF	SF	SSF	SF	SF
Medium	Compost	Cinder / Sawdust	Cinder / Sawdust	Coal Refuse	Subsoil	Gravel	Subsoil	Gravel
HLR ($l/m^2/day$	4	64	32	64	17.1	5.7	410	100
NH_4 Load ($g/m^2/day$)	0.85	24.5	22.7	24.5	3.93	0.76	1.85	1.96

Table 4.6 Loading Design for Vertical Flow Constructed Wetlands Treating Landfill Leachate

Criteria	Justin *et al.*, 2009	Yalcuk *et al.*, 2009	Lavrova *et al.*, 2010
CW Type	VF	VF	VF
Medium	Subsoil	Sand and Gravel	Gravel
HLR ($l/m^2/day$	8.2 – 192	20	1218 – 4992
NH_4 Load ($g/m^2/day$)	2.7 - 63	2.44	241 – 988

An examination of the data contained within Tables 4.5 and 4.6 reveals a significant variation in the range of hydraulic loading and ammonium loading rates. This is discussed in further detail in Chapter 9.

4.10.6 Nature, Loading and Distribution of Effluent

The long-term efficiency of a reed bed treatment system is improved if the effluent receives some form of pre-treatment prior to discharge to the active bed. This may involve the use of settling ponds or filter beds where suspended sediments will settle out and BOD will be reduced.

In order to achieve maximum treatment efficiency of the system, it is essential that the loading rate and contact time is appropriate for the degree and nature of the treatment required.

4.11 Monitoring and Maintenance of Constructed Wetlands

Monitoring of the treatment units in terms of plant health, nutrient status and the removal of invasive species is vital to ensure continued functioning of the system.

4.11.1 Water Quality Monitoring

Regular monitoring and testing of water quality parameters is essential for successful operation.

Suggested monitoring parameters include:

Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Ammonia/Ammonium, Total Oxidised Nitrogen (TON), Conductivity, Dissolved Oxygen, pH, Metals (Mercury, Lead, Zinc, Iron, Cyanide, Arsenic), Phenols and Faecal Coliforms/*E. coli* (especially when dealing with sewage effluent).

4.11.2 Maintenance Requirements

Constructed wetlands tend to be low maintenance systems; however, a certain amount of maintenance and examination is needed to avoid problems within the system. This will entail (Harty, 2004):

- Keeping the wetland moist during dry conditions, especially in the first growing season, and possibly beyond, to help ensure plant health
- Routine maintenance, such as visual checking of inlet and outlet pipes for blockages, along with periodic inspection of plants and water levels within the wetland.

Sustaining a stand of desirable vegetation at the appropriate density within the wetland is crucial to ensure treatment efficiency.

Undesirable plant species or weeds may need to be manually removed and some patches of the reed bed may require replanting due to competition, pest attack and plant die back.

The constructed wetland system may be relatively simple to construct; however, its operation may require close inspection due to the often varying nature of the influent (especially landfill leachate) in terms of its constituents and concentrations.

CHAPTER 5

5. TRIAL PROJECT SITE SELECTION AND CONSTRUCTION

This chapter outlines the steps undertaken during the project construction and start-up phase.

5.1 Trial Project Site Selection and Compatibility with Existing Facilities

The area selected within Kinsale Road Landfill Site for construction of the trial project was chosen because of its compatibility with the existing facilities and the availability of suitable land.

The project was located beside the leachate storage lagoon, where a supply of leachate was readily available.

The topography is gently sloping with a number of plateaus and stepped areas available for positioning the treatment units, with the gentle slope providing for gravity flow of effluent to the stone filter trap (prior to discharge to the sewer with the rest of the leachate generated on site).

This section of the site was top capped with an engineered LLDPE liner and topsoil, and was the most stable section of the landfill site. Further development in this area would not take place until final closure and landscaping of the entire facility.

5.2 Cost Considerations

5.2.1 Construction Cost Estimates

A small building construction firm was engaged to carry out all civil engineering works. Pumps, valves and pipework were supplied and installed by a local mechanical and electrical contractor. A fixed price was agreed with all contractors prior to commencement of works and costings for additional items of works required were agreed up front.

5.2.2 Operation and Maintenance Costs

The principal elements of the operation and maintenance costs were labour, energy and material requirements.

5.2.3 Labour

Although the operation of the system would involve a part-time requirement for one person for approximately a half to one full day per week, other ongoing labour requirements would include; system regulation (pump timer changes etc.) of up to 1–2 hours a week, as well as monitoring of the header tank to ensure that it contained sufficient leachate to feed the system. The filling frequency of the header tank depended on the dosing rate and frequency as well as the number of units in operation at any one time.

5.2.4 Energy Costs

The only energy costs associated with the project was the electricity supply to the 12 pumps dosing each unit (pump model *Vigila 100M*) as well as the slightly larger pump feeding the header tank (pump model *Lowera DLV(m)100*). According to the pump specifications, each of the 110v (50 Hz) pumps operated energy saving systems and would account for a very small percentage of the total energy usage on site. This cost was absorbed in to the overall energy costs for the landfill site.

5.2.5 Equipment and Materials Costs and Availability

The availability of equipment and materials was an essential part of the cost consideration and budget estimates. It was suggested to the author in a personal communication with the then landfill manager that overall costings could be cut drastically if materials could be sourced locally, were readily available to buy, i.e. off the shelf and if the number of specialised components could be kept to a minimum.

Therefore, the components were sourced locally and maximum use was made of existing materials available on site or in other City Council depots.

5.2.6 Materials Required

5.2.6.1 Header Tank

A header tank was required to act as a storage tank for leachate for the project. An old 36m^3 tank was sourced free of charge from the Cork City Water Treatment Works (Figure 5.1). It required some retrofitting by way of plugging a hole at the top and resizing the outlet pipe mechanism, thus creating an effective holding tank.



Figure 5.1 Header tank (36m^3 capacity) sourced from Cork City Water Treatment Works

5.2.6.2 Pipework and Valves

The pipework and valves used were readily available from local builders' providers stores (Figure 5.2). Four different types of pipe were used, namely: ∅ 20mm, ∅ 25mm and ∅ 50mm flexible MDPE pipe and ∅ 110mm non-flexible U-PVC pipe (standard sewer pipe).

The valves used were hand operated plastic ball valves (*Philmac brand, Poly Ball Valve, Nylon, PE and PTFE material (*www.philmac.com.au)). They were simple to operate,

compact and could be used for throttling as well as effluent shut off. The nylon ball insert did not tend to clog or seize up.



Figure 5.2 Flexible MDPE pipe and ball valves used throughout the project

5.2.6.3 Process Units

Two different types of units/receptacles were planned for use. Originally, 12 cylindrical steel galvanised cells measuring 2.8m x 2m high were sought. However, due to cost considerations, the number of cell units was decreased to 10 and a different type of material was considered. After a number of discussions with colleagues, it was decided to use concrete rings for the process units. Each composed of two ∅ 1.8m x 1m concrete rings, sealed with bitumen and placed on a concrete base. 100mm of wet cement was poured in to the cell to create an impermeable internal seal between the base and the ring. The concrete rings are normally used for access to water and sewer chambers, however, on this occasion they were used as storage tanks/cells. The concrete cells mentioned above were much cheaper to purchase and assemble than the original galvanised tanks, which would have required prefabrication and fitting on site.

The design drawings for the process units comprising Ø 1.8m concrete cells are detailed below in Figures 5.3 and 5.4.

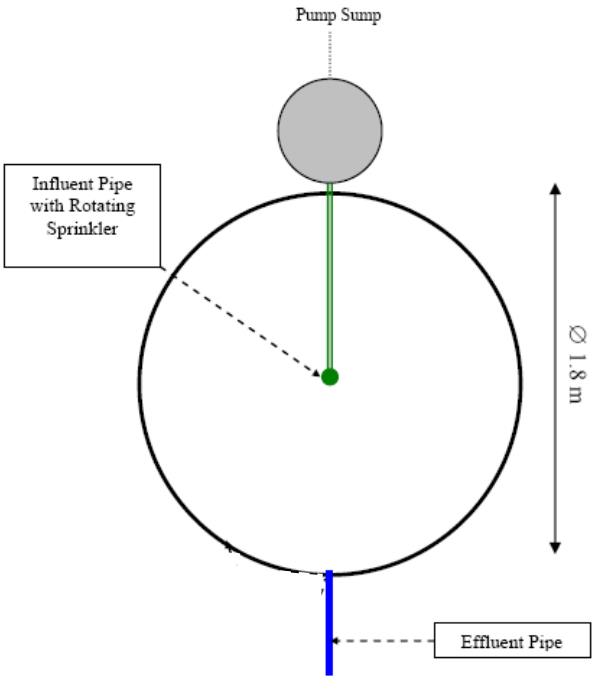


Figure 5.3 Plan View of Cell with Sprinkler System

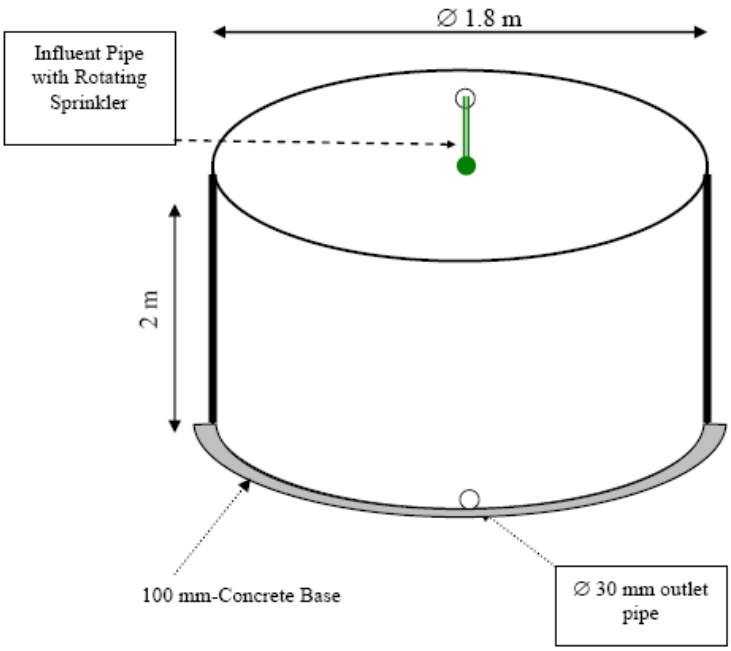


Figure 5.4 3-D View of Cell with Sprinkler System

5.2.7 Reed Beds

Soil bunds were used as the containment unit for the reed beds. A large stockpile of subsoil was available on site. The soil was of good quality and had been used previously to build the SWALE, a surface water trench that rings the landfill site.

The soil bund reed bed units were lined with pond liner (HDPE), available at any landscaping and garden centre. Investigations were made in to purchasing heavy duty LLDPE liner as used in the engineering capping restoration works on site. However, the costs of the material and associated labour expenses, which included welding around buttresses and sealing of outlet pipes etc., proved to be prohibitive. One of the main problems in dealing with this type of specialised material was that at the time of construction there were only two contracting companies in the country that could provide and fit the liner. The quotes received from both companies were deemed to be excessive with respect to the budget available for the research project.

The design drawings for the vertical flow reed beds are detailed below in Figures 5.5–5.8. The design for the horizontal flow reed beds are outlined in Figures 5.9–5.12.

Vertical Flow Reed Beds

Internal Dimensions: 5 m x 5 m
External Dimensions: 7.5 x 7.5 m

Allow for 1% slope - Influent point to Effluent point

Soil Bund walls lined with non-textured HDPE

HDPE liner drape on sand blinding layer for base

2 such reeds beds required.

Sump & Pump / Dosing Pump required at influent point.

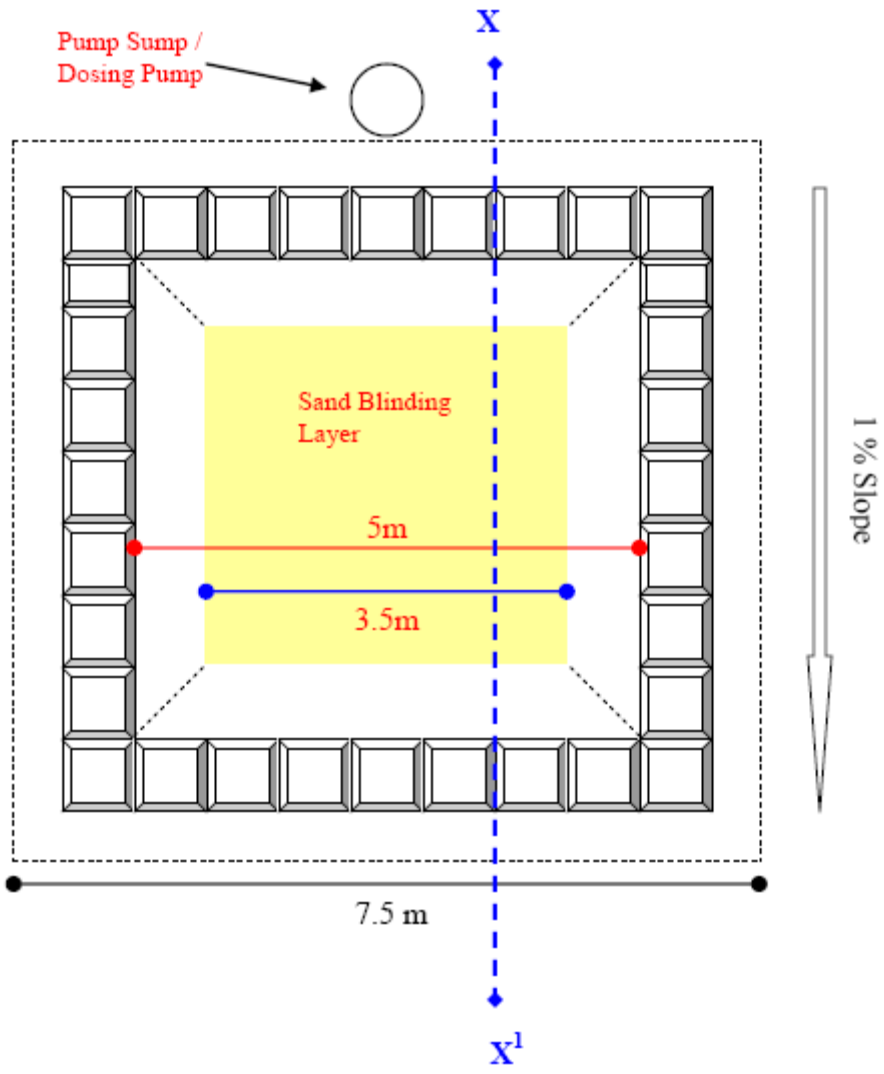


Figure 5.5 Plan View of Vertical Flow (VF) Reed Bed Prior to Infilling with Gravel

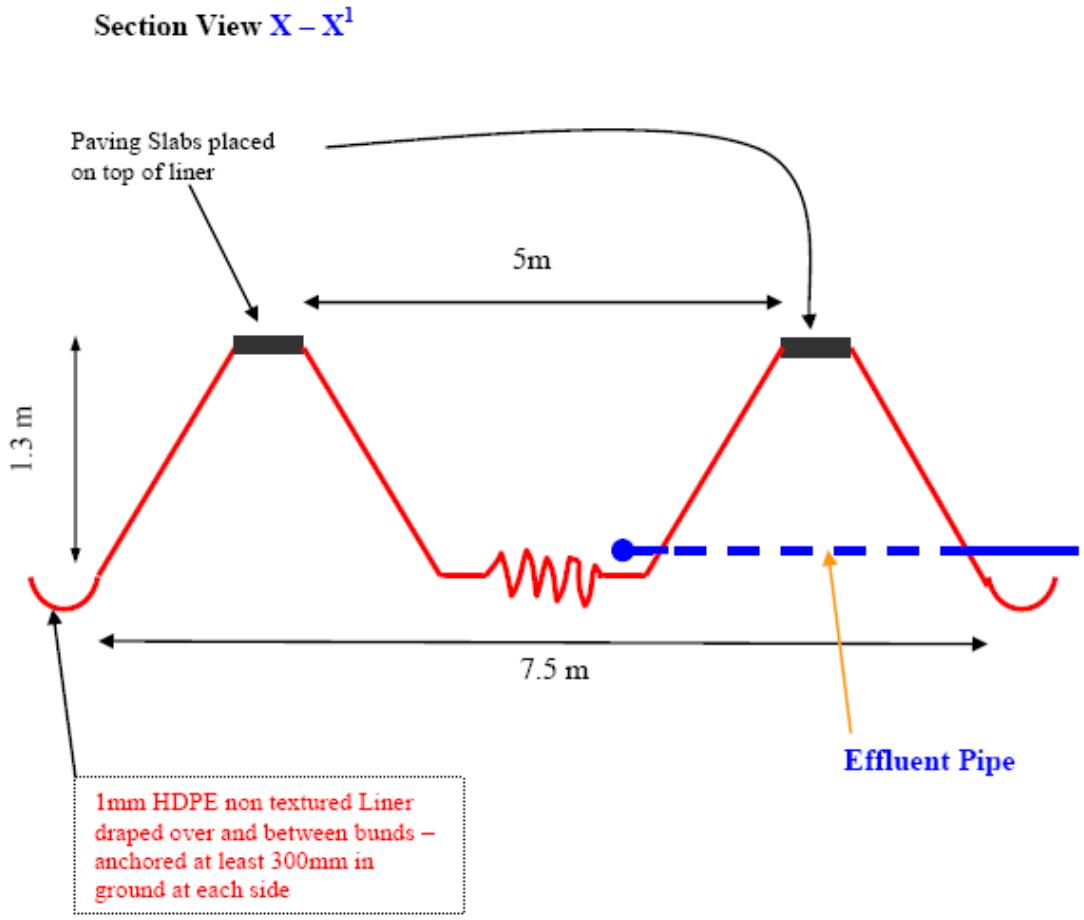
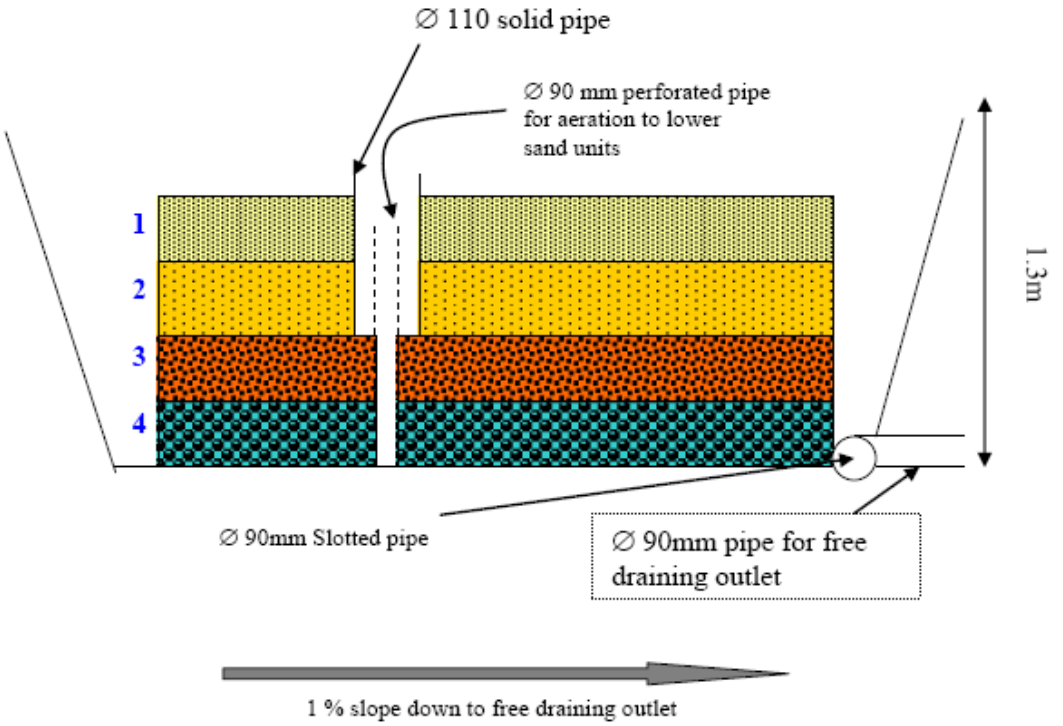
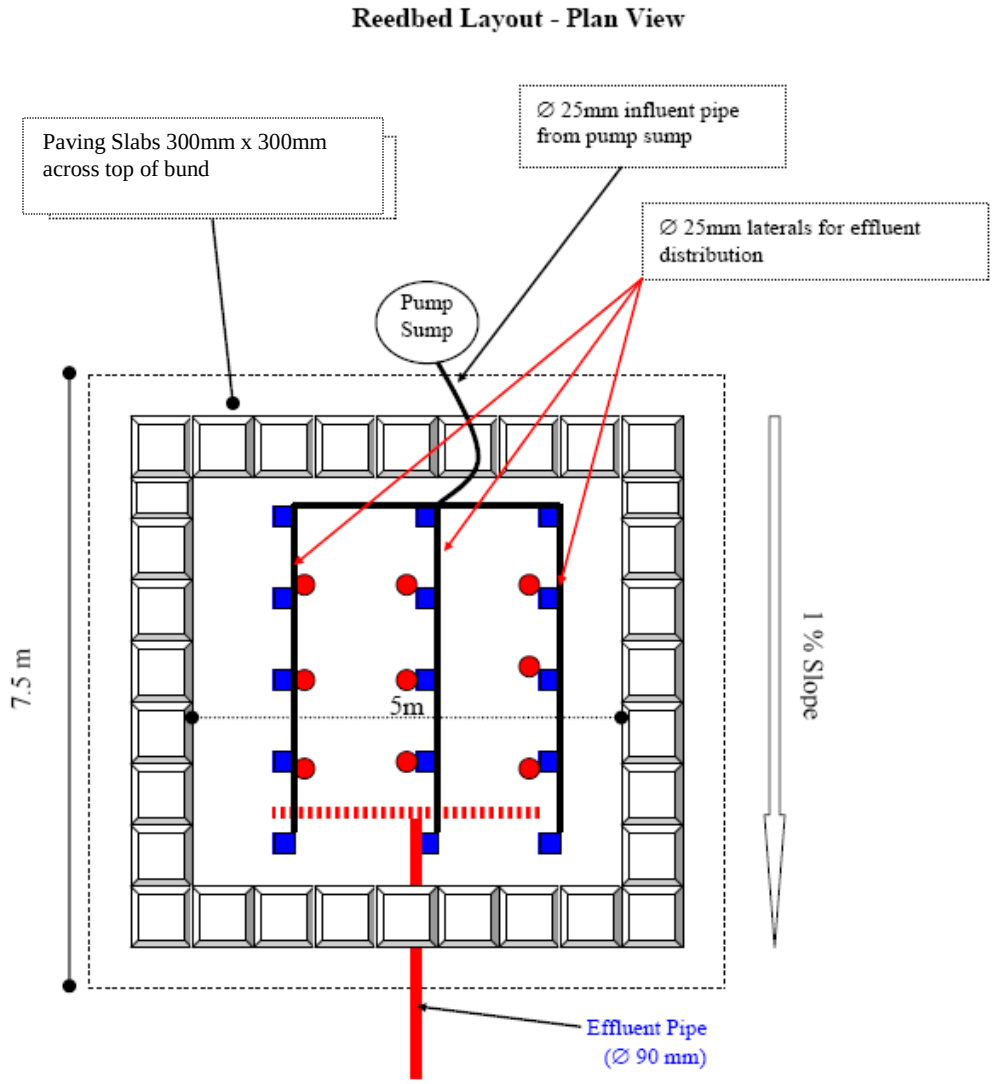


Figure 5.6 Section X – X[1] Showing Liner Material Draped Over Soil Bunds



Key	Colour	Depth	Volume Required
1 = 'Sharp' SAND		**200m**	**10m^3** (5m^3 each bed)
2 = 6mm Gravel		**200m**	**10m^3** (5m^3 each bed)
3 = 12mm GRAVEL		**200m**	**10m^3** (5m^3 each bed)
4 = 14 mm GRAVEL		**200m**	**10m^3** (5m^3 each bed)

Figure 5.7 Cross Section of VF Reed Bed Detailing Sand and Gravel Layers



Key

= **Aeration Pipes**

= **Paving Slabs** 200mm x 200mm (15 no.) on to which leachate is sprayed

Effluent Distribution System
15 no. Ø 3mm holes drilled in to distribution laterals – spraying leachate on to Paving Slabs (200mm x 200mm)

Figure 5.8 Plan View of VF Reed Bed Detailing Effluent Distribution System

Horizontal Flow Reed Beds

Internal Dimensions: 5 m x 5 m
External Dimensions: 7.5m x 7.5m x 1.30m

Allow for 2% slope - Influent point to Effluent point

Soil Bund walls lined with non-textured LDPE

HDPE liner on sand blinding layer for base

2 such reeds beds required.

Plan View

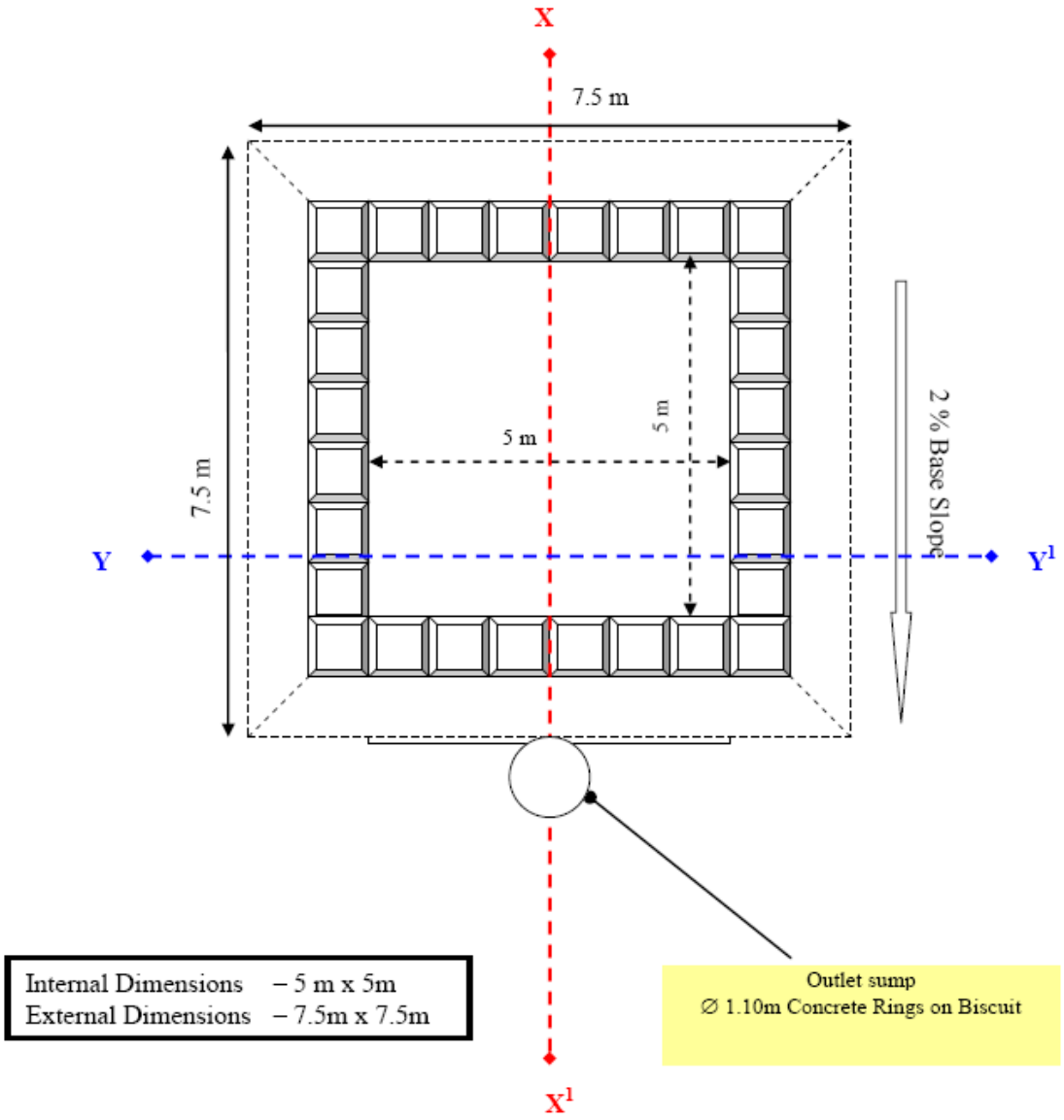


Figure 5.9 Plan View of Horizontal Flow (HF) Reed Bed

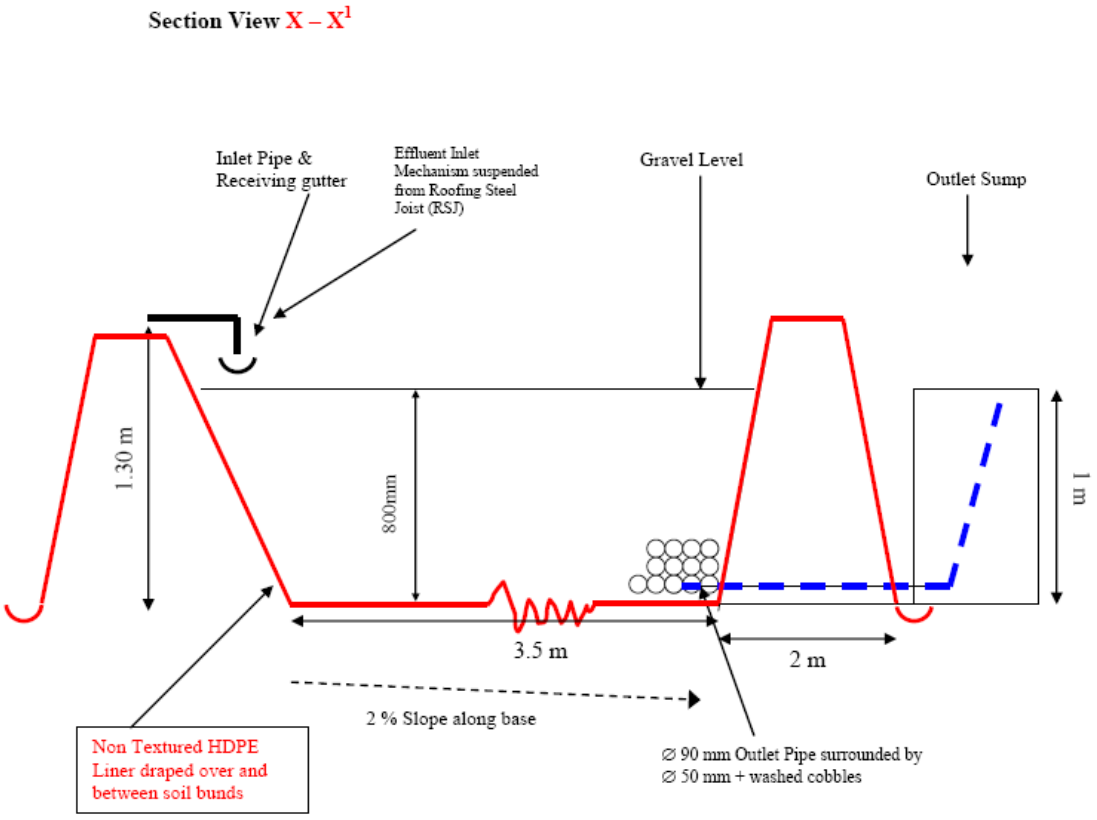


Figure 5.10 Section View X – X^1 of HF Reed Bed

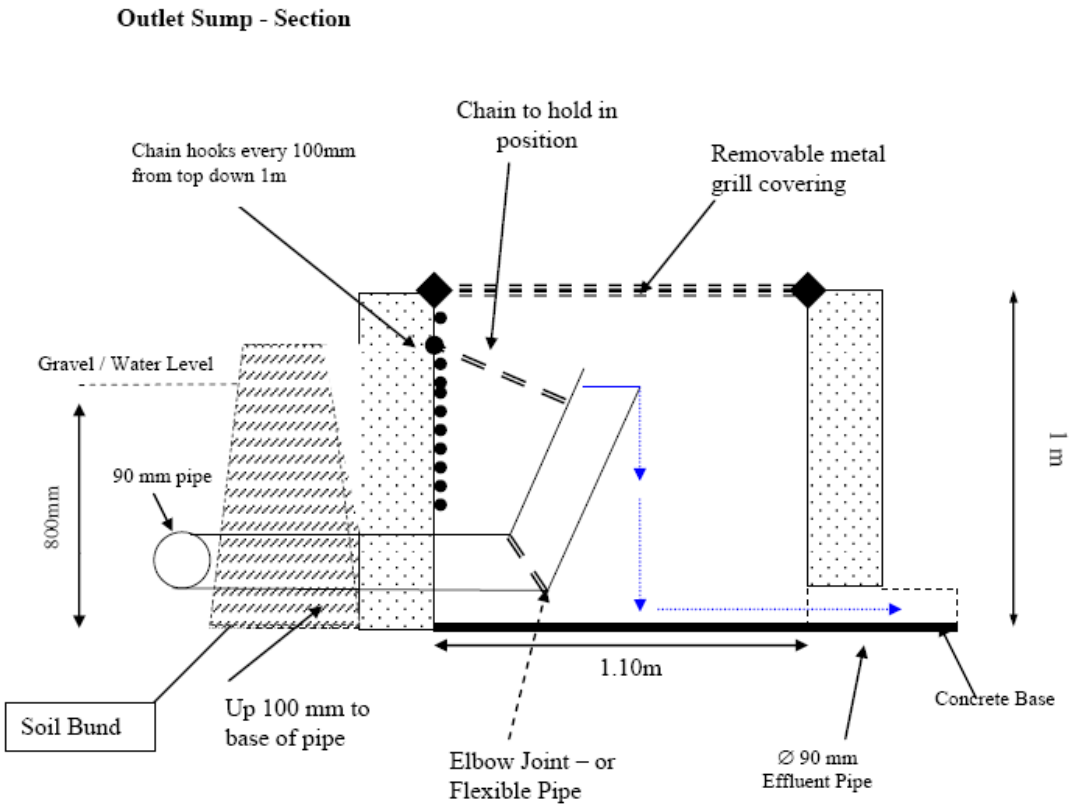


Figure 5.11 Section View of HF Reed Bed Outlet Sump

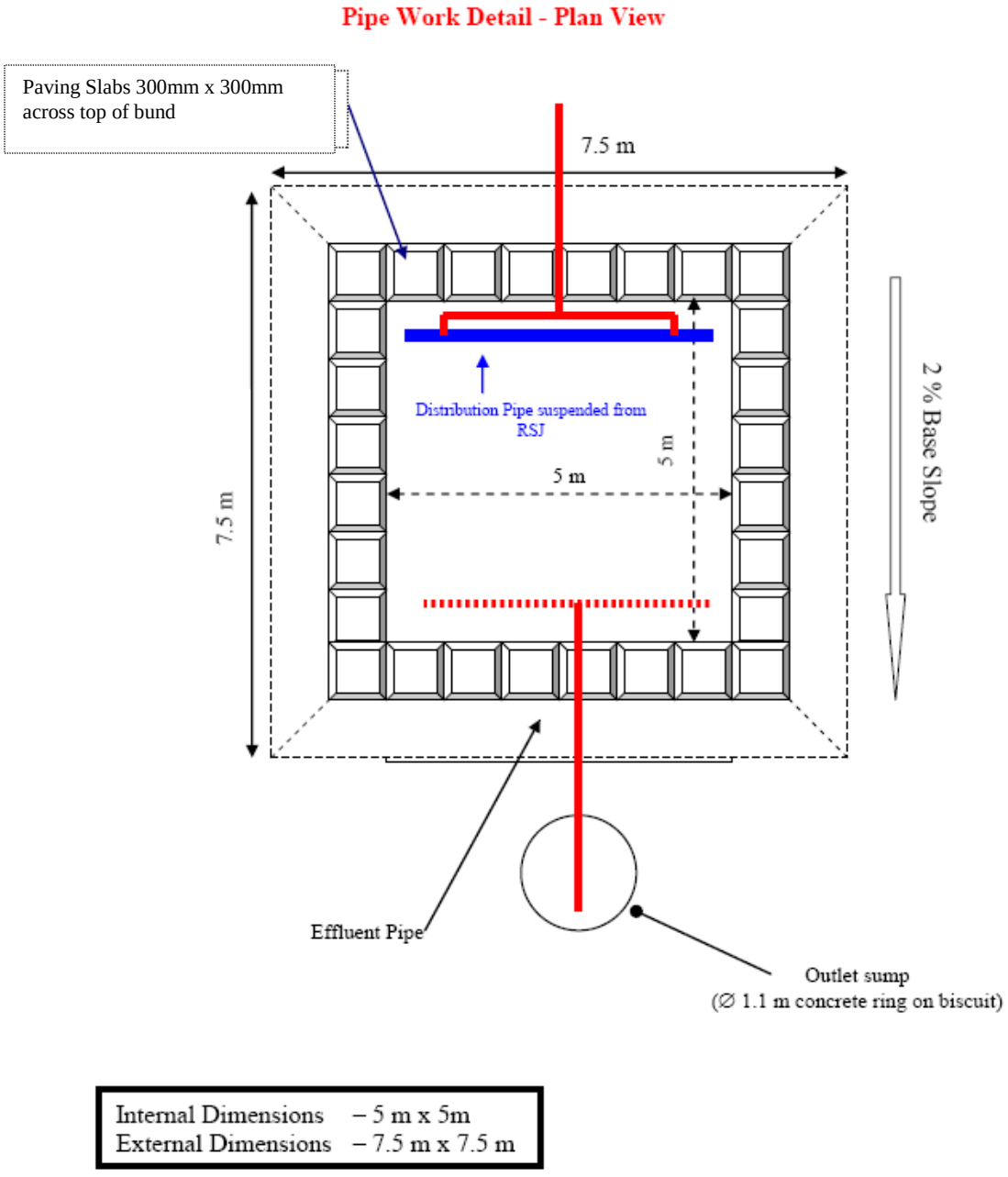


Figure 5.12 Plan View of HF Reed Bed Inlet and Outlet Pipework

5.2.7.1 Pump Design

The pumps were selected based on ‘’Manufacturers Pump Performance Curves’’ which detail the flow rate it is capable of achieving against a known head height and the associated power efficiency per unit volume pumped.

After considerable research and following numerous conversations with the appointed mechanical and electrical contractors, two types of pumps were chosen.

For pumping leachate to the 10 cells and the two vertical flow reed beds, a compact submersible pump set in a 250 litre cylindrical tank (sump) was selected (Figures 5.13 and 5.14). The pump model, *Vigila 100M*, is suitable for light duty pumping of clean or soiled water. It is a non-specialised model, commonly used for pumping drinking water in rural areas, was readily available and easy to maintain (http://global.espa.com).

It was estimated that the application rate to the treatment units would be in the order of 100 – 1000 litres/m^2/day to the cells and 100 – 200 litres/m^2/day to the reed beds.

The reasons for these intended high hydraulic loading rates are outlined in section 5.2.8.

The hydraulic performance specifications for the *Vigila 100M* outlines an operational range of 4.8m^3/hour at a height of 1.3m to 0.6m^3/hour at 5.0m head height. Since the maximum head delivery to the treatment units was under 3m, the pump was capable of operating well within the requirements of this project (from the pump rating curve, at 2.9m head height, the pump was capable of delivering 3m^3/hour (www.q-techshop.es).

The hydraulic performance and electrical features for the *Vigila 100M* pump are outlined in Table 5.1.

Table 5.1 Hydraulic Performance and Electrical Features for *Vigila 100M* Pump

Hydraulic Performance									
Flow (m^3/h)	0	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8
Height (m)	5.5	5.0	4.5	4.0	3.4	2.9	2.4	1.9	1.3
Electrical Features									
Single Phase	Intensity (A)		Input Power P1 (kW)		Motor Power P2		Condenser Capacity (µF)		
50 Hz	1 ~ 230V		1~		(kW)		1~		
Vigila 100M	1.00		0.22		0.11		6µF – 450V		

(after www.q-techshop.es)

Pumping of leachate to the header tank was achieved using a heavier duty pump, *Lowera DLV(M)100* model, suitable for pumping sewage and other industrial wastewater. It has a high temperature tolerance range (0–50°C), can handle a high degree of solids and the impellor and outer casing is made of stainless steel (www.lowera.ie).

During trialling and commissioning, it was noted that the *Lowera DLV(M)100* pump performed well beyond the stated hydraulic operating characteristics. The actual head height from the leachate source tank to the header tank for the trial treatment plant was 15m; whereas the maximum stated operating capacity was $3m^3$/hour at 10.1m head height. Despite the stated operating capacity, the header tank was filled in 8 hours; suggesting a pump delivery rate of $4.5m^3$/hour; so it was decided to remain with the recommended *Lowera DLV(M)100* pump.

In the event that all fourteen treatment units were operating at maximum HLR (i.e. potential system total irrigation of $50m^3$ per day), the *Lowera DLV(M)100* pump would be more than capable of replenishing the header tank (approximately 1.5 fill cycles per day) whilst maintaining an uninterrupted supply of leachate to the system.

The hydraulic performance and electrical features for the *Lowera DLV(M)100* pump are outlined in Table 5.2.

Table 5.2 Hydraulic Performance and Electrical Features for *Lowera DLV(M)100*

Hydraulic Performance

PUMP TYPE	RATED POWER		Q = DELIVERY											
			l/min	0	50	100	150	200	250	300	350	400	450	500	600
			m^3/h	0	3	6	9	12	15	18	21	24	27	30	36
	kW	HP	H = TOTAL HEAD METRES COLUMN OF WATER												
DLV(M) 100	1,1	1,5	10,6	10,1	9,6	9,1	8,6	8,0	7,4	6,6	5,8	4,8	3,7		

Electrical Features

PUMP TYPE SINGLE-PHASE	ABSORBED POWER* kW	ABSORBED CURRENT* 220-240 V A	CAPACITOR µF / 450 V
DLVM100	1,64	7,30	35

(after www.lowera.ie)

Due to the fact that the operator (the author) would not be on site at all times, it was important that the pumps could operate automatically. This was achieved by way of automatic digital timer switches similar to those used for home heating control. The

specific timer control device chosen (*Legrand AlphaRex* (www.legrand.com.au)) (with the help of a City Council electrician based on site) had 48 dosing time options per 24 hours. This was deemed adequate for requirements (in general, no more than 24 dosing options per day were required).



Figure 5.13 Layout of Cells and Pump Sumps



Figure 5.14 Pump Sump (blue) and *Vigila 100M* Pump (inset) with Time Switch Control Mechanism (white box).

5.2.8 Treatment Media

Five different types of treatment media were initially required for the project:

- Reeds – (three different species, *Phragmites sp.*, *Typha sp.* and *Sparganium erectum*) which were available free of charge at KRLF,
- Compost – available free of charge at KRLF,
- Willow trees (*Terra Nova* variety) - available free of charge at KRLF,
- Subsoil - available free of charge at KRLF,
- Sand and gravel – available from a nearby quarry at Ovens, Co. Cork.

A detailed breakdown of the sand and gravel sizes and quantities required can be seen in Table 5.3.

Table 5.3 Sand and Gravel Sizes and Quantities Required

Material Required	Material Available from supplier	Depth	Breakdown	Quantity	Detail	Price / tonne (€)
Cobbles ∅ 50mm +	∅ 30 – 60 mm Washed Cobbles	100mm	0.255m^3 per cell	2.55m^3 for 10 cells	Drainage layer for cells	7.50
Gravel ∅ 12mm	Gravel (∅ 14mm)	100mm	0.255m^3 per cell	2.55m^3 for 10 cells	Drainage layer for cells	7.50
Sand (∅ 0.4 – 1.0 mm)	Washed Sharp Sand (1mm)	400mm	1.02 m^3	1.02 m^3	Filter Layer (Cell 3)	16.60
Sand (∅ 0.4 – 1.0 mm)	Washed Sharp Sand (1mm)	200mm	0.51 m^3	0.51 m^3	Filter Layer (Cell 5)	16.60
6mm Gravel	Pipe Grit (∅ 6mm)	200mm	0.51 m^3	0.51 m^3	Filter Layer (Cell 5)	7.50
10mm GRAVEL	Pea Gravel (∅ 10mm)	200mm	0.51 m^3	0.51 m^3	Filter Layer (Cell 5)	7.50
12 - 14 mm GRAVEL	Gravel (∅ 14mm)	200mm	0.51 m^3	0.51 m^3	Filter Layer (Cell 5)	7.50
Sand (∅ 0.4 – 1.0 mm)	Washed Sharp Sand (1mm)	330mm	0.678 m^3	0.678 m^3	Filter Layer (Cell 8)	16.60
'Sharp' SAND (∅ 0.4 – 1.0 mm)	Washed Sharp Sand (1mm)	200m	5m^3 each VF reed bed	10m^3	VF Reed Bed Filter Layer	16.60
6mm Gravel	Pipe Grit (∅ 6mm)	200m	2.5m^3 each VF reed bed	10m^3	VF Reed Bed Filter Layer	7.50
10mm GRAVEL	Pea Gravel (∅ 10mm)	200m	2.5m^3 each VF reed bed	10m^3	VF Reed Bed Filter Layer	7.50
12 - 14 mm GRAVEL	Gravel (∅ 14mm)	200m	2.5m^3 each VF reed bed	10m^3	VF Reed Bed Filter Layer	7.50
10mm GRAVEL	Pea Gravel (∅ 10mm)	800m	20m^3 HF 2 reed bed	20m^3	HF Reed Bed Filter Layer	7.50
10mm GRAVEL	Pea Gravel (∅ 10mm)	200m	5m^3 HF 1 reed bed	5m^3	HF Reed Bed Filter Layer	7.50

Two sizes of compost were used in the project, fine grade material (crumb) and coarse grade material, often referred to as oversize material (Figures 5.15 and 5.16).



Figure 5.15 Fine Grade Compost used in the Trial Treatment Project



Figure 5.16 Coarse Grade Compost (Oversize) used in the Trial Treatment Project

A sixth medium was added to the project in February 2008:

- Timber Chippings – available free of charge from the timber shredding facility at KRLF.

Intended design loadings to the various treatment media are detailed in Tables 5.4(a) – 5.4(d). In setting these initial hydraulic loading rates, the author utilised data from existing reference material for similar trials treating landfill leachate or municipal wastewater (where an analogy involving leachate was not available). In terms of pollution potential, particular attention was paid to the ammonium loading rates in the literature as this was considered the main polluting parameter of concern.

Since this was a trial project, there was an element of experimentation in design loadings to the treatment media and in many cases, it was decided to push the treatment system to the limits, often well beyond previously stated design loading.

The expected ammonium load for this project was calculated from the average of the highlighted concentrations of the site pumping stations (450mg/l NH_4) as outlined in Chapter 3, Table 3.3.

Table 5.4(a) Intended Design Loadings to Reed Beds

Treatment Media: **Horizontal Flow Reed Beds**									
Criteria	This Project	Nivala *et al.*, 2007	Lin *et al.*, 2003	Lin *et al.*, 2003	Lin *et al.*, 2003	Eckhardt *et al.*, 1999	Eckhardt *et al.*, 1999	DeBusk, 1999	Robinson *et al.*, 1999
CW Type	SSF	SSF	SSF	SSF	SSF	SF	SSF	SF	SF
Medium	Subsoil / Gravel	Compost	Cinder / Sawdust	Cinder / Sawdust	Coal Refuse	Subsoil	Gravel	Subsoil	Gravel
HLR ($l/m^2/day$	100 – 200	4	15.6	31.2	15.6	17.1	5.7	410	100
NH_4 Load ($g/m^2/day$)	Unknown*	0.85	5.97	22.18	5.97	3.93	0.76	1.85	1.96
Note* HF reed beds (this project) to receive treated effluent from VF reed beds									

Treatment Media: **Vertical Flow Reed Beds**				
Criteria	This Project	Justin *et al.*, 2009	Yalcuk *et al.*, 2009	Lavrova *et al.*, 2010
CW Type	VF	VF	VF	VF
Medium	Sand and Gravel	Subsoil	Sand and Gravel	Gravel
HLR ($l/m^2/day$	100 – 200	Up to 3000	20	1218 – 4992
NH_4 Load ($g/m^2/day$)	45 - 90	7.1	2.44	241 – 988

Table 5.4(b) Intended Design Loadings to Compost Cells

Treatment Media: **Compost Cells**					
Criteria	This Project	Tyrell *et al.*, 2008	Jokela *et al.*, 2002	Heavy, 2003	Kõiv *et al.*, 2009
Medium	Compost	Compost	Compost / Timber Chip	Peat	Peat
HLR ($l/m^2/day$	500 - 1000	23 – 223	63 - 117	20 - 60	76
NH_4 Load ($g/m^2/day$)	225 - 450	1 – 5	1 - 15	4 - 13	<1

Table 5.4(c) Intended Design Loadings to Cells Containing Willow Trees and Subsoil

Treatment Media: Willow Trees in Compost / Subsoil						
Criteria	This Project	Justin *et al.*, 2009	T 1 2007	T 2 2007	T 3 2007	Thörneby *et al.*, 2006
Medium	Subsoil / Compost	Recultivated Soil on Landfill Surface	Soil / Greenfield	Soil / Greenfield	Soil / Greenfield	Soil / Greenfield
HLR ($l/m^2/day$	500 - 1000	1.26	2	4	6	4.1
HLR ($m^3/ha/yr$)	1.8×10^6 – 3.6×10^6	4.60×10^3	2.82×10^3	5.64×10^3	8.46×10^3	1.5×10^4
NH_4 Load (kg/ha/yr)	8.21×10^5 – 1.64×10^6	856	140	279	419	900
Note T1, T2 and T3 after Aronsson *et al.*, 2010						

Table 5.4(d) Intended Design Loadings to Sand and Gravel Cell

Treatment Media: Sand and Gravel Cells				
Criteria	This Project	Wichern *et al.*, 2007	USEPA, 1999*	Gill *et al.*, 2005*
Medium	Stratified Sand & Gravel	Homogenous Sand & Gravel	Stratified Sand & Gravel	Stratified Sand & Gravel
HLR ($l/m^2/day$	50 - 100	50 - 161	50	29 – 41
NH_4 Load ($g/m^2/day$)	22 - 45	2 - 7	2	<1 – 1.5
Note* Data for USEPA, 1999 and Gill *et al.*, 2005 refer to sewage waste water				

5.3 Personnel Requirements

The system was designed as a low maintenance, ‘‘low–tech’’ operation, to be supervised by one individual (the author) on a part time basis. The pumping system was automated so personnel supervision required would be minimal, ranging from sampling of the treated effluent from the various treatment units, increasing/decreasing flow rates and application rates along with resting of process units. Other personnel requirements entailed cleansing/de-clogging of influent distribution systems and assessing the health and efficiency of treatment processes (especially the reed bed units where a close watch was kept on reed growth and the potential for invasive weeds). Control over the plant was effected by way of the manually operated valve system. This allowed for numerous combinations and switching of effluent between treatment units providing primary, secondary and tertiary/polishing treatment.

5.4 Energy and Resource Requirements

Energy requirements were not problematic. The pumping system was electrically operated (110 v), and a connection to the power system was available at the Methane Stripping Plant which was within 100m of the trial treatment plant. All other components of the system were either manually operated, i.e. the valve system, or operated under gravity, such as flows to the Horizontal Flow Reed Beds. Final effluent from the treatment units flowed under gravity to the stone filter trap prior to discharge to the sewer.

5.5 Construction Phase

Construction Considerations

Proper installation of the treatment systems is crucial in ensuring the long-term efficiency of any plant. Many potential future problems can also be addressed at the installation stage. The following points were noted at this juncture:

Ensuring Adequate Ground and Slope Stability

The treatment system was built on an area of the landfill site that had been permanently capped since August 2001. Therefore, it was essential to assess the stability of this area to avoid possible zones of subsidence due to further waste degradation beneath the cap. The actual location of the treatment system, along the south east side of the leachate storage lagoon, was chosen in consultation with a lead design engineer who worked with FTC Environmental and Engineering Consultants (this consulting engineering company had designed and managed previous engineering capping contracts at KRLF). This area was deemed to be the most stable capped area across the site.

With respect to slope stability, slopes above 20 degrees were avoided to prevent movement and potential failure of leachate containment units and to avoid potential rotational slippage of the sediments above the liner system (i.e. the surface water drainage system within the subsoil and topsoil).

Provision of Appropriate Access for Construction Traffic and Personnel

Due to the fact that all pipework was due to be laid above or near ground level, it was imperative that protection was afforded to exposed/shallow pipework in zones where traffic would be likely to pass. Consequently, the pipework in these pass-over zones was encased in concrete pipes and in stone filled trenches. The emplacement of a permanent/semi permanent thoroughfare around the treatment process units allowed access for maintenance with minimal disturbance to the plant

5.6 Construction and Programme Management

5.6.1 Initial Site Survey

The site chosen for the project was first mapped out on a topographical survey map of the area in question. A scaled plan model of the process units was overlaid on the topographical survey map to assess best fit for each unit.

The process units were laid out on five foundation bases:

1. Foundation base for the Header Tank – the main tank for feeding effluent to the succeeding process units
2. Foundation base for cells 1, 3, 5, 7 and 9
3. Foundation base for cells 2, 4, 6, 8 and 10
4. Foundation base for Vertical Flow reed beds 1 and 2
5. Foundation base for Horizontal Flow reed beds 1 and 2.

A best fit for each unit was achieved on paper, allowing for gravity flow from the header tank to the pump sumps for cells 1, 3, 5, 7 and 9; then on to the pump sumps for cells 2, 4, 6, 8 and 10; to the pump sumps for vertical flow reed beds 1 and 2; to horizontal flow reed beds 1 and 2 and finally to the stone filter trench where the wastewater would be conveyed to the municipal sewer. This is outlined diagrammatically in Figure 5.17.

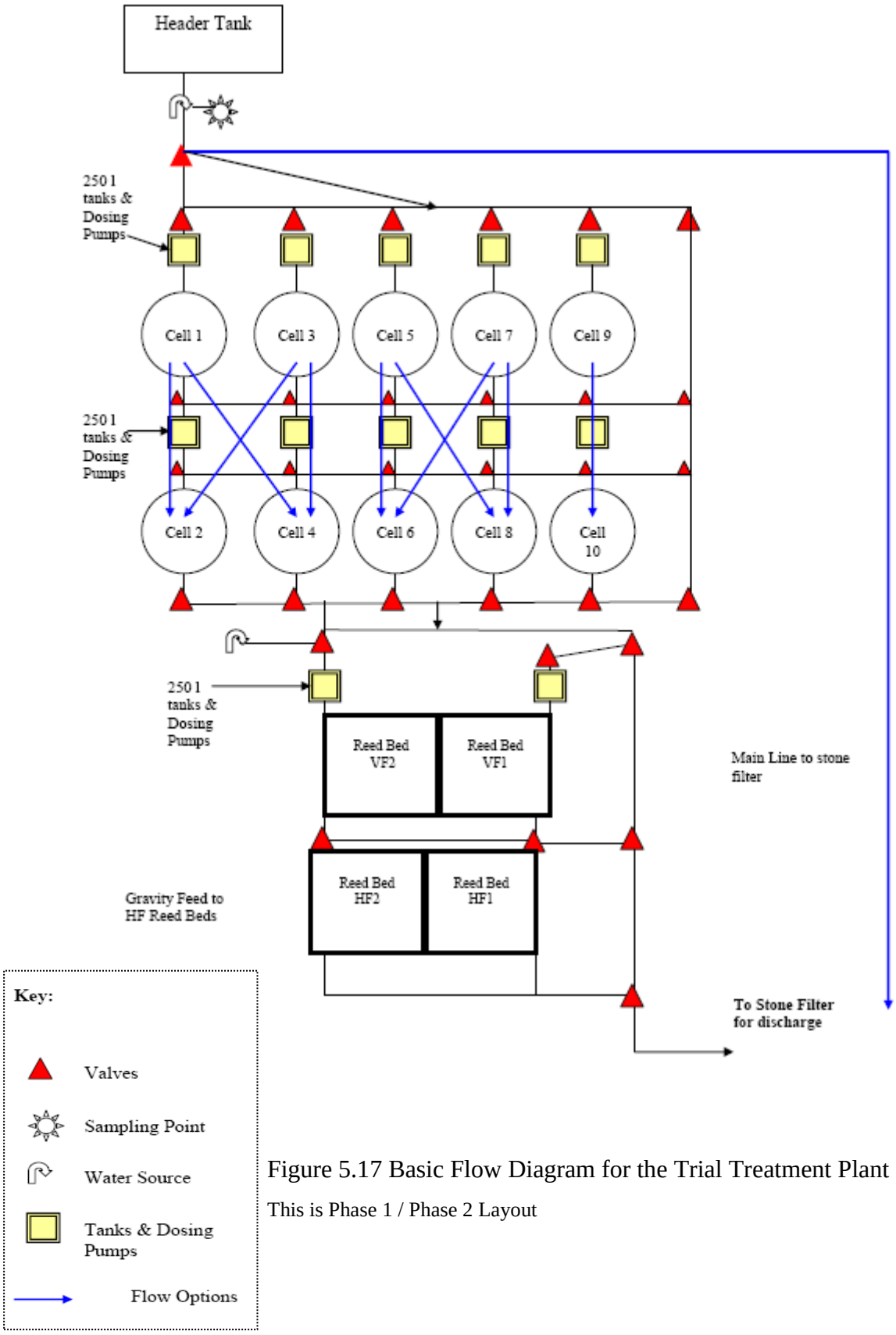


Figure 5.17 Basic Flow Diagram for the Trial Treatment Plant

This is Phase 1 / Phase 2 Layout

The actual survey was carried out in January 2006 by the author with the assistance of a site technician. The results of the survey revealed that at a number of points, the ground had to be cut (lowered) by up to 0.3 metres to achieve the required level for the base of the horizontal flow reed beds.

The foundation bases for the units were constructed of crushed rock (≤100 mm) covered over with soil and grass seeded for stability. They were raised by up to 0.5m above ground level at the highest point (the header tank was raised 1m).

The dimensions of the bases can be seen in Table 5.5.

Table 5.5 System Dimensions

System Dimensions (m)

Area Required for Trial Plant Construction	44 x 20	880m^2

System Length

Header Tank	4
Spacing between units	5
Cells Foundation	3.5
Spacing between units	3
Cells Foundation	3.5
Spacing between units	4
VF Reed Beds	7.5
Spacing between units	3
HF Reed Beds	7.5
Spacing between units	1
Total Length	42

Width

Max Length for Cells Foundation

Spacing	1
Cell 1	2
Spacing	1
Cell 2	2
Spacing	1
Cell 3	2
Spacing	1
Cell 4	2
Spacing	1
Cell 5	2
Spacing	1
Total Length	16

Area Required for Foundations to Cells and Reed Beds

Detail	Length	Width	Area m^2
Header Tank	4	4	16
Cells Foundation (5 no. Cells)	16	3.5	56
Cells Foundation (5 no. Cells)	16	3.5	56
VF Reed Beds	7.5	15	112.5
HF Reed Beds	7.5	15	112.5

5.6.2 Construction of the Process Units

The header tank (∅ 3.2m, 5m high) was placed at the highest point of the system. A layer of fine sand was placed on the stone and soil foundation to produce a level surface.

Downhill to the east, five cells were placed on the next foundation base. Each cell was composed of two ∅ 1.8m x 1m concrete rings stacked on a 200mm thick circular concrete base (commonly referred to as 'concrete biscuits'). The ring sections were sealed using bitumen rubber and 200mm of concrete was poured into the base to create a watertight seal.

The remaining five cells were placed on the succeeding base in exactly the same manner (Figure 5.18). Each cell had a 30mm hole bored at the base to allow for effluent discharge and 200mm of gravels and cobbles (100mm of ∅ 12mm gravels above 100m of ∅ 30–60mm cobbles) were placed in each to act as a filtering and drainage medium.

The cells were dosed using a submersible pump set in a 250-litre sump. Using a time control switch, leachate was delivered to the units via a ∅ 25mm flexible hose with a sprinkler mechanism attached to the end to achieve maximum spread of the effluent over the surface of the treatment media.

For the initial start-up phase in July 2007, eight cells were filled to a depth of 800 mm with varying filter media. Each cell had a surface area of 2.54 m^2.

The exact detail of the contents of the cells is outlined in Table 5.6.

Table 5.6 Contents of Treatment Cells

Cell No.	Medium	Depth
Cell 1	Compost – (coarse grade)	800mm
Cell 2	Willow Trees (x 2) planted in Compost (fine grade)	800mm
Cell 3	Compost (fine grade) Sand Compost – (fine grade) Sand This was replaced with Timber Chip (medium grade) in February 2008	200mm 200mm 200mm 200mm
Cell 4	Compost (fine grade)	800mm
Cell 5	Sand (1mm ‘’Sharp Sand’’) Grit (∅6mm) (Ø 10mm) Gravel (Ø 14mm) Gravel	200mm 200mm 200mm 200mm
Cell 6	Willow Trees (x 2) planted in Sub-Soil	800mm
Cell 7	Sub-Soil This was replaced with Timber Chip (medium grade) in June 2009	800mm
Cell 8	Soil/Sand/Compost Equal Quantities (⅓ / ⅓ / ⅓) This was replaced with Timber Chip (medium grade) in June 2009	800mm
Cell 9	Compost (coarse grade) and Timber Chip (medium grade) 50:50 mix – placed in the cell in February 2008.	800mm
Cell 10	Compost – (coarse grade) This was replaced with Timber Chip/Compost mix in June 2009	800mm



Figure 5.18 Construction and Placement of Header Tank and Cells 1–10 (March 2006)

The vertical flow reed beds (VF 1 and VF 2) were placed side by side on the same foundation base. Each was constructed of 1m high soil bunds (sloping 1:1.5) with a 2mm HDPE pond liner draped over and across the bunds to create an impermeable surface in which the reeds would grow.

Paving slabs were laid on top of the soil bunds for ease of access and to prevent erosion. Grass was sown on the exposed surfaces to help stabilise the soil bunds.

Each reed bed measured 5m x 5m internally and was filled with the following media (top to bottom):

Media	**Depth**
Sharp Sand (1mm)	200mm
∅ 6 mm Gravel	200mm
∅ 10 mm Gravel	200mm
∅ 14 mm Gravel	200mm

The horizontal flow reed beds (HF 1 and HF 2) were constructed down-slope in much the same manner as the vertical flow reed beds. Each reed bed measured 5m x 5m internally and was filled with the following media:

Horizontal Flow Reed Bed 1 (HF 1)

Medium	*Depth*
Subsoil	800mm
∅ 10mm Gravel	200mm (drainage layer)

Horizontal Flow Reed Bed 2 (HF 2)

Medium	*Depth*
∅ 10mm Gravel	800mm

Vertical aeration pipes (∅ 100mm) were buried to a depth of 600mm from the surface. Nine such pipes were evenly spaced throughout each of the reed beds.

The outlet flow mechanism consisted of a ∅ 110mm pipe draining in to a ∅ 1.10m concrete chamber. The water level within the HF reed beds was controlled via a flexible hose attached to the pipe which could be raised and lowered within the outlet chamber to achieve the required depth within the reed bed.

Since the vertical flow reed beds were free draining, the outlet mechanism consisted of a ∅ 110mm pipe passing from the base of the reed bed, through the impermeable HDPE pond liner and the retaining soil bund. The pipe was then connected to a sequence of valves which allowed the operator the option to send the effluent by gravity flow to either of the horizontal flow reed beds or to drain it to the wastewater line emptying to the stone filter trench at the end of the system.

Details of the reed beds and the outlet chambers are outlined in Figures 5.19 – 5.21.



Figure 5.19 Construction of Horizontal Flow Reed Beds (March 2006)



Figure 5.20 Outlet Mechanism for the Horizontal Flow Reed Beds



Figure 5.21 Vertical Flow Reed Bed Showing HDPE Liner and Outlet Mechanism

5.7 Reed Bed Planting

Each reed bed had a surface area of 25m^2 (5m x 5m). Three different types of reed species was planted; *Phragmites sp*., *Typha sp.* (bulrush), which were planted in the vertical flow reed beds (*Phragmites sp*. in VF 1, *Typha sp.* in VF 2) and *Sparganium erectum* (bur-reed) which was planted in each the horizontal flow reed beds.

One hundred plants were placed in each reed bed (4 plants per m^2) with the roots buried to a depth of 200mm. All reeds were sourced on site; *Phragmites sp*. and *Typha sp.* were harvested from a natural wetland area at the eastern end of the site and *Sparganium erectum* was harvested from the Tramore River which flows along the southern and western boundary of the landfill. Since all the reeds were harvested and planted as mature plants in August 2006, bamboo sticks were used to initially support each individual reed (see Figures 5.22-5.24).



Figure 5.22 Planting of *Typha sp.* in August 2006



Figure 5.23 Full Reed Bed of *Typha sp.* Planted in August 2006



Figure 5.24 Full Sward of *Phragmites sp.* Planted in August 2006

Due to an incident of vandalism in October 2006 in which a number of pump units and valves were stolen along with pipework being damaged, dosing of the reed beds with leachate did not get underway until July 2007. By this time the initial crop of reeds had died back giving way to new growth that had begun to show in February/March 2007.

The vertical flow reed beds were dosed using a submersible pump set in a 250l tank. Using a time control switch, leachate was delivered to the reeds via three ∅ 25mm pipe laterals, each with five evenly spaced 3mm orifices along each lateral. To avoid pitting of the sand layer, each spray jet was directed on to a concrete paving slab (200mm x 200mm). This helped achieve an even spread of the leachate across the surface area of the reed bed during each dosing phase (Figure 5.25).



Figure 5.25 Effluent Distribution to the Vertical Flow Reed Beds

Effluent distribution to the horizontal flow reed beds was achieved via gravity flow through a 110mm pipe emptying on to a 150mm gutter pipe, which was closed off at each end. The gutter pipe was suspended 5cm above the water level at the upper end of the reed bed and the effluent was evenly distributed to the system through a series of ∅ 7.5mm holes drilled every 200mm along its length (Figure 5.26).



Figure 5.26 Effluent Distribution to the Horizontal Flow Reed Beds

All of the features detailed above can be seen in an aerial photograph of the trial treatment plant taken in August 2008 (Figure 5.27).

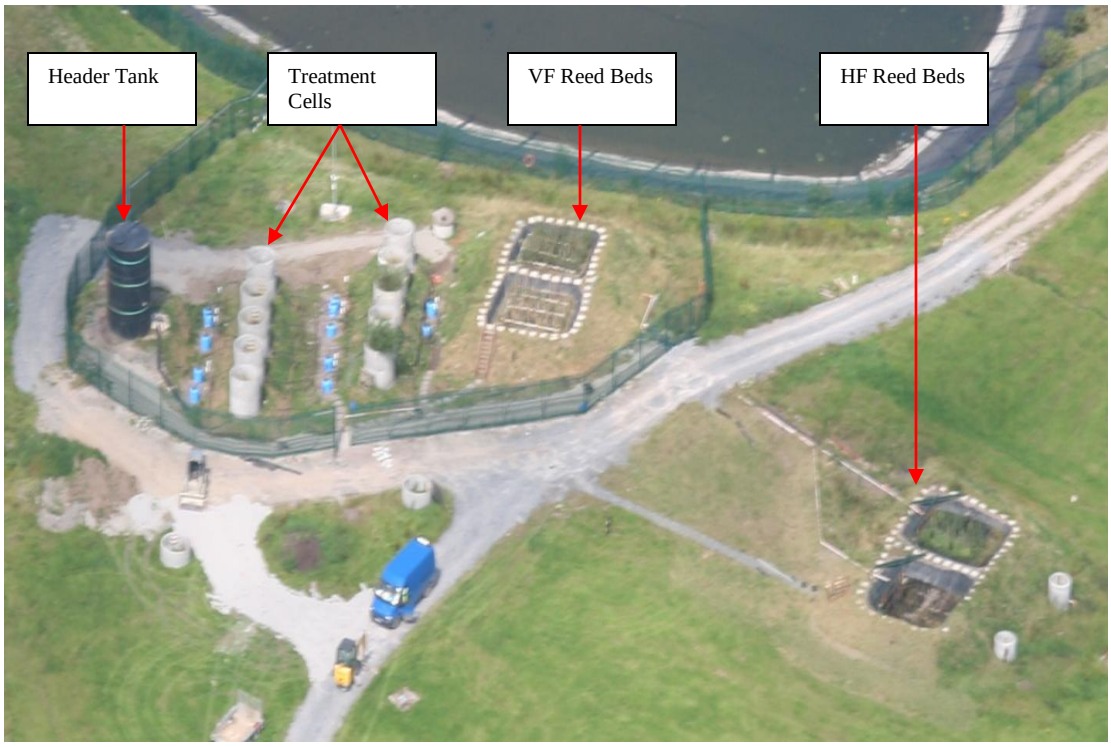


Figure 5.27 Aerial View of the Trial Treatment Plant (August 2008)

CHAPTER 6

6. TRIAL PLANT COMMISSIONING AND OPERATION

6.1 Introduction

Commissioning of the trial plant began in July 2007. A number of trial runs were first carried out to test the performance of the pumps and to assess flow rates and fill times for the 250l pump sumps and header tank.

The header tank was first filled to its maximum capacity of $36m^3$. The fill time was 8 hours. Leachate was then allowed to flow to the pump sumps (12 in number; 10 Cells and 2 Vertical Flow Reed Beds) to ensure that all the pipelines were flowing freely. The stopcock in each pump sump ensured the sump did not overflow.

Trial pump tests were performed on each unit to assess dosing times and pulse frequency. Influent feed lines from the pump sumps were throttled back to decrease the application rate and increase the dosing pulse time. This helped prevent overloading and surface ponding in the treatment units where the dosing time and volume exceeded media permeability.

Effluent distribution within each of the cells was achieved through a modified sprinkler which consisted of a plastic end cap glued over a Ø 25mm non flexible HDPE pipe with 16 no. Ø 3.5mm holes drilled evenly around the circumference of the end cap. The sprinkler was centred in each cell and set 600mm above the treatment media. Overall, the simple set up provided an efficient method of distributing the leachate evenly across the surface area of each treatment cell.

When the author was satisfied that the pumping rate had been calculated for each pump and that an even distribution of the influent had been achieved across each cell, the system was ready for switch on.

Each of the time switch control units was set to the required pulse time and frequency for wastewater delivery.

6.2 **Phase 1 Plant Operations** (July – November 2007)

6.2.1 Introduction

Eight treatment units were put into operation for the first run of the system. Each treatment cell was dosed initially with raw, untreated leachate, as was each of the vertical flow reed beds (VF 1 and VF 2).

The horizontal flow reed beds (HF 1 and HF 2) were dosed via gravity flow with treated leachate from each of the preceding vertical flow reed beds.

A chart detailing alterations in irrigation rates and changes to media material in the treatment units during phase 1 operations is presented in Table 6.1.

The pulse time, dosing volume and flow sequence for each treatment unit is set out in Tables 6.2 and 6.3.

Table 6.1 Chart Detailing Phase 1 Operations

Time Period of Plant Operation: Phase 1: July - November 2007

		Phase 1				
		Jul-07	Aug-07	Sep-07	Oct-07	Nov-07
	Month of Operation	1	2	3	4	5
Treatment Unit	Medium	HLR ($l/m^2/day$)				
Cell 1	Compost (coarse)		945	945	945	945
Cell 2	Willows in Compost	945	945	945	945	945
Cell 3	Stratified Compost (fine) and Sand		945	945	945	945
Cell 4	Compost (fine)	945	945	945	945	945
Cell 5	Sand/Grit/Gravel		189	189	189	OFF
Cell 6	Willows in Subsoil	945	472	472	472	472
Cell 7	Subsoil		945	945	945	945
Cell 8	Mixed Soil/Sand/Compost	945	472	472	472	OFF
Cell 9						
Cell 10	Compost (coarse)					945
VF 1	*Phragmites* in Sand/Grit/Gravel Matrix	192	192	192	192	192
VF 2	*Typha* in Sand/Grit/Gravel Matrix	192	192	192	192	192
HF 1	*Sparganium* in Subsoil	192	192	192	192	192
HF 2	*Sparganium* in Gravel	192	192	192	192	192

Note: Grey shaded = Unit operational
OFF = Unit switched off

Table 6.2 Pulse Times and Dosing Volumes for Plant Start-up (July 2007)

Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 2 Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 4 Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 6 Willow Trees (x 2) planted in Sub-Soil	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 8 Mixed Soil/Sand/Compost	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
VF 1 Vertical Flow Reed Bed 1	24 pulses per day (every hour) 200 l per pulse	4800l/unit/day	192 litres /m^2/day
VF 2 Vertical Flow Reed Bed 2	24 pulses per day (every hour) 200 l per pulse	4800l/unit/day	192 litres /m^2/day
HF 1 Horizontal Flow Reed Bed 1	Secondary effluent from VF 1 via gravity flow	4800l/unit/day	192 litres /m^2/day
HF 2 Horizontal Flow Reed Bed 2	Secondary effluent from VF 2 via gravity flow	4800l/unit/day	192 litres /m^2/day

Table 6.3 Flow Sequence to Treatment Units for Plant Start-up (July 2007)

Flow Sequence to Treatment Units
Raw Leachate → Cell 2
Raw Leachate → Cell 4
Raw Leachate → Cell 6
Raw Leachate → Cell 8
Raw Leachate → VF 1 → HF 1
Raw Leachate → VF 2 → HF 2

The header tank was topped-up daily to ensure adequate supply of leachate to the trial plant. The leachate volume within the tank at any time was determined by the level in a clear vertical HDPE tube connected to the outflow pipe and strapped to the outside of the tank.

Wastewater from the system was diverted to the waste leachate line, which discharged to the stone filter drain, located at the base of the slope adjacent to the main leachate treatment plant for the site. From the stone filter drain, the wastewater was discharged to the sewer along with the air-sparged leachate from the rest of the site.

In August 2007, four additional treatment units were brought into operation; Cell 1 (coarse compost), Cell 3 (stratified sand and compost), Cell 5 (stratified sand, grit, gravel) and Cell 7 (subsoil).

The pulse time, dosing volume and flow sequence for Cells 1, 3, 5 and 7 are set out in Tables 6.4 and 6.5.

To avoid pitting of the sand surface layer in Cell 5, the leachate was sprayed directly on to a 200 x 200 mm concrete paving slab. The high pressure jet of wastewater spraying on to the paving slab from two Ø 4mm orifices in the spray nozzle provided an even distribution of effluent droplets across the treatment medium.

The application rates and flow sequences for Phase 1 Plant Operations are detailed in Tables 6.4 and 6.5.

Table 6.4 Phase 1 Pulse Times and Dosing Volumes - August 2007

Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 1 Compost (coarse grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 2 Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 3 Stratified sand and compost	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 4 Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 5 Stratified sand, grit, gravel	24 pulses per day (every hour) 20 l per pulse	480l/unit/day	189 litres /m^2/day
Cell 6 Willow Trees (x 2) planted in Sub-Soil	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	472.5 litres /m^2/day
Cell 7 Subsoil	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 8 Mixed Soil/Sand/Compost	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	472.5 litres /m^2/day
VF 1 Vertical Flow Reed Bed 1	24 pulses per day (every hour) 200 l per pulse	4800l/unit/day	192 litres /m^2/day
VF 2 Vertical Flow Reed Bed 2	24 pulses per day (every hour) 200 l per pulse	4800l/unit/day	192 litres /m^2/day
HF 1 Horizontal Flow Reed Bed 1	Secondary effluent from VF 1 via gravity flow	4800l/unit/day	192 litres /m^2/day
HF 2 Horizontal Flow Reed Bed 2	Secondary effluent from VF 2 via gravity flow	4800l/unit/day	192 litres /m^2/day

Table 6.5 Phase 1 Flow Sequence to Treatment Units - August 2007

Flow Sequence to Treatment Units
Raw Leachate → Cell 1
Raw Leachate → Cell 2
Raw Leachate → Cell 3
Raw Leachate → Cell 4
Raw Leachate → Cell 5
Raw Leachate → Cell 6
Raw Leachate → Cell 7
Raw Leachate → Cell 8
Raw Leachate → VF 1 → HF 1
Raw Leachate → VF 2 → HF 2

6.2.2 Trouble Shooting

6.2.2.1 Introduction

During the period August to November 2007, the author carried out a series of trouble shooting exercises on the treatment units. The problems related to effluent overloading and unit flooding, reduced media permeability as well as clogging of influent filters at the pump sumps. In particular, Cells 6, 8 and 5 were experiencing problems of surface ponding. Consequently, dosing volumes to Cells 6 and 8 were halved to 1200 litres per day and the leachate application rate to Cell 5 was reduced to 20 litres per hour to approximate that of VF 1 and VF 2 (i.e. 192 litres/m^2/day). Since the media in all three units (Cell 5, VF 1 and VF 2) were identical (stratified sand–grit–gravel) it was atticipated that the phytoremediation of leachate attributed to the reeds in VF 1 and VF 2 could be quantified over and above the treatment of leachate associated with the media (and surface biofilm) alone.

6.2.2.2 Iron Build-up

Iron buildup and surface cementation of the top 10mm in a number of the treatment units was becoming evident one month into plant operation. In particular VF 1, VF 2 and Cell 5 were affected due to high surface aeration of the leachate (splash plate effect on the receiving paving slab) and subsequent release of iron (both suspended and in solution) from the leachate.

This issue would require careful management in to the future. As a preliminary measure, the iron pan/surface cementation was simply scraped off and removed from the surface of the treatment units. The top 200 mm of Cell 5 was turned using a shovel and loosened to increase media permeability.

6.2.2.3 New Sprinkler System

A new sprinkler system was trialled in Cells 1, 3 and 7. The *ROTOFRAME* butterfly style sprinkler was a self-rotating system and provided an increased surface area spread of droplets over the treatment media. The set-up was exactly the same as the previous sprinkler, centred in the unit and set 600 mm above the media. Consideration would be given to replacing the sprinklers in the other units depending on the results of the trial.

6.2.2.4 Pump Sump Inlet Filters

A monthly procedure of cleaning and de-clogging all inlet filters to pump sumps was initiated. It was found that small pieces of plastic and on occasion small amounts of the treatment media became lodged in the filter piece. Iron buildup in the filter and on the ball cock mechanism was also becoming an issue. If left unattended, the buildup of detritus in the filters tended to impair flow to the pump sumps resulting in a lowering of the application rate to the respective unit.

6.2.2.5 Gravel Filter Units

In late October 2007, three gravel filters were installed at the head of the system to assist in the removal of solids from the leachate prior to dosing within the treatment units.

Three Intermediate Bulk Containers (IBCs) were connected in parallel to the outlet line from the leachate header tank. IBCs are widely used for bulk storage of liquids.

Each IBC had a capacity of 1000 l, was light weight (50 kg approx.), measured 1000 x 1200 x 1160 (width/depth/height) and composed of LLDPE material. For added strength, each IBC was positioned in a galvanised steel cage.

The IBCs were slightly modified whereby the lids were removed and inlet and outlet pipes attached. The inlet pipe level was set at 100mm invert from the top and the outlet pipe was fixed at 300mm from the base, allowing for 300 l standing capacity in the unit.

Flow control at the IBC inlet was achieved using a hydraulic level regulator (*Quick Stop Advance*) which had an operating capacity of 0.2 to 6 bar.

Once all the pipes and hydraulic level regulators (2 per IBC) had been connected up; including header tank connections to the IBC inlet lines and the outlet pipe connections to the pump sumps; the tanks were filled with Ø 14mm gravel up to the 800 litre level mark.

As an additional measure for leachate filtration, a sediment strainer (*RVUFM Sediment Strainer, FIP Products*) was connected to the inlet line linking the header tank to the IBCs. The sediment strainer collected solid impurities in suspension in the fluid conveyed by means of a filter screen, which was easily removed for cleaning and maintenance.

The IBCs were then deemed ready for operation.

The layout for the IBC gravel filters is detailed in Figures 6.1 and 6.2.



Figure 6.1 Layout of IBC Gravel Filter Units



Figure 6.2 IBC Gravel Filter Unit with Vertical Aeration Pipes

6.2.2.6 Activated Carbon Filters

In late November 2007, the author tried to augment wastewater filtration within the IBCs using activated carbon. A filter was constructed using a 200mm long segment of Ø 90mm slotted pipe set in a permeable canvas bag. The space between the pipe and the canvas bag was filled with an even mixture of 'sharp' sand, Ø 5mm gravels and granular activated carbon (charcoal filter granules) (see Figure 6.3). Two such filters were constructed and placed in one of the IBCs just below the invert of the inlet pipe. The aim of trialling the carbon filters was to achieve additional removal of suspended solids and to bring iron out of solution through aeration and absorption onto the surface of the carbon granules.

The activated carbon filters were operational for a period of one week during which time they performed poorly; with a low removal rate for suspended solids and soluble iron; and were subsequently removed.



Figure 6.3 Activated Carbon Filters with Charcoal Filter Granules (inset)

A final effort to incorporate an activated carbon filter was made between November 2007 and January 2008 whereby a layer of Ø 5mm gravels topped with a film of granular activated carbon (100mm and 40mm thick layers respectively) was placed in one of the IBCs. Raw untreated leachate was pumped on to the surface of the IBC from a pump sump (similar to those used for dosing the treatment units) every 30 minutes. To avoid pitting of the surface layer and to achieve maximum liquid spread across the surface area the leachate spray jet was directed on to a 200 x 200mm concrete paving slab.

However, on testing the iron concentration within the leachate stream, before and after passing through the carbon filter, the removal rates for the suspended solids and soluble iron were found to be low. The filter was removed in early January 2008 and the IBCs were returned to gravel only filters.

6.3 Phase 2 Plant Operations (November 2007 – July 2008)

6.3.1 Introduction

During the period November 2007 to July 2008 a number of changes to the operation of the trial plant were initiated.

6.3.2 New Treatment Units in Operation

Previously empty treatment units, Cell 10 and Cell 9 were brought into operation. Cell 10 was filled with coarse grade compost in November 2007, and in April 2008, Cell 9 was filled with a 50:50 mix of coarse grade compost and timber chippings. Each cell was filled in a similar manner and dosed with effluent via sprinklers (not *Rotoframe* sprinklers) as per the other cells in operation. The application rate for the cells was 2400l per unit per day (954L/m^2/day).

6.3.3 Changes to Flow Sequences

A number of changes were made to the flow sequences between treatment units. In November 2007 effluent from Cell 1 (coarse compost) was dosed to VF 2 (*Typha* VF reed bed), which in turn free flowed to HF 2 (gravel based HF reed bed). Likewise, effluent from Cell 10 (coarse compost) was dosed to VF 1 (*Phragmites* VF reed bed), from which the secondary treated effluent flowed to HF 1 (soil based HF reed bed). This

provided for primary, secondary and tertiary treatment of the leachate. Chemical and biological analysis of the leachate from these flow sequences provided the first real set of positive results in terms of pollutant removal rates. This set the trend for the remainder of the trial experiment and resulted in a number of additions to existing flow sequences.

In March and April 2008, an additional unit was added to each series. Treated leachate from Cell 1 (coarse compost) was dosed to Cell 2 (willow trees in compost), which dosed to VF 2 (*Typha* VF reed bed) and then on to HF 2 (gravel based HF reed bed). Similarly, an additional unit was added to the other sequence to provide leachate treatment in four units in series, namely; effluent from Cell 9 (compost/timber chip) was dosed to Cell 10 (coarse compost), which dosed to VF 1 (*Phragmites* VF reed bed) and finally to HF 1 (soil based HF reed bed).

In May 2008 a fifth treatment unit was added to provide the following leachate treatment sequence: Cell 1 (coarse compost) → Cell 2 (willow trees in compost) → Cell 4 (fine compost) → VF 2 (*Typha* VF reed bed) → HF 2 (gravel based HF reed bed). Despite the additional treatment step in the sequence, results from chemical and biological analysis of the leachate did not show an increase in pollutant removal rates.

The key to increased pollutant removal within the leachate stream seemed to lie not necessarily in the number of units in the sequence but instead on the type and nature of the media in each unit. Coarser grained material did not tend to foul as often as finer material. Coarser grained material provided increased and unimpeded flow paths for leachate percolating through the media, which in turn led to the growth and maintenance of a healthy microbial population to effect treatment.

6.3.4 Replacement of Treatment Media

Exploratory coring of all treatment units was carried out in February 2008 to ascertain the degree of media compaction within the cells and reed beds and to assess the nature of the iron pan that had formed on the surface the media. The coring was carried out using an open window Edelman gouge auger and the results of the exercise are detailed in Chapter 7.

Analysis of the cores revealed significant media compaction in a number of units, in particular Cell 3 (stratified compost and sand), where the two compost strata had been

compressed to 50% of the original thickness. The degree of compaction can be seen in Figure 6.4.



Figure 6.4 Compaction of Compost Layers in Cell 3
Note: 300mm Graduations on Staff Pole

The unit had been out of operation since December 2007 due to surface ponding and media fouling. In addition, the results from laboratory analysis of effluent from Cell 3 between August and November 2007 revealed a very limited potential for leachate treatment.

To this end, the sand and compost media were removed from Cell 3 and replaced with medium grade timber chippings. The source material for the timber chippings and actual timber chippings can be seen in Figure 6.5. The new material was placed in the cell unit to a depth of 800mm. The leachate application rate remained the same, i.e. 2400l per day, 12 pulses per day at 200l per pulse.

On inspection of the iron pan that had developed in the units, it was discovered that it consisted of a 10mm thick surface cementation which was easily removed.



Figure 6.5 Timber Chipping Source Material with Timber Chippings (inset)

6.3.5 Osmotic Shock of Willow Trees in Treatment Units

The health of the willow trees in Cell 2 and Cell 6 seemed to deteriorate during June and July 2008. The foliage on each of the four trees (two per cell) seemed to wilt, while the branch ends turned black, became brittle and could be snapped off with ease. The author first thought this was the result of wind stress and low night-time temperatures. However, following a site visit by a horticulturist from Cork City Council's Parks and Recreation Department, it was pointed out that the poor condition of the trees was most probably due to salt stressing.

This explanation tallied with the high chloride values recorded in the raw leachate during June 2008. The chloride concentration of 844 mg/l in the leachate was more than double the normal concentration for the site (typically ranging 200-400 mg/l). It is evident that the trees suffered osmotic shock resulting from a brief period of salt (NaCl) overloading caused by irrigation with a hypertonic leachate. The low water potential of the root

medium lead to water deficits in the willows. This coupled with the toxic effects of the NaCl ions caused a nutrient imbalance in the trees (Al-Garni, 2006).

Ultimately, the poor condition of the trees resulted in a significant decrease in treatment efficiency within the units. The units were turned off and rested for two months in the hope that the trees would recover. However on recommencement of leachate irrigation in September 2008 (at a much lower application rate of 240l per unit per day), laboratory analysis of the treated effluent from each cell did not show any increase in pollutant removal efficacy. The cells were turned off permanently in June 2009 and abandoned.

The extent to which the foliage on the willow trees was wilted is detailed in Figures 6.6 and 6.7.



Figure 6.6 Wilted Willow Trees in Cell 2 (June 2008)



Figure 6.7 Wilted Willow Trees in Cell 6 (Dead Leaves on Blackened Branch inset) (June 2008)

A chart detailing alterations in irrigation rates and changes to media material in the treatment units during phase 2 operations is presented in Table 6.6.

The application rates and flow sequences for Phase 2 Plant Operations are detailed in Tables 6.7 and 6.8.

Table 6.6 Chart Detailing Phase 2 Operations

Time Period of Plant Operation: Phase 2: November 2007 – July 2008

		Phase 2								
		Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08
	Month of Operation	5	6	7	8	9	10	11	12	13
Treatment Unit	Medium	HLR (l/m^2/day)								
Cell 1	Compost (coarse)	945	945	945	945	945	1408	1408	1205	1205
Cell 2	Willows in Compost	945	945	945	945	945	1408	1408	1205	OFF
Cell 3	Sand & Compost (fine)/ Timber Chip	945	OFF	OFF	OFF	945	945	Timber Chip 945	945	945
Cell 4	Compost (fine)	945	OFF	945	945	709	945	945	945	945
Cell 5	Sand/Grit/Gravel	189	189	189	189	189	189	95	95	OFF
Cell 6	Willows in Subsoil	472	472	472	472	472	472	236	236	OFF
Cell 7	Subsoil	945	945	945	945	472	472	472	472	472
Cell 8	Mixed Soil/Sand/Compost	OFF	OFF	OFF	OFF	472	472	472	236	236
Cell 9	Coarse Compost & Timber Chip						945	945	945	945
Cell 10	Compost (coarse)	945	945	945	945	945	945	945	945	945
VF 1	*Phragmites* in Sand/Grit/Gravel Matrix	192	192	192	192	192	192	192	192	192
VF 2	*Typha* in Sand/Grit/Gravel Matrix	192	192	192	192	192	192	192	192	192
HF 1	*Sparganium* in Subsoil	192	192	192	192	192	192	192	192	192
HF 2	*Sparganium* in Gravel	192	192	192	192	192	192	192	192	192

Note: Grey shaded = Unit operational
OFF = Unit switched off
Cross over between Phases 1 and 2 in November 2007
Cell 3 media change to Timber Chippings in May 2008

Table 6.7 Phase 2 Pulse Times and Dosing Volumes (Nov 2007 – July 2008)

Cell No. and Detail	Pulse Frequency and Volume Delivery	Volume per Day litres/unit/day	Hydraulic Loading Rate litres/m^2/day
Cell 7* Subsoil	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 8* Mixed Soil / Sand / Compost	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	427.5 litres /m^2/day
Cell 1(1) Compost (coarse grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 10(1) Compost (coarse grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
VF 1(1) Vertical Flow Reed Bed 1	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	96 litres /m^2/day
VF 2(1) Vertical Flow Reed Bed 2	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	96 litres /m^2/day
HF 1(1) Horizontal Flow Reed Bed 1	Secondary effluent from VF 1 via gravity flow	2400l/unit/day	96 litres /m^2/day
HF 2(1) Horizontal Flow Reed Bed 2	Secondary effluent from VF 2 via gravity flow	2400l/unit/day	96 litres /m^2/day
Cell 2(2) Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 9(3) Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 3(4) Timber Chippings	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 4(4) Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 5(4) Stratified Sand, Grit, Gravel	12 pulses per day (every 2 hours) 20 l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 7(4) Subsoil	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	472.5 litres /m^2/day
Cell 6(5) Willow Trees (x 2) planted in Sub-Soil	12 pulses per day (every 2 hours) 100 l per pulse	600l/unit/day	236 litres /m^2/day
Cell 8(5) Mixed Soil / Sand / Compost	12 pulses per day (every 2 hours) 50 l per pulse	600l/unit/day	236 litres /m^2/day

Note: (1) – (5) Time Series (commencement of (new) dosing volumes to units)

* No Change from Phase 1 Plant Operations

(1) November 2007 (3) April 2008 (5) June 2008

(2) March 2008 (4) May 2008

Table 6.8 Phase 2 Flow Sequence to Treatment Units (Nov 2007 – July 2008)

Time Series	Flow Sequence to Treatment Units
1	Raw Leachate → Cell 1 → VF 2 → HF 2
1	Raw Leachate → Cell 10 → VF 1→ HF 1
2	Raw Leachate → Cell 1 → Cell 2 → VF 2 → HF 2
3	Raw Leachate → Cell 9 → Cell 10 → VF 1→ HF 1
4	Raw Leachate → Cell 1 → Cell 2 → Cell 4 → VF 2 → HF 2
4	Raw Leachate → Cell 3*
5	Raw Leachate → Cell 6
6	Raw Leachate → Cell 1 → Cell 4 → VF 2 → HF 2
	Raw Leachate → Cell 7**
	Raw Leachate → Cell 8**

Note: * Original media in Cell 3 replaced with timber chippings

** No change from previous settings in Phase 1 Plant Operations

Cell 2 and Cell 6 turned off in July 2008

Time Series (commencement of dosing to units)

1 November 2007
2 March 2008
3 April 2008
4 May 2008
5 June 2008
6 July 2008

6.4 **Phase 3 Plant Operations** (August 2008 – November 2008)

6.4.1 Introduction

Phase 3 plant operations involved carrying out some minor adjustments to the system in terms of effluent dosing volumes to units as well as switching flow sequences.

6.4.2 Switch Off of Horizontal Flow Reed Bed 1

Flows to HF 1 were suspended in August 2008 due to a reduction in medium permeability. Leachate flow through the unit had ceased altogether resulting in surface ponding and over topping of the reed bed containment bunds. A thick algal growth had developed on the stagnant surface water, which began to impair reed growth within the unit.

It took over a month for the unit to drain sufficiently to allow for removal of the algal mat, which on drying out was approximately 10mm thick.

Since commencement of operations, this unit had not removed pollutants from the influent wastewater stream to any great degree. Further use and analysis of the horizontal flow reed bed as a treatment unit was no longer deemed a priority in light of the time and resources available. The unit was switched off, but would be revisited later on as detailed in Phase 4 Plant Operations.

6.4.3 Switch Off of Cell 7 and Cell 8

Cells 7 and 8 were also turned off (October 2008) for much the same reasons as explained above in 6.4.2; i.e. media fouling, unit flooding and poor pollutant removal rate results. The units would be resurrected later in Phase 4 Plant Operations.

6.4.4 Invasive Species in Vertical Flow Reed Bed 2

The vertical flow reed bed containing *Typha sp.* had become overgrown by grasses and invasive weeds in late July – August 2008. On closer inspection of the reed bed, it was noted that one invasive species in particular was predominant. This was identified as *Atriplex hastata* during a site visit by Dr Pádraig Whelan from the Department of Plant Science, University College Cork. *Atriplex hastata* is a salt tolerant, halophyte species that grows predominantly on the foreshore area and can also be found on disturbed soil in

waste ground (Plants For A Future, 1996-2008). It can accumulate high concentrations of NaCl in the plant tissue and continue to function optimally (Ungar, 1991).

On July 30th and 31st, 2008 the author set about clearing all grasses and invasive weeds from the reed bed as they were beginning to inhibit fresh growth of the reeds. A selection of the *Atriplex hastata* plants was carefully transplanted to Cell 5. It was hoped that the halophyte species would uptake nitrate from the wastewater stream while tolerating high fluxes in chloride levels. The plants were sown in clusters of four plants per $10cm^2$ within the sand/grit media of Cell 5 (1000 plants in total).

The extent of cover of the invasive species can be seen in Figure 6.8.



Figure 6.8 Extent of Weed Cover in VF 2 (July 2008)
Close up of *Atriplex hastata* inset top left

6.4.5 Changes to Flow Sequences

During Phase 3 Plant Operations, the following changes to flow sequences were made:

Cells 3 and 5

Cells 3 and 5 were connected up in series (August 2008) and treated effluent from Cell 3 was dosed to Cell 5, which had been planted with *Atriplex hastata*. It was hoped that the *Atriplex* plants would utilise a proportion of the nitrate within the (nitrified) leachate effluent from Cell 3 (containing timber chippings). The application rate to each cell was reduced to 240l per day (94L/m^2/day). Dosing between the cells commenced in August with some promising results. A further addition to the set up was made in October 2008 when HF 2 was added to the sequence to provide tertiary treatment for a two-week trial period.

Vertical Flow Reed Beds 1 and 2

Following clearance of the grass and invasive species from VF 2, the pump sump feeding the reed bed was repositioned to allow effluent flow from VF 1 to fill the (VF 2) dosing pump sump. During this period, effluent was treated in series between five units, namely; Raw → Cell 9 → Cell 10 → VF 1→ VF 2 → HF 2. Results from analysis of leachate samples from this sequence displayed a high degree of pollutant treatment efficiency.

Cells 1 and 4

Since Cell 2 had been turned off in July 2008, Cells 1 and 4 were now directly connected. Dosing volumes to the units was halved in October 2008 to 1200l per day (472L/m^2/day) with an application rate of 100l per pulse every two hours. It was hoped that the lower application rate would result in greater treatment efficiencies.

A chart detailing alterations in irrigation rates and changes to media material in the treatment units during phase 3 operations is presented in Table 6.9.

The application rates and flow sequences for Phase 3 Plant Operations are detailed in Tables 6.10 and 6.11.

Table 6.9 Chart Detailing Phase 3 Operations

Time Period of Plant Operation: Phase 3: August - November 2008

		Phase 3			
		Aug-08	Sep-08	Oct-08	Nov-08
	Month of Operation	14	15	16	17
Treatment Unit	Medium	HLR (l/m^2/day)			
Cell 1	Compost (coarse)	1205	1205	472	472
Cell 2	Willows in Compost	OFF	OFF	189	189
Cell 3	Timber Chip	95	95	95	95
Cell 4	Compost (fine)	945	945	472	472
Cell 5	Sand/Grit/Gravel	95	95	95	95
Cell 6	Willows in Subsoil	OFF	95	95	95
Cell 7	Subsoil	472	472	OFF	OFF
Cell 8	Mixed Soil/Sand/Compost	236	236	OFF	OFF
Cell 9	Coarse Compost & Timber Chip	945	945	945	945
Cell 10	Compost (coarse)	945	945	945	945
VF 1	*Phragmites* in Sand/Grit/Gravel Matrix	96	96	96	96
VF 2	*Typha* in Sand/Grit/Gravel Matrix	96	96	96	96
HF 1	*Sparganium in Subsoil*	OFF	OFF	OFF	OFF
HF 2	*Sparganium in Gravel*	96	96	96	96

Note: Grey shaded = Unit operational
OFF = Unit switched off

Table 6.10 Phase 3 Pulse Times and Dosing Volumes (August 2008 – Nov 2008)

Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume / Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 7* Subsoil	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	472.5 litres /m^2/day
Cell 8* Mixed Soil / Sand / Compost	12 pulses per day (every 2 hours) 50 l per pulse	600l/unit/day	236 litres /m^2/day
Cell 1(1) Compost (coarse grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 3(1) Timber Chippings	12 pulses per day (every 2 hours) 20 l per pulse	240l/ unit/day	94.5 litres /m^2/day
Cell 4(1) Compost (fine grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres /m^2/day
Cell 5(1) Stratified Sand, Grit, Gravel	12 pulses per day (every 2 hours) 20 l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 9(1) Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 10(1) Compost (coarse grade)	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	945 litres/m^2/day
VF 1(1) Vertical Flow Reed Bed 1	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	96 litres/m^2/day
VF 2(1) Vertical Flow Reed Bed 2	12 pulses per day (every 2 hours) 200 l per pulse	2400l/unit/day	96 litres/m^2/day
HF 1(1) Horizontal Flow Reed Bed 1	Switched off in August 2008		
HF 2(1) Horizontal Flow Reed Bed 2	Secondary effluent from VF 2 via gravity flow	2400l/unit/day	96 litres/m^2/day
Cell 2(2) Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 20 l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 6(2) Willow Trees (x 2) planted in subsoil	12 pulses per day (every 2 hours) 20 l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 2(3) Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 40 l per pulse	480l/unit/day	189 litres/m^2/day
Cell 1(3) Compost (coarse grade)	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	472.5 litres/m^2/day
Cell 4(3) Compost (fine grade)	12 pulses per day (every 2 hours) 100 l per pulse	1200l/unit/day	472.5 litres/m^2/day
HF 2(3) Horizontal Flow Reed Bed 2	Gravity Flow from Cell 5	240l/unit/day	9.6 litres/m^2/day

Note: (1) – (3) Time Series (commencement of (new) dosing volumes to units)

* No change from previous settings in Phase 2 Plant Operations
(1) August 2008
(2) September 2008
(3) October 2008
Switch in flow to HF 2 was for a two week trial only

Table 6.11 Phase 3 Flow Sequence to Treatment Units (August 2008 – Nov 2008)

Time Series	Flow Sequence to Treatment Units
1	Raw Leachate → Cell 3 → Cell 5
1	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2→ HF 2
1	Raw Leachate → Cell 1 → Cell 4
2	Raw Leachate → Cell 2*
2	Raw Leachate → Cell 6*
3	Raw Leachate → Cell 3 → Cell 5 → HF 2
3	Raw Leachate → Cell 3 → Cell 5
3	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2→ HF 2
	Raw Leachate → Cell 7**
	Raw Leachate → Cell 8**
Note: * Cells 2 and 6 turned on – no samples retrieved due to continued fouling of the treatment medium **Cell 7 and Cell 8 turned off in October 2008	
Time Series (commencement of dosing to units) 1 August 2008 2 September 2008 3 October 2008	

6.4.6 Power Failure to Plant

On 15th November 2008, engineering contractors engaged in restoration capping works elsewhere on site accidently severed a number of electricity cables. These cables were supplying power both to the main leachate treatment plant on site and to the trial treatment plant. Due to the complex nature of the repairs required, both treatment plants were out of operation for two weeks. During this down time, routine maintenance was carried out on the trial plant. This entailed cleaning filters to pump sumps, maintaining flow integrity of feed lines as well as turning over and aerating the top surface of the media in a number of units.

Power was restored on 27th November and normal operations were resumed.

6.5 **Phase 4 Plant Operations** (December 2008 – October 2010)

6.5.1 Introduction

Phase 4 plant operations encompassed the main body of work carried out during the trial treatment project. Laboratory analysis and results for nitrification and removal rates achieved for a range of other parameters influenced the scope of work for Phase 4 operations. New media were trialled, further adjustment to flow rates and sequencing between units was carried out as well as extensive experimentation with denitrification and nitrogen removal methods.

6.5.2 New Media

Vegetated Grass Planes

Horizontal Flow Reed Beds 1 and 2 were converted to Vegetated Grass Planes (VP 1 and VP 2) in April 2009. The HF reed beds had not performed to expectations and were no longer useful as treatment units.

The reeds and media were dug out and replaced with a sand-grit-gravel matrix fining upwards and planted with a seed mix of salt tolerant grasses (Proturf – Coastal/Saline Mix) typically used on golf links courses.

The vegetated grass planes were dosed much the same way as the vertical flow reed beds. Using a time control switch and submersible pump set in a 250 litre sump, leachate was delivered to the vegetated grass planes via 3 no. ∅ 25mm pipe laterals each with 5 no. evenly spaced 4mm orifices along each lateral. Each spray jet was directed onto a concrete paving slab (200mm x 200mm) to avoid pitting of the sand layer. This helped achieve an even spread of the leachate across the surface area of the vegetated grass plane during each dosing phase.

The pump sumps were positioned so that VP 1 and VP 2 could operate in series or in parallel. For the first run (May 2009) the units were operated in series providing sequential treatment across six treatment units namely; Raw Leachate – Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2.

The media in each Vegetated Grass Plane (VP 1 and VP 2) is detailed in Table 6.12 and the grass species sown in each unit are outlined in Table 6.13.

Table 6.12 Media in Vegetated Grass Plane (VP 1 and VP 2)

VP 1			VP 2		
Unit	Detail	Depth	Unit	Detail	Depth
1	Sand (sharp)	200 mm	1	Sand (sharp)	200 mm
2	Ø 6mm Gravel	500 mm	2	Ø 6mm Gravel	200 mm
3	Ø 10mm Gravel	200mm	3	Ø 10mm Gravel	500 mm

Table 6.13 Grass Species Sown in VP 1 and VP 2

Proturf Coastal/Saline Mix	
Species	*Content %*
Dwarf Perennial – BRIGHTSTAR SLT	20.56
Strong Creeper – BARUSTIC	30.84
Slender Creeper - CEZANNE	20.56
Tall Fescue – COCHISE	25.70
Agrostis palustris – SEASIDE II	2.33

Cells 7 and 8

The contents of Cell 7 (subsoil) and Cell 8 (mixed soil; sand; compost) were removed in May 2009. The cells had become ineffectual as treatment units due to persistent surface ponding caused by media siltation and compaction.

Each unit was filled with medium grade timber chippings to a depth of 800mm (as per Cell 3). The leachate application rate was adjusted to 2400l per day (945L/m^2/day; 12 pulses per day at 200l per pulse) and the units were set to run in series (Raw - Cell 7 – Cell 8).

Cell 10

After 20 months of operation, the compost medium in Cell 10 began to breakdown and humify. This led to problems with compaction of the medium and surface ponding and it was decided in June 2009 to replace the compost with a timber chip – compost mix (as per Cell 9). The unit was out of operation for a week after which it was reconnected to the original flow sequence at the same application rate.

Cells 2 and 6

Cell 2 (willow trees in compost) and cell 6 (willow trees in subsoil) were switched off permanently in June 2009. Neither unit had recovered from the salt stressing episode and tree dieback in June 2008. It was decided that time and resources could be better utilised elsewhere and the units were abandoned.

6.5.3 Denitrification Trials

6.5.3.1 Introduction

Denitrification trails commenced in December 2008. A good deal of knowledge and experience had been built up at this point in time regarding nitrification of ammonium (one of the main pollutants of concern) within the various treatment units. It was now time to assess if denitrification could be achieved through the installation of additional process units.

6.5.3.2 Denitrification Trials # 1

Two denitrification units (two IBCs) were set up in series and placed immediately downstream of HF 2 (*Sparganium* in gravel). HF 2 was at the time receiving effluent from VF 2 (vertical flow reed bed, *Typha* in sand/gravel).

Each denitrification unit (N1 and N2) had an operating capacity of 868l and received effluent from the flow sequence Raw → Cell 9 → Cell 10 → VF 1 → VF 2 → HF 2. Denitrification unit 1 (N1) was gravity fed with a carbon source (sugar water) on a continuous basis from a 2000l feed tank (2 x $1m^3$ IBC) at a rate of 60ml per minute (86.4 litres per day) (see Figure 6.9). The aim of dosing N1 with a carbon was to assist in cell growth and metabolic processes that would remove free oxygen from the system. This

would result in an oxygen deficient environment whereby bacteria would be encouraged to consume nitrate (Traut, 2007).

The effluent flow rate to N1 and N2 was initially set at 2400 l per day giving a residence time of approximately 8 hours per unit. The first set of results for denitrification rates within N1 and N2 were very promising. However, problems arose following a stint of cold weather in late December 2008 and early January 2009. The surface water in HF 2 froze for a number of days and some pipes and valves burst. On thawing, there were difficulties in maintaining levels within HF 2 and flows to N1 and N2 were sporadic. In late January, due to continuing difficulties in maintaining levels in the reed bed, HF 2 was by-passed and N1 and N2 connected directly to VF 2. Flow to the system was halved to 1200l per day to increase residence time in N1 and N2 in an attempt to increase denitrification rates.

Despite these efforts, the denitrification system did not recover and analysis of the effluent from N1 and N2 recorded only one instance of reduction in nitrate levels in the subsequent months. The denitrification units were turned off in May 2009 and a new strategy was considered.

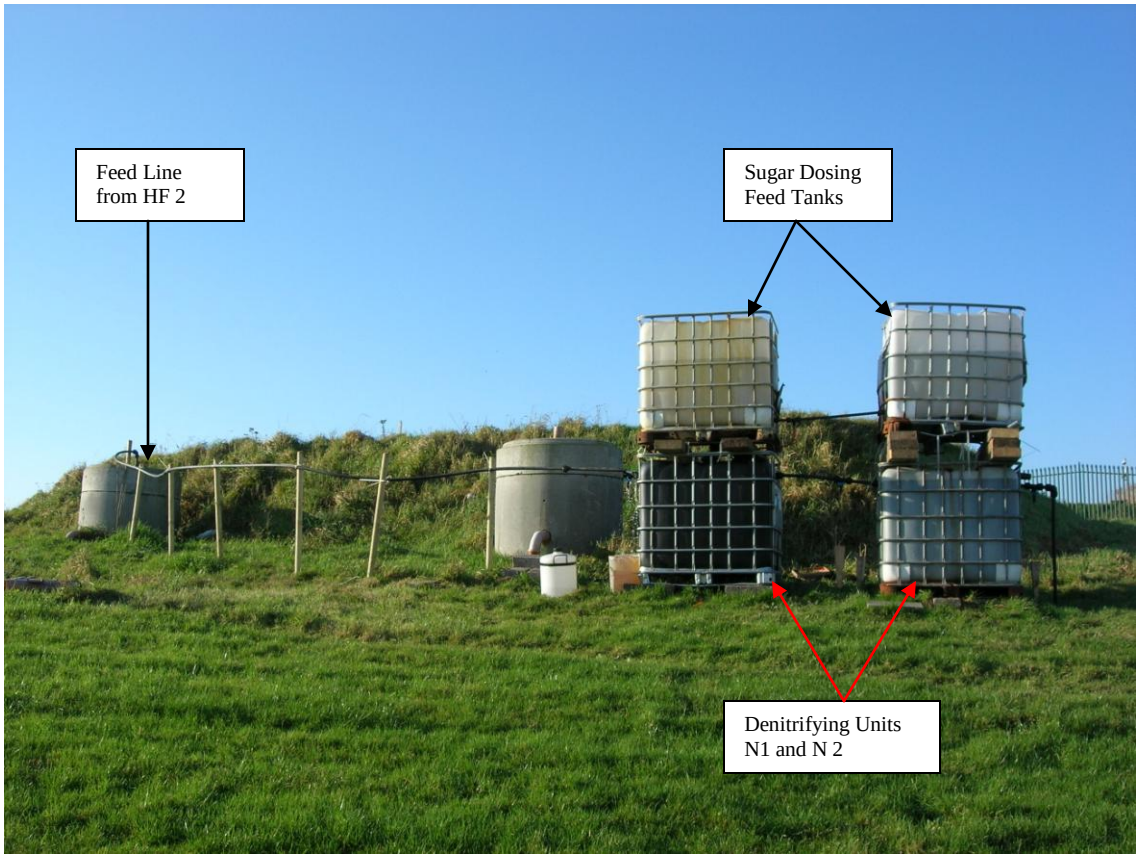


Figure 6.9 Unit Set Up for Denitrification Trials # 1

6.5.3.3 Denitrification Trials # 2

The second attempt at denitrification involved placing four denitrification units (Intermediate Bulk Containers (IBCs)) in series at the base of the system inside the compound of the main leachate treatment plant for the landfill site. IBCs had previously been used in the project as gravel filters for sediment straining from the leachate.

Each IBC had a capacity of 1000 l, was light weight (50 kg approx.), measured 1000 x 1200 x 1160 (width/depth/height) and composed of LLDPE material. The units were slightly modified; holes were bored at the top of each IBC to accommodate a Ø 25mm inlet and outlet pipe; and connected up in series.

Each denitrification unit (N1, N2, N3 and N4) had an operating capacity of 868 litres and received effluent from the flow sequence Raw → Cell 9 → Cell 10 → VF 1 → VF 2 → VP 1 → VP 2.

The denitrification system was an experimental design and IBCs were utilised as they were readily available, relatively inexpensive (€100 per unit) and could be easily reconfigured for pipe attachments. It was felt that four units in series would provide adequate residence time for denitrification to occur.

Commencing in September 2009, denitrification unit 1 (N1) was dosed intermittently (via dosing pump and time control switch) with a carbon source from a $10m^3$ feed tank at a rate of 1.19l per hour (28.56 litres per day). The effluent flow to the denitrification units was by gravity. A fall between each succeeding denitrification unit was engineered so that flow from N1 to N4 was also by gravity.

The flow rate to the denitrification units was set at 2400l per day giving a residence time of approximately 8 hours per unit.

The carbon source utilised in this instance was Sorbitol®, which is a sugar substitute used in the pharmaceutical industry for the production of sugar free tablets. It is easily dissolved in cold water (unlike sugar) and is available in powder form. One tonne of Sorbitol was dissolved in $10m^3$ of cold water in the feed tank (also located within the main leachate treatment plant) and dosed intermittently to N1.

The denitrification system was not inoculated or pre-seeded with denitrifying bacteria during the trial.

Results for denitrification rates within N1, N2, N3 and N4 during the period September to December 2009 were disappointing. Despite the fact that a dissolved oxygen level within the denitrification units of 0.5 mg/l was maintained, nitrate reduction was not taking place. The process was again hindered by very low temperatures during November 2009 to January 2010. Due to a continuance of the cold spell between 22nd December 2009 and 21st January 2010; where night-time temperatures remained below freezing; the entire trial treatment plant was switched off and units were drained in order to preserve the integrity of pipework, valves and to prevent frost heave damage.

On recommencement of plant operations on 22nd January 2010, the denitrification units remained off while minor adjustments and maintenance activities were carried out.

In April 2010 the dosing pump delivering carbon (Sorbitol) to the system was replaced with a metering pump ("K" Series, KCL Model) specifically designed for low volume dosing of chemicals. The control mechanism allowed for stroke speed (frequency) and stroke length adjustment, which provided a greater degree of accuracy over the previously installed *Vigila 100M* model with respect to dosing volumes. The Sorbitol dosing rate to reactor N1 was set at 520ml per hour (12.48 litres day at 121.5g/l COD concentration in the feedstock tank) to achieve a COD concentration of 632mg/l in the vessel (excluding influent COD in treated leachate). The aim was to achieve a COD/N ratio of between two and three. Successful denitrification trials using sugar or similar substitutes have been described elsewhere in literature at COD/N rations of between 6.5 and 5.5 (Fernandez-Nava *et al*., 2010) and 3.8 (Lee *et al*., 1996).

It was hoped that sludge production could be minimised in this project by applying a lower COD/N ratio using Sorbitol as the carbon source.

Phosphorus (P) was also added to the system as this was deemed to be the limiting factor in achieving denitrification. 25kg of Di-Potassium Phosphate (K_2HPO_4) at 17% P concentration was added to 1000 litres of water in an IBC to give a P concentration of 425mg/l in the feedstock dosing tank. Using a K" Series, KCL Model dosing pump, both P and Sorbitol were intermittently dosed to N1. Phosphate (as P) was dosed to N1 at a rate of 100ml per hour to maintain a steady state P concentration of 5 mg/l in the vessel.

Corrugated land drain pipes were placed in three of the units (N1, N2 and N3) to provide surface area for denitrifying bacteria to attach. Hitherto one of the main problems with the denitrification system was the buildup of biomass sludge and adherence to pipework and vessel walls. In total over 121m^2 of surface area was created within the three units, 48m^2 in N1, 36m^2 in N2 and 37m^2 in N3. It was anticipated that the increased surface area available for attached growth would extend wastewater – denitrifier contact time and reduce the buildup of solids around the inlet and out pipes.

To help prevent further damage to the system from freeze – thaw action, each IBC unit was insulated with 'ThermaWrap', a loft insulating material consisting of 4mm thick plastic bubble wrap coated on each side with high reflective aluminium foil. The material is available in rolls of 1m x 7m and the easy handling made it ideal for covering the denitrification units.

The effluent flow rate to the denitrification units was again set at 2400l per day and the denitrification process was allowed to run until October 2010.

The unit set up for the denitrification trials (# 2) is outlined in Figure 6.10.



Figure 6.10 Unit Set Up for Denitrification Trials # 2

6.5.4 Nitrate Uptake Trials

6.5.4.1 Introduction

Two separate methods to facilitate nitrate uptake through plant growth were trialled. The first involved the use of duckweed (*Lemna minor*) while the other process included the use of spray irrigation to vegetated grass planes.

6.5.4.2 Duckweed Planting

Duckweed is a small, fast growing aquatic plant that floats on the surface of ponds. It is known to uptake nitrate and phosphorus at a higher rate than any other aquatic plant (including algae). It has been used in the past as a water purifier in urban and rural settings as a bioremediator (Waterwereld, 2002 – 2009).

In December 2008, up to 40kg of duckweed was transplanted from the ponds on site (used for storm water remediation) to HF 2. The water level in the reed bed was raised 200mm above the gravel medium and the duckweed was spread evenly across the surface. At the time, the unit was receiving treated effluent from VF2 (switched from receiving effluent from Cell 5 in late October 2008) at a rate of 2400l per day. The flow sequence was as follows: Raw Leachate → Cell 9 → Cell 10 → VF 1 → VF 2 → HF 2 → N1→ N2.

Flow to the duckweed seeded HF reed bed commenced on 22nd December 2008 and continued until 27th January 2009 when HF 2 was switched off. Unfortunately, due to a combination of problems relating to freezing night-time temperatures, broken influent pipes and trouble with maintaining a steady water level within the reed bed, the nitrate uptake trials involving *Lemna minor* were unsuccessful.

6.5.4.3 Vegetated Grass Planes

Vegetated Grass Planes (VP 1 and VP 2) were set up in April 2009 replacing HF 1 and HF 2. It was anticipated that dosing the salt tolerant grass mix species with a high nitrate load would produce a lush grass growth, and coupled with regular mowing and removal of the biomass would result in significant nitrate removal rates from the effluent stream.

Dosing to VP 1 and VP 2 began in May 2009 and the flow sequence was set as follows; Raw Leachate → Cell 9 → Cell 10 → VF 1 → VF 2 → VP 1 → VP 2; at an application rate of 2400l per day to the system.

In September 2009 the denitrification units N1 – N4 were added to the sequence (Raw Leachate → Cell 9 → Cell 10 → VF 1 → VF 2 → VP 1 → VP 2 → N1 → N2 → N3 → N4). This flow sequence was maintained until June 2010 when VP 1 was altered to receive effluent from Cell 8 (timber chip unit). The application rate to the new sequence (Raw → Cell 7 (timber chip) → Cell 8 (timber chip) → VP1 (vegetated plane)) was reduced to 600 l per day (236L/m^2/day to cells, 24L/m^2/day to VP unit).

Dosing to each of the grass planes continued until October 2010.

Mowing of the vegetated grass planes began in October 2009 (it had taken almost six months for the grass to fully grow in each unit). The grass in VP 1 and VP 2 was mown using a handheld strimmer and the biomass was removed and weighed (wet weight). Two 10g samples of the freshly cut grass was oven dried at 110°C for two hours to attain the dry matter weight. Nitrate uptake was measured in terms of nitrate removal from the effluent dosed to VP1 and VP2 and expressed as nitrate uptake per square metre of treatment unit, with reference to the dry matter removal weight.

Between October 2009 and September 2010, the grass was mown in each unit on six occasions.

6.5.5 Changes to Flow Sequences

During Phase 4 Plant Operations, a number of changes were made to the flow sequences.

A chart detailing alterations in irrigation rates and changes to media material in the treatment units during phase 4 operations is presented in Table 6.14.

The application rates and flow sequences for Phase 4 Plant Operations are detailed in Tables 6.15 (a – j) and 6.16.

Table 6.14 Chart Detailing Phase 4 Operations

Time Period of Plant Operation: Phase 4: December 2008 - October 2010

		Phase 4																							
		Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09	Oct-09	Nov-09	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10
	Month of Operation	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Treatment Unit	Medium	HRL ($l/m^2/day$)																						
Cell 1	Compost (coarse)	472	236	236	236	236	236	236	236	236	236	472	472	472	472	472	472	472	472	472	472	472	472	472
Cell 2	Willows in Compost	189	236	236	945	945	945	Unit abandoned – willow trees died																
Cell 3	Timber Chip	95	95	189	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95
Cell 4	Compost (fine)	472	236	236	236	236	236	236	236	236	236	472	472	472	472	472	472	472	472	472	472	472	472	472
Cell 5	Sand/Grit/Gravel	95	95	189	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95
Cell 6	Willows in Subsoil	95	95	95	95	95	95	Unit abandoned – willow trees died																
Cell 7	Subsoil / Timber Chip	Subsoil Unit abandoned						945	945	945	945	945	945	945	945	945	945	945	945	236	236	236	236	236
Cell 8	Mixed Soil/Sand/Compost / Timber Chip	Mixed subsoil/sand/compost Unit abandoned						945	945	945	945	945	945	945	945	945	945	945	945	236	236	236	236	236
Cell 9	Coarse Compost & Timber Chip	945	945	472	472	472	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945
Cell 10	Compost (coarse) / Compost & Timber Chip	945	945	472	472	472	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945	945
VF 1	*Phragmites* in Sand/Grit/Gravel Matrix	96	96	48	48	48	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
VF 2	*Typha* in Sand/Grit/Gravel Matrix	96	96	48	48	48	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96
HF 1/VP 1	*Sparganium* in Subsoil/ Grass in Sand/Gravel	HF 1 abandoned					96	96	96	96	96	96	96	96	96	96	96	96	96	24	24	24	24	24
HF 2/VP 2	*Sparganium* in Gravel/Grass in Sand/Gravel	96	HF 2 abandoned				96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96	96

Key: Grey shaded = Unit operational

Note: Original media in Cells 7 and 8 replaced with timber chip in June 2009; Compost in Cell 10 replaced with Compost & Timber Chip Mix; HF Reed Beds (HF 1 and HF 2) replaced with Grass Planes (VP 1 and VP 2) end April 2009

Table 6.15(a) Phase 4 Pulse Times and Dosing Volumes (Continued from Phase 3 Operations)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 1* Compost (coarse grade)	12 pulses per day (every 2 hours) 100l per pulse	1200l/unit/day	472.5 litres/m^2/day
Cell 2* Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 40l per pulse	480l/unit/day	189 litres/m^2/day
Cell 3* Timber Chippings	12 pulses per day (every 2 hours) 20l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 4* Compost (fine grade)	12 pulses per day (every 2 hours) 100l per pulse	1200l/unit/day	472.5 litres/m^2/day
Cell 5* Stratified Sand, Grit, Gravel	12 pulses per day (every 2 hours) 20l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 6* Willow Trees (x 2) planted in subsoil	12 pulses per day (every 2 hours) 20l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 9* Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 10* Compost (coarse grade)	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
VF 1* Vertical Flow Reed Bed 1	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VF 2* Vertical Flow Reed Bed 2	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
HF 2* Horizontal Flow Reed Bed 2	Gravity flow from VF 2	2400l/unit/day	96 litres/m^2/day

Table 6.15(b) Phase 4 Pulse Times and Dosing Volumes (December 2008)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume / Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
N1(1) Denitrifying Unit 1	Gravity flow from HF 2	2400l/unit/day	8 hours Residence Time
N2(1) Denitrifying Unit 1	Gravity flow from N2	2400l/unit/day	8 hours Residence Time

Table 6.15(c) Phase 4 Pulse Times and Dosing Volumes (January 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume / Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 1[2] Compost (coarse grade)	12 pulses per day (every 2 hours) 50l per pulse	600l/unit/day	236 litres/m^2/day
Cell 2[2] Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 50l per pulse	600l/unit/day	236 litres/m^2/day
Cell 4[2] Compost (fine grade)	12 pulses per day (every 2 hours) 50l per pulse	600l/unit/day	236 litres/m^2/day
HF 2[2] Horizontal Flow Reed Bed 2	Off		

Table 6.15(d) Phase 4 Pulse Times and Dosing Volumes (February 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume / Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 9[3] Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 100l per pulse	1200l/unit/day	472.5 litres/m^2/day
Cell 10[3] Compost (coarse grade)	12 pulses per day (every 2 hours) 100l per pulse	1200l/unit/day	472.5 litres/m^2/day
VF 1 [3] Vertical Flow Reed Bed 1	12 pulses per day (every 2 hours) 100l per pulse	1200l/unit/day	48 litres/m^2/day
VF 2 [3] Vertical Flow Reed Bed 2	12 pulses per day (every 2 hours) 100l per pulse	1200l/unit/day	48 litres/m^2/day
N1[3] Denitrifying Unit 1	Gravity flow from VF 2	1200l/unit/day	16 hours Residence Time
N2[3] Denitrifying Unit 1	Gravity flow from N2	1200l/unit/day	16 hours Residence Time
Cell 3[3] Timber Chippings	12 pulses per day (every 2 hours) 40 l per pulse	480l/unit/day	189 litres/m^2/day
Cell 5[3] Stratified Sand, Grit, Gravel	12 pulses per day (every 2 hours) 40l per pulse	480l/unit/day	189 litres/m^2/day

Table 6.15(e) Phase 4 Pulse Times and Dosing Volumes (March 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 2[4] Willow Trees (x 2) planted in Compost (fine grade)	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 3[4] Timber Chippings	12 pulses per day (every 2 hours) 20l per pulse	240l/unit/day	94.5 litres/m^2/day
Cell 5[4] Stratified Sand, Grit, Gravel	12 pulses per day (every 2 hours) 20l per pulse	240l/unit/day	94.5 litres/m^2/day

Table 6.15(f) Phase 4 Pulse Times and Dosing Volumes (May 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 9[5] Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 10[5] Compost (coarse grade)	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
VF 1[5] Vertical Flow Reed Bed 1	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VF 2[5] Vertical Flow Reed Bed 2	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VP 1[5] Vegetated Plane 1	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VP 2[5] Vegetated Plane 2	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
N1[5] Denitrifying Unit 1	Off		
N2[5] Denitrifying Unit 2	Off		

Table 6.15(g) Phase 4 Pulse Times and Dosing Volumes (June 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 7[6] Timber Chippings	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 8[6] Timber Chippings	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 2[6] Willow Trees (x 2) planted in Compost (fine grade)	Off		
Cell 6[6] Willow Trees (x 2) planted in subsoil	Off		

Table 6.15h) Phase 4 Pulse Times and Dosing Volumes (September 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
N1[7] Denitrifying Unit 1	Gravity flow from VP 2	2400l/unit/day	8 hours Residence Time
N2[7] Denitrifying Unit 2	Gravity flow from N2	2400l/unit/day	8 hours Residence Time
N3[7] Denitrifying Unit 3	Gravity flow from N2	2400l/unit/day	8 hours Residence Time
N4[7] Denitrifying Unit 4	Gravity flow from N3	2400l/unit/day	8 hours Residence Time

Table 6.15(i) Phase 4 Pulse Times and Dosing Volumes (October 2009)			
Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 7[8] Timber Chippings	24 pulses per day (every hour) 100l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 8[8] Timber Chippings	24 pulses per day (every hour) 100l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 1[8] Compost (coarse grade)	24 pulses per day (every hour) 50l per pulse	1200l/unit/day	472.5 litres/m^2/day
Cell 4[8] Compost (fine grade)	24 pulses per day (every hour) 50l per pulse	1200l/unit/day	472.5 litres/m^2/day

Table 6.15(j) Phase 4 Pulse Times and Dosing Volumes (May 2010)

Cell No. and Detail	**Pulse Frequency and Volume Delivery**	**Volume per Day** litres/unit/day	**Hydraulic Loading Rate** litres/m^2/day
Cell 7[9] Timber Chippings	24 pulses per day (every hour) 25l per pulse	600l/unit/day	236 litres/m^2/day
Cell 8[9] Timber Chippings	24 pulses per day (every hour) 25l per pulse	600l/unit/day	236 litres/m^2/day
VP 1[9] Vegetated Plane 1	12 pulses per day (every 2 hours) 50l per pulse	600l/unit/day	24 litres/m^2/day

Note: [1] – [10] Time Series (commencement of (new) dosing volumes to units)

* No change from previous settings in Phase 3 Plant Operations

[1] December 2008
[2] January 2009
[3] February 2009
[4] March 2009
[5] May 2009
[6] June 2009
[7] September 2009
[8] October 2009
[9] May 2010

Cell 10 medium (compost) replaced with Compost and Timber Chippings mix in June 2009

Table 6.16 Phase 4 Flow Sequence to Treatment Units (December 2008 – October 2010)

Time Series	Flow Sequence to Treatment Units
P 3	Raw Leachate → Cell 2*
P 3	Raw Leachate → Cell 6*
P 3	Raw Leachate → Cell 1 → Cell 4
1	Raw Leachate → Cell 3 → Cell 5
1	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → HF 2 → N1 → N2
2	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → N1** → N2**
3	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → VP 1 → VP 2
4	Raw Leachate → Cell 7 → Cell 8
5	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → VP 1 → VP 2 → N1 → N2 → N3 → N4
6	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → VP 1 → VP 2
7	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → VP 1 → VP 2 → N1 → N2 → N3 → N4
8	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → VP 2 → N1 → N2 → N3 → N4
8	Raw Leachate → Cell 7 → Cell 8 → VP 1

Note: * Cells 2 and 6 turned off in June 2009

** N1 and N2 (Denitrification Trials # 1) turned off in May 2009

Time Series (commencement of dosing to units)

P 3 Continuance from Phase 3 Plant Operations
1 December 2008
2 January 2009
3 May 2009
4 June 2009
5 September 2009
6 January 2010
7 May 2010
8 End May 2010

6.5.6 Trouble Shooting – Phase 4 Plant Operations

6.5.6.1 Introduction

During the period December 2008 to October 2010 the author carried out a series of trouble shooting exercises on the treatment units relating to problems of reduced media permeability, clearing of invasive species to reed beds, dealing with pipe breakages due to freeze-thaw action as well as biomass buildup in denitrifying units.

6.5.6.2 Invasive Species in Vertical Flow Reed Bed 2

The surface medium in VF 2 containing *Typha sp.* required weeding and clearing early in the growing season in 2009 and 2010. During this period, grasses were the main invasive species. Removing the grasses was an onerous task, taking approximately one day to clear the $25m^2$ area of the reed bed. However, this provided the opportunity for the new reed shoots to flourish.

6.5.6.3 Freezing Temperatures

The plant had to be shut down entirely on two occasions during phase 4 plant operations due to freezing temperatures. In early January 2009, the plant was turned off for four days during a cold snap and in December 2009, all units were shut down for one month during a prolonged period of extremely cold night-time temperatures.

On each occasion, all units and pump sumps were drained of any residual liquid and all pipes and valve fittings were loosened and cleared of any standing water. Taking such precautions helped prevent damage to infrastructure due to freeze–thaw action.

6.5.6.4 Biomass Buildup in Denitrification Units

Biomass buildup in the denitrification units N1 to N4 became an increasing problem as denitrifying trials progressed. Sludge buildup in the influent and effluent pipes in particular was causing difficulties, impeding flow between the units and causing a drop in nitrate removal rates. De-sludging and clearance of pipes had become a weekly exercise by May 2010.

6.6 **Phase 5 Plant Operations** (October 2011 - December 2011)

6.6.1 Introduction

Trial plant operations and sample analysis were completed in October 2010. The plant had been in operation for over three years and it was decided that sufficient data had been collected.

However in June 2011, an opportunity arose whereby an Erasmus Ph.D. exchange student from the Czech Republic had requested some practical work experience as part of a four month exchange programme (October – December 2011) with the Department of Geology, University College Cork.

The author and the project supervisor put together a work experience programme for the visiting student based on microbiological analysis (*E. coli* and total coliforms) of the leachate from the trial treatment plant. This was an area of leachate analysis that had not been investigated during the course of the project.

To this end, trial plant operations were reinitiated in June 2011. The plant had been idle for eight months and required some maintenance prior to switch on. Cells 9, 10, VF 1, VF 2, VP 1 and VP 2 were turned on in June (29th and 30th June 2011) and the remainder of the cells; Cell 1, 3, 5, 7 and 8; were switched on in October (13th October 2011). Cells 2, 4 and 6 remained off.

6.6.2 Bacteriological Analysis of Leachate

Sampling of leachate from the various treatment units recommenced on 10th October 2011 and was carried out weekly thereafter until 12th December 2011. Analysis of the leachate samples for the presence of *Escherichia coli* (*E. coli*) and Total Coliforms was carried out at the laboratory located at the landfill site. The author supervised and provided training for the first set of tests. All subsequent laboratory analysis was carried out by the Erasmus student.

On-site sampling was a joint effort as this required specialist knowledge of the plant.

6.6.3 Flow Sequences and Application Rates

A chart detailing alterations in irrigation rates and changes to media material in the treatment units during phase 5 operations is presented in Table 6.17.

The application rates and flow sequences for Phase 5 Plant Operations are detailed in Tables 6.18 and 6.19.

Table 6.17 Chart Detailing Phase 5 Operations

Time Period of Plant Operation: Phase 5 - Bacteriological Testing: October - December 2011

		Phase 5								
		10/10/2011	17/10/2011	24/10/2011	07/11/2011	14/11/2011	21/11/2011	28/11/2011	05/12/2011	12/12/2011
	Week of Operation	1	2	3	4	5	6	7	8	9
Treatment Unit	Medium	HLR ($l/m^2/day$)								
Cell 1	Compost (coarse)	472	472	472	472	472	472	472	472	472
Cell 3	Timber Chip	189	189	189	189	189	189	189	189	189
Cell 5	Sand/Grit/Gravel	189	189	189	189	189	189	189	189	189
Cell 7	Timber Chip	118	118	118	118	118	118	118	118	118
Cell 8	Timber Chip	118	118	118	118	118	118	118	118	118
Cell 9	Coarse Compost & Timber Chip	945	945	945	945	945	945	945	945	945
Cell 10	Coarse Compost & Timber Chip	945	945	945	945	945	945	945	945	945
VF 1	*Phragmites* in Sand/Grit/Gravel Matrix	96	96	96	96	96	96	96	96	96
VF 2	*Typha* in Sand/Grit/Gravel Matrix	96	96	96	96	96	96	96	96	96
VP 1	Grass in Sand/Gravel	96	96	96	96	96	96	96	96	96
VP 2	Grass in Sand/Gravel	96	96	96	96	96	96	96	96	96

Table 6.18 Phase 5 Pulse Times and Dosing Volumes
(29th June 2011 – 22nd December 2011)

Cell No. and Detail	Pulse Frequency and Volume Delivery	Volume per Day litres/unit/day	Hydraulic Loading Rate litres/m^2/day
Cell 9(1) Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
Cell 10(1) Compost (coarse grade) and timber chippings	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	945 litres/m^2/day
VF 1(1) Vertical Flow Reed Bed 1	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VF 2(1) Vertical Flow Reed Bed 2	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VP 1(1) Vegetated Plane 1	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
VP 2(1) Vegetated Plane 2	12 pulses per day (every 2 hours) 200l per pulse	2400l/unit/day	96 litres/m^2/day
Cell 1(2) Compost (coarse grade)	24 pulses per day (every hour) 50l per pulse	1200l/unit/day	472.5 litres/m^2/day
Cell 3(2) Timber Chippings	24 pulses per day (every hour) 20l per pulse	480l/unit/day	189 litres/m^2/day
Cell 5(2) Stratified Sand, Grit, Gravel	24 pulses per day (every hour) 20l per pulse	480l/unit/day	189 litres/m^2/day
Cell 7(2) Timber Chippings	12 pulses per day (every 2 hours) 25l per pulse	300l/unit/day	118 litres/m^2/day
Cell 8(2) Timber Chippings	12 pulses per day (every 2 hours) 25l per pulse	300l/unit/day	118 litres/m^2/day

Note: (1) – (2) Time Series (commencement of (new) dosing volumes to units)

(1) 29th June 2011
(2) 13th October 2011

Table 6.19 Phase 5 Flow Sequence to Treatment Units
(29th June 2011 – 22nd December 2011)

Time Series	Flow Sequence to Treatment Units
1	Raw Leachate → Cell 9 → Cell 10 → VF 1→ VF 2 → VP 1 → VP 2
2	Raw Leachate → Cell 1
2	Raw Leachate → Cell 3 → Cell 5
2	Raw Leachate → Cell 7 → Cell 8
Time Series (commencement of dosing to units) 1 29th June 2011 2 13th October 2011	

6.7 Phases 1 - 5 Plant Operations

The phases and timescales during which treatment units were operational over the entire period of the trial treatment project are detailed in graphical format in Table 6.20.

Table 6.20 Chart Detailing Phases 1 – 5 Plant Operations

Time Period of Plant Operation: Phase 1 - Phase 5: July 2007 - December 2011

| | | Phase 1 | | | | | Phase 2 | | | | | | | Phase 3 | | | | Phase 4 | | | | | | |

CHAPTER 7

7. LEACHATE ANALYSIS AND PHYSICAL EXAMINATION OF TREATMENT UNITS

7.1 Introduction

This chapter outlines the sampling methodology and the parameters measured in the leachate influent and effluent streams. Field-testing of the media matrix of each treatment unit is also described.

7.2 Sampling Protocol

7.2.1 Introduction

The purpose of the sampling programme was to assess the operation of the treatment units within the system regarding pollutant removal efficiencies.

Analysis of results from the sampling programme also provided information and guidance on the potential for new flow sequences between the units and on alterations to dosing volumes.

7.2.2 Sampling Frequency and Timing

Frequency

Sampling of key wastewater constituents (BOD, COD, ammonium etc.) were carried out monthly.

Sampling for metals (except for iron and manganese) and salts was carried out annually for year 1 of operation and biannually thereafter.

List I and List II substances were analysed twice during trial plant operation.

Iron and manganese were sampled monthly for the first year of operation and subsequent sampling was biannual.

Toxicity tests were sent for analysis on two occasions, June 2009 and August 2010.

Bacteriological sampling (total coliforms and *E. coli*) was weekly (for a nine week period).

Timing

Initially the monthly sampling exercise was split into two sets carried out over consecutive weeks (usually week 3 and week 4 in any given month). However, from July 2008, the monthly sampling regime was streamlined and carried out in one operation.

All sampling took place in the morning between 10.30 and 11.30 am. Depending on the number and type of samples required, the exercise usually took 30 to 40 minutes to complete.

The timing of the sampling exercise was set so that it occurred close to the halfway point between dosing pulses to each treatment unit.

In units where the pulse frequencies were every two hours, sampling took place between pulse time plus 45 minutes and pulse time plus 75 minutes (45 mins. $\leq$ Sampling $\leq$ 75 mins.).

In units where the pulse frequencies were hourly, sampling took place at pulse time plus 30 minutes.

7.2.3 Sampling Methods

7.2.3.1 Introduction

This section details the techniques employed in retrieving and storing samples from the treatment units, and the adjacent river as well as sourcing fresh leachate samples from the active waste tipping area.

7.2.3.2 Sampling Receptacles

The following receptacles were used for sample collection throughout the project:

- Standard Monthly Samples — 2 litre plastic bottle
- Metals — 200ml plastic bottle
- Mercury — 40ml sterile glass bottle with 0.5ml HNO_3 and Gold preservative
- Bacteriological Samples (Total Coliforms and *E. coli*) — 250ml sterile plastic bottle (field sample); 120ml sterile plastic bottle with Sodium-Thiosulphate preservative (in laboratory)

- Methane — 40ml sterile glass vial (field sample); 22ml sterile glass vial (in laboratory)
- VOC — 1 litre sterile glass bottle
- SVOC — 40ml sterile glass vial with Sodium-Thiosulphate preservative
- Toxicity Test — 1 litre sterile glass bottle

Prior to use, the 2 litre and 200ml plastic bottles were washed thoroughly with a non-phosphate laboratory detergent in a dishwasher (Hamo LS-650 Model) on a forty-minute cycle at 60°C. On completion of the wash cycle, the bottles were rinsed with distilled water.

All other sample bottles were sterile one-use only receptacles.

7.2.3.3 Field Sampling

All sample bottles were labelled in the laboratory prior to field sampling (date, time, sample name/number). A field sheet was completed for each sampling exercise. The following was recorded on the sample field sheets: sample number and name, time, date, sampler and analyst (name) as well as weather conditions.

The header tank and all treatment units (except for HF 1 and HF 2 / VP 1 and VP 2) were fitted with sample taps from which the effluent sample was retrieved.

HF 1 and HF 2 / VP 1 and VP 2 operated under constant gravity flow (continuously draining) and samples were retrieved from the outlet pipe at the downstream end of the units.

Effluent from the header tank and from each unit was allowed to flow for 2 minutes to purge any stagnant liquid in the sample tap. This also allowed for the discharge of solids that may have built up at the base of the unit or feed tank.

Sample bottles were first rinsed with a little of the effluent from the unit being sampled to wash out any sterile water remaining at the base of the bottle. This procedure did not apply to pre-preserved sample bottles.

The sample bottles were filled to the brim with effluent to avoid air bubbles and the cap was replaced prior to transport. Air bubbles in the sample can cause loss of volatile organic compounds as well as excessive oxygenation of samples (EPA, 2003).
Pre-preserved sample bottles were topped-up to the indicated fill-line.
On the occasion where a treatment unit did not present any sample due to media compaction coupled with decreased permeability or due to evaporation on hot days, the test sheet was labelled ‘’No Sample Available’’.

7.2.3.4 Leachate Sampling from the Active Area

Sampling of leachate generated within the active tipping area commenced in May 2009. The samples were collected from an open sump at the toe of the slope of the active area. It was not practical to purge the sump so a grab sample was retrieved using an extension rod with a sample bottle attached.

7.2.3.5 River Sampling

Samples from the Tramore River were retrieved by the author entering in to the river and sampling from midstream at mid depth (the river at its maximum depth was 700mm).
The author stood down stream and sampled into the flow of the water.
Care was taken not to disturb riverbed sediment.

7.2.3.6 Sample Storage

On completion of sample collection, the sample bottles were returned to the onsite laboratory. Temperature and electrical conductivity (EC) were recorded and the sample bottle was placed in an incubator at 20°C for one hour prior to further analysis.
Samples marked for metals analysis were preserved with nitric acid prior to placing in the incubator.
Where analysis by an external laboratory was required, samples were delivered to their destination within 6 hours of collection.

7.3 Parameters Measured

7.3.1 Introduction

Throughout the course of the project a range of chemical, biological, toxicological and bacteriological parameters were determined from the leachate and river samples collected.

7.3.2 Chemical Analysis

Chemical analysis of the leachate and river samples can be grouped in to the following categories: key wastewater constituents; metals and salts and List I and List II substances.

7.3.2.1 Key Wastewater Constituents

The following key wastewater constituents were measured:

5 Day Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Suspended Solids (SS), Chloride (Cl), Ammonium (NH_4), Nitrite (NO_2), Nitrate (NO_3) and Electrical Conductivity (EC).

7.3.2.2 Metals and Salts

The following metals and salts were measured:

Boron (B), Cadmium (Cd), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Magnesium (Mg), Manganese (Mn), Mercury (Hg), Nickel (Ni), Phosphate (measured as P), Potassium (K), Sodium (Na), Sulphate (SO_4), Zinc (Zn), Alkalinity (Alk) and Calcium (Ca).

7.3.2.3 List I and List II Substances

Background

List I and List II Substances are catalogues of chemical compounds that are classed as hazardous (List I) or have a deleterious effect (non-hazardous but requiring control) (List II) to groundwater and to the aquatic environment. The catalogue originates from the Directive on Water Pollution by Discharges of Certain Dangerous Substances (76/464/EEC) with further interpretation in the EC Groundwater Directive (80/68/EEC).

Under the directives the introduction of List I substances to groundwater was prohibited and List II substances were to be controlled to prevent pollution of groundwater.

List I

List I contains certain individual substances which belong to the following families and group of substances, selected mainly on the basis of their toxicity, persistence and bioaccumulation, with the exception of those which are biologically harmless or which are rapidly converted into substances which are biologically harmless, namely (ANNEX of Council Directive 76/464/EEC):

1. organohalogen compounds and substances which may form such compounds in the aquatic environment;
2. organophosphorus compounds;
3. organotin compounds;
4. substances in respect of which it has been proved that they possess carcinogenic properties in or via the aquatic environment;
5. mercury and its compounds;
6. cadmium and its compounds;
7. persistent mineral oils and hydrocarbons of petroleum origin, *and*
8. persistent synthetic substances which, may float, remain in suspension or sink and which interfere with any use of the water.

List II

List II substances include the following families and group of substances which have a deleterious effect on the aquatic environment (ANNEX of Council Directive 76/464/EEC):

1. Metalloids, metals and their compounds, namely:

1.1 Zinc	1.6 Selenium	1.11 Tin	1.16 Vanadium
1.2 Copper	1.7 Arsenic	1.12 Barium	1.17 Cobalt
1.3 Nickel	1.8 Antimony	1.13 Beryllium	1.18 Thallium
1.4 Chromium	1.9 Molybdenum	1.14 Boron	1.19 Tellurium
1.5 Lead	1.10 Titanium	1.15 Uranium	1.20 Silver

2. Biocides and their derivatives not appearing on List I (including pesticides);
3. Substances which have a deleterious effect on the taste and/or smell of the products for human consumption derived from the aquatic environment and compounds liable to give rise to such substances in water;
4. Toxic or persistent organic compounds of silicon, and substances which may give rise to such compounds in water, excluding those which are biologically harmless or which are rapidly converted in water into harmless substances;
5. Inorganic compounds of phosphorus and elemental phosphorus;
6. Non-persistent mineral oils and hydrocarbons of petroleum origin;
7. Cyanides, fluorides, and
8. Substances, which have an adverse effect on the oxygen balance, particularly ammonia and nitrites.

In recent literature, reference to List I and List II Substances has largely been superseded by the list of Priority Substances referred to in Annex X of the Water Framework Directive (2000/60/EC) (as amended), in Annex II of the Directive on Environmental Quality Standards (2008/105/EC) (also known as the Priority Substances Directive) and in Annex I substances as assessed by the Joint Agencies Groundwater Directive Advisory Group (JAGDAG*). However, List I and List II Substances are still referred to in waste licences issued by the EPA.

It should be noted that the catalogue of Priority Substances and other compounds listed in Annex I, Annex II and Annex X are undergoing constant revision and as new data/evidence becomes available, a substance can be re-assessed using a new assessment method developed by the Environmental Protection Agency (EPA, 2010).

Note*

JAGDAG is a UK body comprising the Environment Agency (EA), the Scottish Environment Protection Agency (SEPA), the Northern Ireland Environment Agency (NIEA), together with the Department of Environment, Food and Rural Affairs (DEFRA) and other regulators and industry representatives. The Irish Environmental Protection Agency is an invited representative to this group.

Analysis of List I and II Substances

A total of 138 compounds contained within the List I and II catalogue were analysed on two occasions (July 2009 and August 2010) by an external laboratory. The full list of compounds is detailed in Appendix 1.

7.3.3 Toxicity Testing

7.3.3.1 Introduction

The toxicity (hazard) of a substance is measured by carrying out toxicity tests on a range of test species ranging from fish, crustaceans and algae. The tests are usually short-term (acute) exposures and can be used to assess the potential hazard of a broad range of substances such as effluents, solid wastes, sediments, landfill leachates and chemicals. Substances are deemed harmful to the aquatic environment if they persist, bio-accumulate and are toxic (SATL, 2012).

Toxicity is chemical specific and organism specific i.e. different chemicals act in different ways and different organisms respond in different ways. No one species is always the most sensitive for any given set of chemicals or effluents. Therefore, when characterising a wastewater using aquatic toxicity tests, an initial toxicity screen test should be undertaken against species from different trophic levels (e.g. bacteria, plants/algae, crustacean and fish).

During the toxicity test, a group of test organisms are exposed to a series of dilutions of the test substance or mixture, under controlled conditions. On the basis of the recorded effect frequencies in the various dilutions, the effect concentrations (EC) and lethal concentration (LC) are usually calculated for the 10, 50, and 90% mortality or effect level in the population (EPA, 1998).

On completion of the test, a concentration-effect graph and calculation of an LC_{50} (Median Lethal Concentration) or EC_{50} (Median Effective Concentration) is plotted.

For reporting purposes and to avoid confusion, toxicity data are often expressed as a function of the undiluted sample. This form of expression is known as the Toxic unit (Tu) and is defined as follows (SATL, 2011(a)):

$$Tu = \frac{100}{EC_{50}}$$

Acute toxicity results have been classified into five different categories as outlined in Table 7.1.

Table 7.1 Classification of Acute Toxicity Expressed as Toxic Units

Toxic Units	Description
< 3	Non Toxic
3 - 10	Slightly Toxic
10 - 50	Toxic
50 - 100	Very Toxic
> 100	Extremely Toxic

(after SATL, 2011(b))

7.3.3.2 Toxicity Testing on Samples from the Trial Treatment Plant

During the course of the project, toxicity tests were carried out on selected samples (river, raw leachate and treated leachate) by an external laboratory (Shannon Aquatic Toxicity Laboratory) on two separate occasions (June 2009 and August 2010).

Seven samples were sent for testing in 2009 and eight in 2010. On each occasion, the following test species were used: *Daphnia magna* (freshwater crustacean (water flea)) and *Vibrio fischeri* (freshwater bacteria).

7.3.4 Bacteriological Analysis of Leachate

7.3.4.1 Introduction

There is a wide variety of microorganisms that may be found in water. These include some that are pathogenic and others that are non-pathogenic. The principal concern for microbial quality is the potential contamination by pathogens. They can be classified according to their group or family and include viruses, bacteria, protozoa, and helminth eggs or larvae. Infectious diseases caused by these pathogenic organisms are the most common and widespread health risk associated with drinking water (WHO, 2011).

Faeces are an important source of many pathogens. In general terms, the greatest microbial risks are associated with ingestion of water that is contaminated with faeces from humans or animals (Dufour *et al.,* 2012). Therefore, monitoring of microbial water quality (specifically drinking water) is the most important aspect from a public health perspective (WHO, 2012).

To determine the presence of a particular genus or species of bacteria/pathogen it is essential to create the necessary conditions (special media/incubation period) suitable only to the bacteria under investigation (Tebbutt, 1992). However, it is impractical to attempt the routine isolation of specific pathogens, as they are usually present in relatively small numbers compared with other types of microorganism. Moreover, there are many types of pathogen and each requires a unique microbiological isolation technique. The approach that has been commonly adopted is to analyse for indicator organisms that inhabit the gut in large numbers and are excreted in human and other warm-blooded animal faeces. The presence of these indicator organisms in water is evidence of faecal contamination and the presence of pathogens is a possibility. If indicator organisms are present in large numbers, the contamination is considered to be recent and/or severe (Bartram *et al*., 1996).

Total coliforms are an indicator bacteria group typically used in determining microbial water quality. The group includes thermotolerant coliforms and bacteria of faecal origin (including *Escherichia coli* (*E. coli*)), as well as some bacteria that may be isolated from environmental sources. Both total coliforms and *E. coli* shall be explained in more detail below.

7.3.4.2 Escherichia coli

Escherichia coli (*E. coli*) is a member of the family Enterobacteriaceae, and is characterised by possession of the enzymes b-galactosidase and b-glucuronidase. It grows at 44–45°C on complex media, ferments lactose and mannitol with the production of acid and gas, and produces indole from tryptophan. However, some strains can grow at 37°C but not at 44–45°C, and some do not produce gas.

A number of tests have been developed for rapid and reliable identification of the organism and these methods have been standardised at international and national levels.

Escherichia coli is abundant in human and animal faeces; in fresh faeces it may attain concentration counts of 109 per gram. It is found in sewage, treated effluents, and all natural waters and soils subject to recent faecal contamination, whether from humans, wild animals, or agricultural activity. Because animals can transmit pathogens that are infective in humans, the presence of *E. coli* or thermotolerant coliform bacteria is a definitive indicator that the water has been faecally contaminated (WHO, 1997).

7.3.4.3 Coliform Organisms (Total Coliforms)

Coliform organisms have long been recognised as a suitable microbial indicator of drinking water quality, largely because they are easy to detect and enumerate in water. The term "coliform organisms" refers to Gram-negative, rod-shaped bacteria capable of growth in the presence of bile salts or other surface-active agents with similar growth-inhibiting properties and able to ferment lactose at 35–37°C with the production of acid, gas, and aldehyde within 24–48 hours.

The coliform bacteria group is heterogeneous and includes lactose fermenting bacteria, such as *Enterobacter cloacae* and *Citrobacter freundii*, which can be found in both faeces and the environment (nutrient-rich waters, soil, decaying plant material) as well as in drinking water containing relatively high concentrations of nutrients. The group also include some species that are rarely found in faeces and yet may multiply in relatively good quality drinking water (i.e. *Serratia fonticola*, *Rahnella aquatilis* and *Buttiauxella agrestis*).

The existence both of non-faecal bacteria that fit the definitions of coliform bacteria and of lactose-negative coliform bacteria limits the applicability of this group as an indicator

of faecal pollution. Coliform bacteria should not be detectable in treated water supplies and, if found, suggest inadequate treatment, post-treatment contamination, or excessive nutrients. The coliform test can therefore be used as an indicator both of treatment efficiency and of the integrity of the distribution system. Although coliform organisms may not always be directly related to the presence of faecal contamination or pathogens in drinking water, the coliform test is still useful for monitoring the microbial quality of treated piped water supplies. If there is any doubt, especially when coliform organisms are found in the absence of thermotolerant coliforms and *E. coli*, identification to the species level or analyses for other indicator organisms may be undertaken to investigate the nature of the contamination (WHO, 1997).

7.3.4.4 Bacteriological Analysis of Samples from the Trial Treatment Plant

During the course of the project, bacteriological analysis was carried out on selected samples (river, raw leachate and treated leachate) at the onsite laboratory. Sampling and analysis was carried out over nine consecutive weeks from October-December 2011.

Total Coliforms and *E. coli* were used as indicator bacteria to assess the presence of pathogens in the effluent samples and the river water. Sampling was carried out under sterile conditions and testing was a relatively straightforward procedure using a pre-prepared test kit. Where there was a positive result for the presence of total coliforms and *E. coli*, the bacteriological count was expressed using a statistical table as Most Probable Number (MPN)/100 ml. The method of analysis is detailed in Appendix 2.

Testing for the presence of total coliforms, faecal coliforms and/or *E. coli* in leachate and storm water emissions from a landfill site would not typically form part of the suite of monitoring requirements contained in waste licences granted by the EPA. Where such tests are called for in waste licences it is usually just an annual requirement and applies to landfill sites that either discharge leachate directly to surface water post treatment (of which there is only one such facility in the Republic of Ireland), or to facilities that are within 500 m of a potable groundwater supply in use by local residents, where a baseline value is required. In these circumstances, a minimum reporting value (MRV) of 10 MPN/100ml applies (EPA, 2003). There is no requirement for bacteriological analysis of leachate or surface water emissions from the Kinsale Road Landfill Site.

7.4 Physical Analysis of Treatment Units

7.4.1 Introduction

After six months of operation, it was decided to core the media of each treatment unit. The aim of the coring was threefold:

1) to assess the depth to which an iron pan had formed in each unit;
2) to ascertain the degree to which the original media as emplaced at the start of the project had broken down/humified (specifically the compost units) or had mixed (as in the stratified sand/gravel units etc.); and
3) to analyse each stratigraphical unit from each core for the accumulation of metals.

Exploratory coring was undertaken using an open window Edelman gouge auger (Figure 7.1). This method of coring provides a relatively quick and easy way of obtaining stratigraphic data. In each cell/reed bed cores were taken by hand and described in the field using the Tröels-Smith (1955) sediment classification system.

7.4.2 Tröels-Smith Sediment Classification

The Tröels-Smith description of the sediments enables fast and objective classification of sedimentary units in the field.

The scheme adopts a three step approach involving:

(a) a description of the physical properties of the sediments within the core;

(b) a description of its constituent parts; and

(c) a brief description of the sedimentary unit.

The notes on the stratigraphy of each core are presented in the following manner (Brooks *et al*., 2005):

(a) *written description of sediments* - e.g. Sandy Silt with occasional organics

(b) *constituent parts of sediment unit* - e.g. Ag3 Gg(min)1 Th+ As++

The relative abundance of each constituent part was noted on a four point scale in which:

4 = 100% of the sediment composition

3 = 75% of the sediment composition

2 = 50% of the sediment composition

1 = 25% of the sediment composition

+ = trace

(The sum of the constituents of a sediment sample should equal 4)

Abbreviations used in describing the Sediment Composition for the Tröels-Smith Classification Scheme and a description of the Five Point Scale for Grading of Physical Properties are detailed in Tables 7.2(a) and 7.2(b).

(c) *physical properties of sediment unit* – e.g. 1 + 0 3 0 4 3

Whereby: first number = colour (+ indicates a deeper shade),

second number = degree of stratification

third number = degree of elasticity

fourth number = degree of dryness

fifth number = the sharpness of sediment boundary between adjacent units

sixth number = degree of humification

Table 7.2(a) Abbreviations used in describing the Sediment Composition for the Tröels-Smith Classification Scheme

Class	Symbol	Element	Description
Turfa	Tb	*T. bryoiphytica*	Mosses, + / - humus substance
	Tl	*T. lignosa*	Stumps, roots, intertwined rootlets of ligneous plants + / - trunks, stems, branches etc. + / - humus substance
	Th	*T. herbacea*	Roots, intertwined rootlets & rhizomes of herbaceous plants + / - stems, leaves etc. + / - humus substance
Detritus	Dl	*D. lignosus*	Fragments of ligneous plants > 2mm
	Dh	*D. herbasus*	Fragments of herbaceous plants > 2mm
	Dg	*D. granosus*	Fragments of ligneous and herbaceous plants <2mm> ca. 0.1 mm
Limus	Ld	*L. detrituosus*	Fragments of plants and animals < ca. 0.1 mm + / - humus substance
	Ls	*L. siliceus*	Diatoms, needles of sponge, siliceous skeletons etc. of organic origin < ca 0.1 mm
	Lc	*L. calcareus*	Marl < ca. 0.1 mm
	Lf	*L. ferrugineus*	Iron oxide < ca. 0.1 mm
Argilla	As	Clay	Mineral particles < 0.002 mm
	Ag	Silt	Mineral particles 0.002 mm to .6mm
Grana	Ga	Fine Sand	Fine Sand particles 0.06mm to 0.6mm
	Gs	Coarse sand	Coarse Sand particles 0.6mm to 2mm
	Gg(min)	Gravel	Fine – Medium Gravel particles 2mm to 6mm
	Gg(maj)	Gravel	Medium – Coarse Gravel particles ≥ 6mm
Substantia humosa	Sh	Humous substance	Completely disintegrated organic substances and precipitated humic acids

(after Tröels-Smith, 1955)

Table 7.2(b) Tröels-Smith Five Point Scale for Grading of Physical Properties

	Colour (Nig)	Stratification (Strf)	Elasticity (Elas)	Dryness (Sicc)	Unit Boundary (Lim)	Humification (Humo) Scale 1 - 5
0	Light Shades	Homogenous	Inelastic	Saturated	Diffuse > 10mm	N/A
1						Undecomposed
2						
3						
4	Dark Shades	Finely Laminated	Highly Elastic	Air Dry	Very Sharp < .5mm	
5	N/A	N/A	N/A	N/A	N/A	Completely Decomposed

(after Tröels-Smith, 1955)



Figure 7.1 Coring using an Open Window Edelman Gouge Auger

7.4.3 Stratigraphic Logs

The results gathered in the field from coring using the hand auger are presented below in stratigraphic column format (Figures 7.2 – 7.13 and Tables 7.3 – 7.26). The original stratigraphy as was emplaced at the start of the project is shown on the left, with the core sample retrieved in February 2008 displayed on the right.

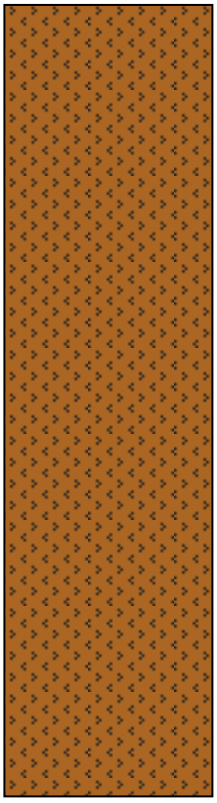
The abbreviations used in describing the sediment composition for the Tröels-Smith Classification Scheme are detailed in Table 7.2(a).

Where space does not allow for a complete description adjacent to the stratigraphic column, the data are referenced as a Unit number and explained underneath.

A photograph was taken of each core sample retrieved and of the surface cementation where it had developed on the media (Figures 7.14 – 7.27).

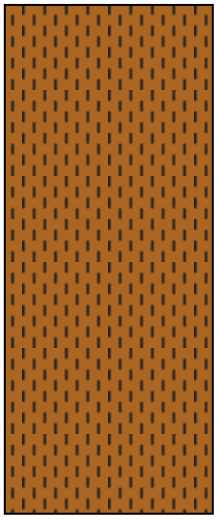
Cell 1 – Coarse Compost (100%)

Cell 1 - Original Medium (August 2007) Cell 1 – Core Sample (February 2008)



Mid-Brown
Coarse Compost
Dl2 Dh1 Tl1 Th+
3 0 2 3 N/A
Humo 2+

80 cm



Mid-Brown
Coarse Compost
Dl1 Dl1Tl1 Th1
3+ 0 2 3 N/A
Humo 3

50 cm

Figure 7.2 Stratigraphic Log for Cell 1

Table 7.3 Cell 1 Original Medium – August 2007

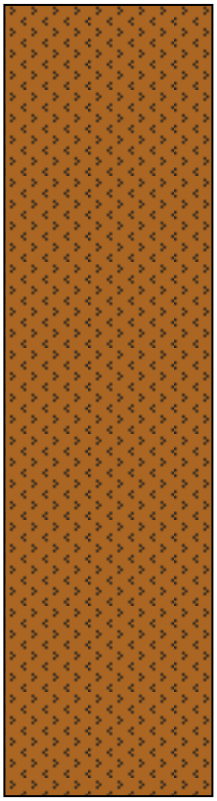
Cell 1	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Compost	Mid-Brown Coarse Compost	3	0	2	3	N/A	2+	Dl2 Dh1Tl1 Th+

Table 7.4 Cell 1 Core Sample - February 2008

Cell 1	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 50cm Compost	Mid-Brown Coarse Compost	3+	0	2	3	N/A	3+	Dl1 Dh1Tl1 Th1

Cell 2 – Willow Trees set in Coarse Compost (100%)

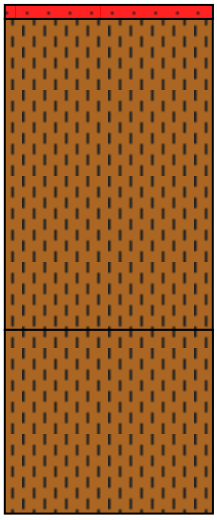
Cell 2 - Original Medium (July 2007)



Mid-Brown
Coarse Compost
Dl2 Dh1 Tl1 Th+
3 0 2 3 N/A
Humo 2+

80 cm

Cell 2 – Core Sample (February 2008)



Unit 1 – Iron Pan

Mid-Brown
Coarse Compost
Dl1 Dl1Tl1 Th1
3+ 0 2 3 3
Humo 3 - 4

28 cm

Mid-Brown
Coarse Compost
Dl1 Dl1Tl1 Th1
3+ 0 2 3 1
Humo 3+

50 cm

Figure 7.3 Stratigraphic Log for Cell 2

Table 7.5 Cell 2 Original Medium – July 2007

Cell 2	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Compost	Mid-Brown Coarse Compost	3	0	2	3	N/A	2+	Dl2 Dh1Tl1 Th+

Table 7.6 Cell 2 Core Sample – February 2008

Cell 2	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface cementing top 2 cm of compost	3	1	0	3	N/A	2+	Lf1 Dl1 DH1 Tl1 Th+
Unit 2 2 – 28cm Compost	Dark-Brown Coarse Compost / Immature Peat	3+	0	2	3	1	3	Dl1 Dh1Tl1 Th1
Unit 3 28 – 50cm Compost	Dark-Brown Coarse Compost / Immature Peat	3+	0	2	3	1	3+	Dl1 Dl1Tl1 Th1

Cell 3 – Stratified Compost, Sand, Compost, Sand (1:1:1:1)

Cell 3 – Original Media (August 2007) Cell 3 – Core Sample (February 2008)

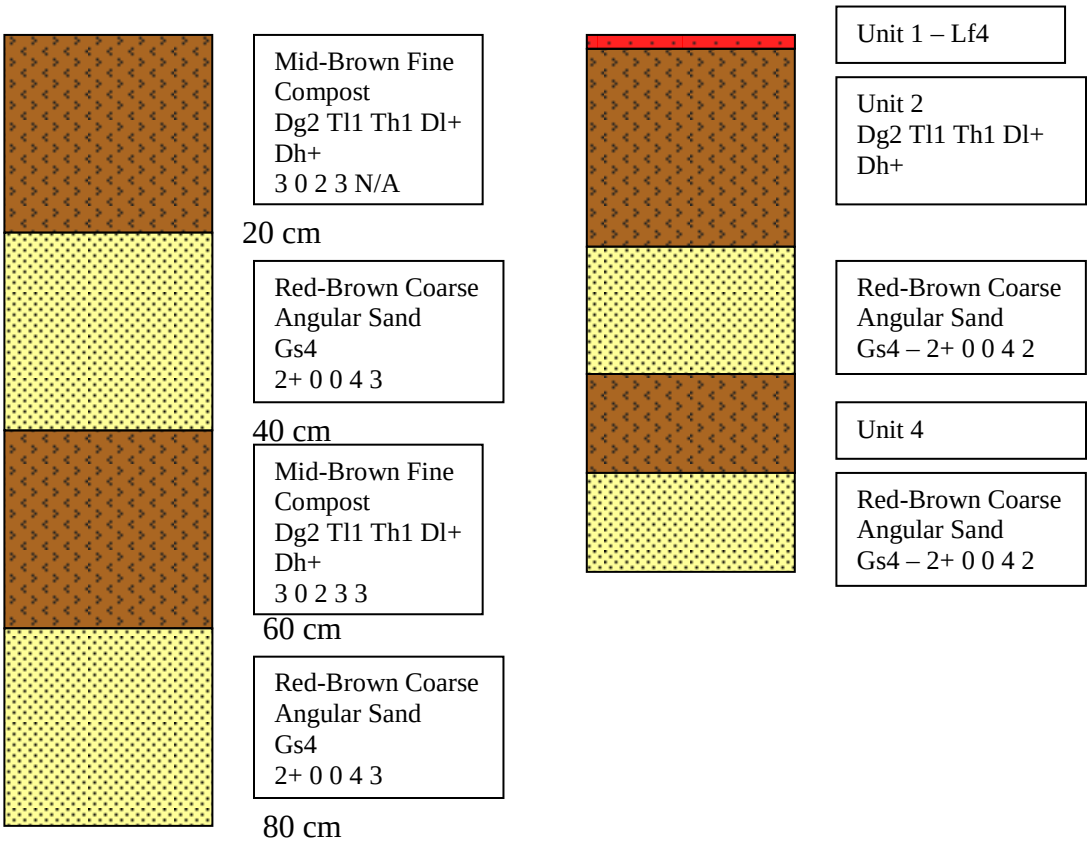


Figure 7.4 Stratigraphic Log for Cell 3

Table 7.7 Cell 3 Original Media – August 2007

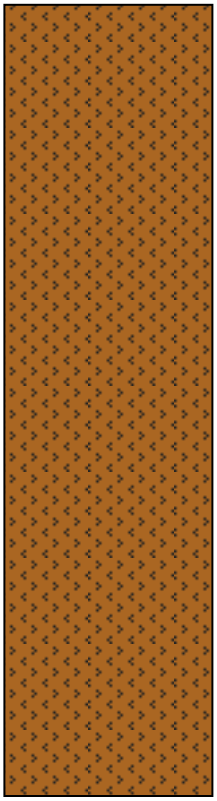
Cell 3	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 20cm Compost	Mid-Brown Fine Compost	3	0	2	3	N/A	2+	Dg2 Tl1 Th1 Dl+ Dh+
Unit 2 20 - 40cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	3	N/A	Gs4
Unit 3 40 – 60cm Compost	Mid-Brown Coarse Compost	3	0	2	3	3	2+	Dg2 Tl1 Th1 Dl+ Dh+
Unit 4 60 – 80cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	3	N/A	Gs4

Table 7.8 Cell 3 Core Sample – February 2008

Cell 3	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface binding top 2cm of compost together	3	1	0	3	N/A	N/A	Lf1 Dg1 Tl1 Th1 Dl+ Dh+
Unit 2 2 - 22cm Compost	Mid-Brown Fine Compost	3+	0	2	3	3	3	Dg2 Tl1 Th1 Dl+ Dh+
Unit 3 22 - 40cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	2	N/A	Gs4
Unit 4 40 – 50cm Compost	Mid-Brown Fine Compost	3+	0	2	3	2	3	Dg2 Tl1 Th1 Dl+ Dh+ Gs+
Unit 5 50 – 60cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	2	N/A	Gs4

Cell 4 – Fine Grade Compost – (100%)

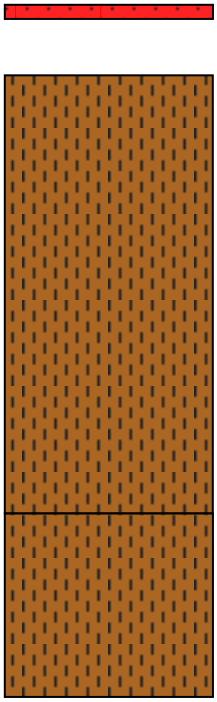
Cell 4 – Original Medium (July 2007)



Mid-Brown
Fine Compost
Dg2 Tl1 Th1 Dl+
Dh+
3 0 3 2 N/A
Humo 2+

80 cm

Cell 4 – Core Sample (February 2008)



Unit 1 – Lf4

10 cm

Mid-Brown Coarse
Compost
Dg2 Tl1 Th1 Dl+ Dh+
3+ 0 2 3 N/A
Humo 3

50 cm

Mid-Brown
Fine Compost
Dg2 Tl1 Th1 Dl+ Dh+
3+ 0 2 3 0 1
Humo 3+

70 cm

Figure 7.5 Stratigraphic Log for Cell 4

Table 7.9 Cell 4 Original Medium – July 2007

Cell 4	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Compost	Mid-Brown Fine Compost	3	0	2	3	N/A	2+	Dg2 Tl1 Th1 Dl+ Dh+

Table 7.10 Cell 4 Core Sample – February 2008

Cell 4	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface binding top 2cm of compost together	3	1	0	3	N/A	N/A	Lf1 Dg1 Tl1 Th1 Dl+ Dh+
Unit 2 2 – 10cm	Uppermost section of Unit 2 was not retrieved in the core							
Unit 2 10 – 50cm Compost	Mid-Brown Fine Compost	3+	0	2	3	N/A	3	Dg2 Tl1 Th1 Dl+ Dh+
Unit 3 50 - 70cm Compost	Mid-Brown Fine Compost, slightly more humified	3+	0	2	3	1	3+	Dg2 Tl1 Th1 Dl+ Dh+

Cell 5 – Stratified Sand, Grit, Gravel (6 – 10 mm), Gravel (10 – 12 mm) (1:1:1:1)

Cell 5 – Original Media (August 2007) Cell 5 – Core Sample (February 2008)

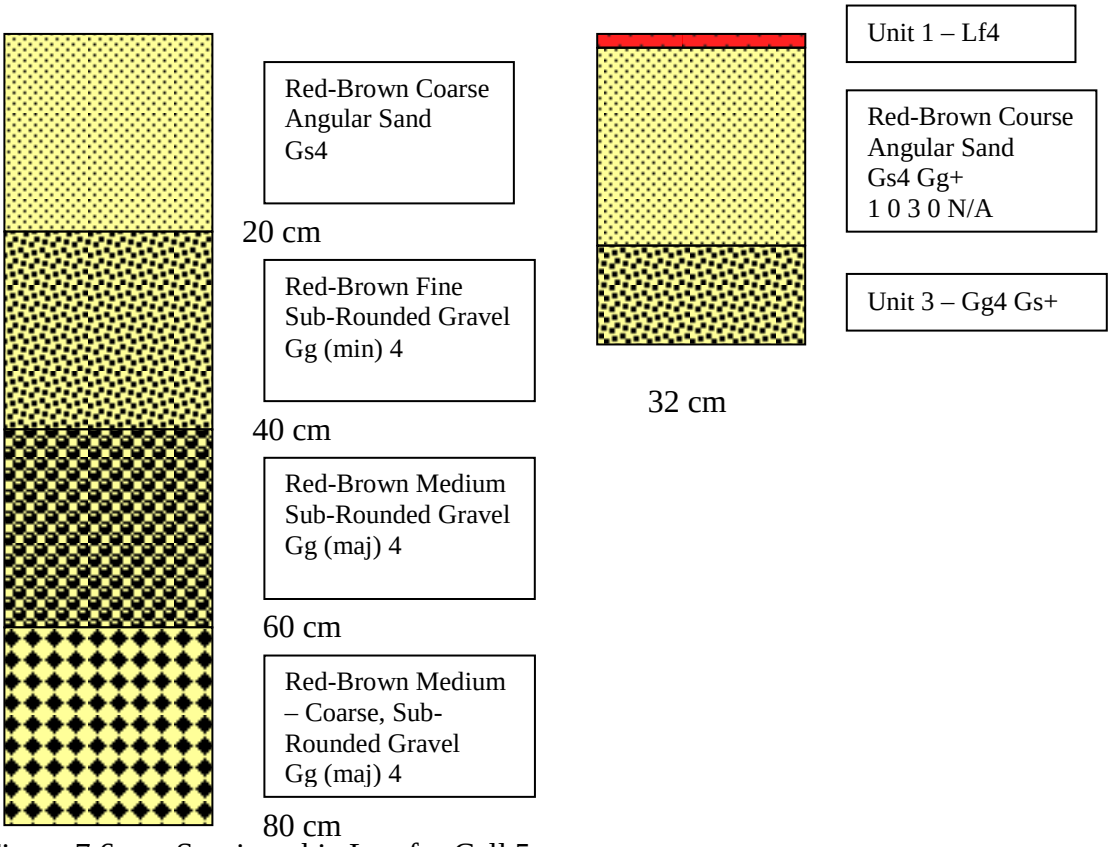


Figure 7.6 Stratigraphic Log for Cell 5

Table 7.11 Cell 5 Original Media – August 2007

Cell 5	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 20cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	0	N/A	Gs4
Unit 2 20 - 40cm Sand	Red-Brown, Small – Medium, Sub angular – Sub rounded Gravel	2+	0	0	4	3	N/A	Gg (min)
Unit 3 40 – 60cm Gravel	Red-Brown, Medium, Sub rounded – Rounded Gravel	2+	0	0	4	3	N/A	Gg (maj)
Unit 4 60 – 80cm Gravel	Red-Brown, Medium - Coarse, Sub rounded – Rounded Gravel	2+	0	0	4	3	N/A	Gg (maj)

Table 7.12 Cell 5 Core Sample – February 2008

Cell 5	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface binding top 2cm of sand together	3	1	0	4	N/A	N/A	Lf1 Gs3
Unit 2 2 - 22cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	2	N/A	Gs4 Gg+
Unit 3 22 – 32cm Gravel	Red-Brown, Medium, Sub rounded – Rounded Gravel	2+	0	0	4	2	N/A	Gg (min) 4 Gs+
	Unable to retrieve a core sample below depth of 32cm due to the loose nature of the gravels							

Cell 6 – Willow Trees set in Sub-Soil (100%)

Cell 6 – Original Medium (July 2007) Cell 6 – Core Sample (February 2008)

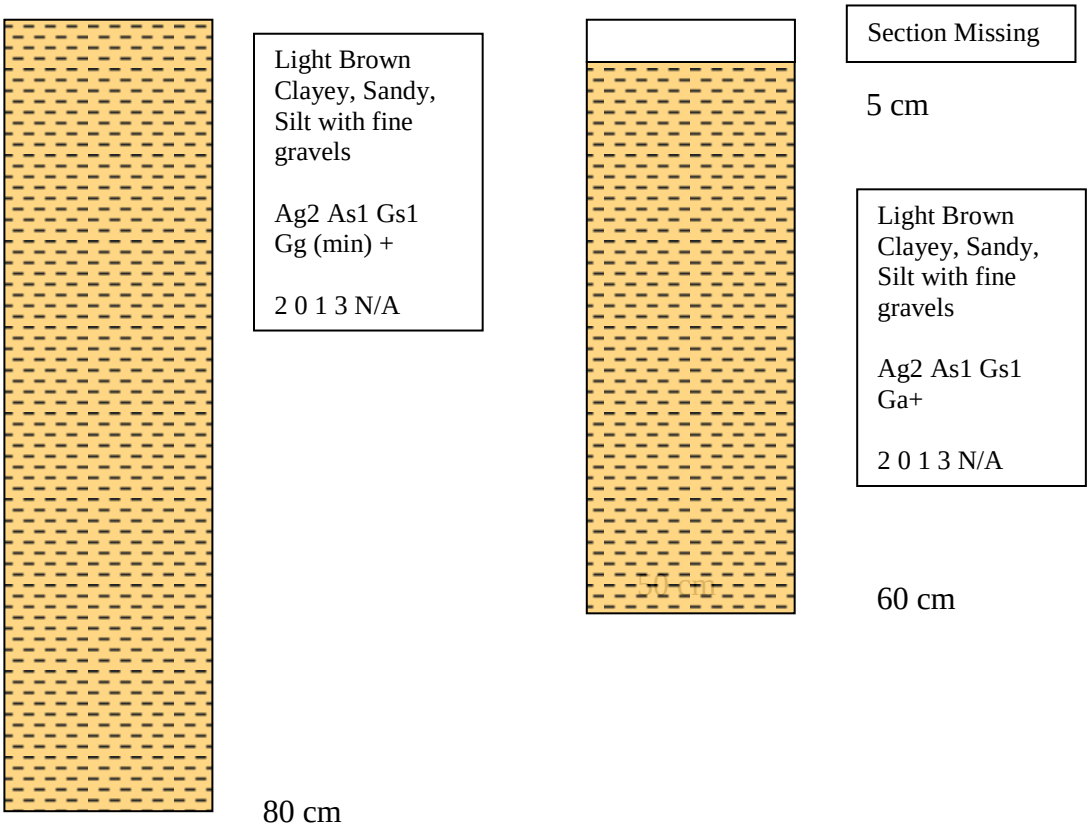


Figure 7.7 Stratigraphic Log for Cell 6

Table 7.13 Cell 6 Original Medium – July 2007

Cell 6	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Sub-Soil	Light Brown, Clayey, Sandy, Silt with fine gravels	2	0	1	3	N/A	N/A	Ag2 As1 Gs1 Gg (min) +

Table 7.14 Cell 6 Core Sample – February 2008

Cell 6	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
0 – 5cm	Top 5 cm of core was not retrieved – (cell was flooded)							
Unit 1 5 – 60cm Sub-Soil	Light-Brown Clayey, Sandy, Silt with fine gravels	2	0	1	3	N/A	N/A	Ag2 As1 Gs1 Ga+

Cell 7 – Sub-Soil (100%)

Cell 7 – Original Medium (August 2007) Cell 7 – Core Sample (February 2008)

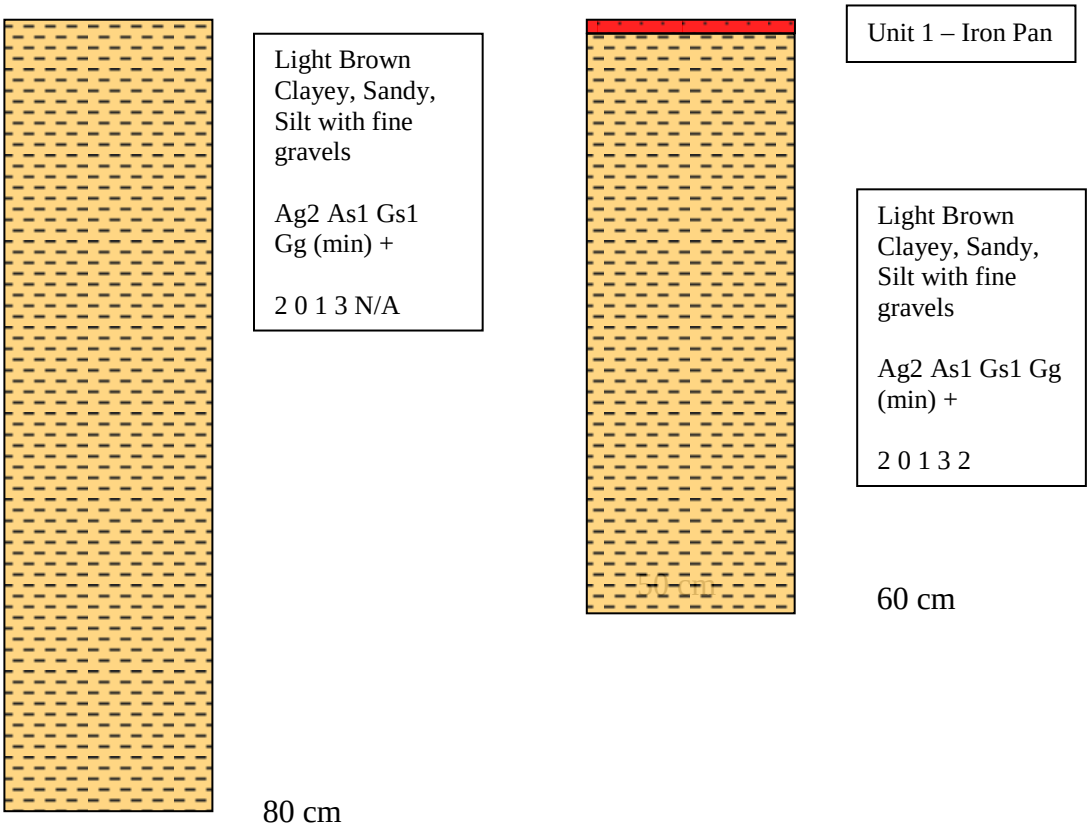


Figure 7.8 Stratigraphic Log for Cell 7

Table 7.15 Cell 7 Original Medium – August 2007

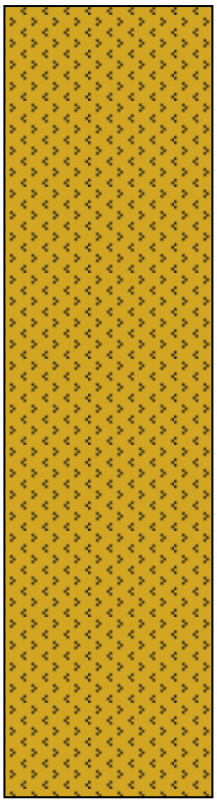
Cell 7	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Sub-Soil	Light Brown, Clayey, Sandy, Silt with fine gravels	2	0	1	3	N/A	N/A	Ag2 As1 Gs1 Gg (min) +

Table 7.16 Cell 7 Core Sample – February 2008

Cell 7	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface binding top 2cm of soil together	3	1	0	3	N/A	N/A	Lf1 Ag2 As1 Gs+
Unit 2 2 – 60 cm Sub-Soil	Light-Brown Clayey, Sandy, Silt	2	0	1	3	2	N/A	Ag2 As1 Gs1 Gg (min) +

Cell 8 – Mixed Sub-Soil/Sand/Compost (fine grade) 1:1:1

Cell 8 – Original Media (July 2007)



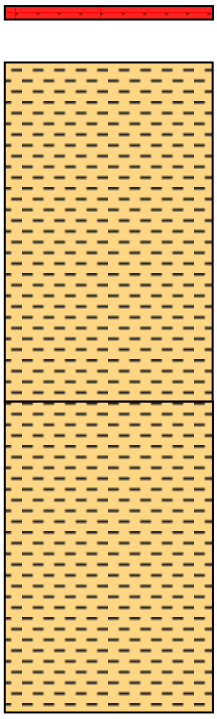
Light – Mid Brown, Slightly Clayey, Sandy Silt with organics Loamy Soil

Ag2 Dh1 Gs1 Gg+ As+

3 0 1 3 N/A

80 cm

Cell 8 – Core Sample (February 2008)



Unit 1 – Lf4

Medium-Brown Slightly Sandy, Clayey, Silt

Ag1 As1 Gs1 Dg1
3 0 1 3 N/A

40 cm

Medium-Brown Sandy, Clayey Silt

Ag2 As1 Gs1
3+ 0 1 3 0

68 cm

Figure 7.9 Stratigraphic Log for Cell 8

Table 7.17 Cell 8 Original Media – July 2007

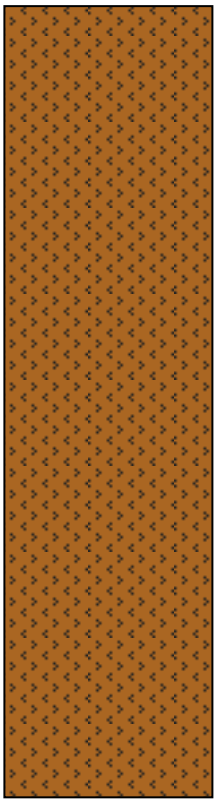
Cell 8	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Loam Soil	Light – Mid Brown, Slightly Clayey, Sandy Silt with organics Loamy Soil	2	0	1	3	N/A	N/A	Ag2 Dh1 Gs1 Gg+ As+

Table 7.18 Cell 8 Core Sample – February 2008

Cell 8	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface	3	1	0	3	N/A	N/A	Lf1 Ag1 Dh1 Gs1
2 – 5cm	Top section of core was not retrieved							
Unit 2 5 – 40cm Soil / Sand / Compost	Medium-Brown Slightly Sandy, Clayey Silt with organics	3	0	1	3	N/A	N/A	Ag1 As1 Gs1 Dg1
Unit 3 40 – 68cm Soil / Sand / Compost	Medium-Dark Brown Sandy, Clayey Silt with organics	3+	0	1	3	0	N/A	Ag2 As1 Gs1

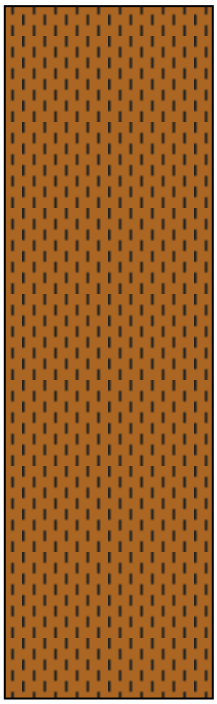
Cell 10 – Coarse Compost (100%)

Cell 10 – Original Medium (November 2007) Cell 10 – Core Sample (February 2008)



Mid-Brown
Coarse Compost
Dl2 Dh1 Tl1 Th+
3 0 2 3 N/A
Humo 2+

80 cm



Mid-Brown
Coarse Compost
Dl1 Dh1Tl1 Th1
Dg+
3+ 0 2 3 N/A
Humo 3

67 cm

Figure 7.10 Stratigraphic Log for Cell 10

Table 7.19 Cell 10 Original Medium – November 2007

Cell 10	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Compost	Mid-Brown Coarse Compost	3	0	2	3	N/A	2+	Dl2 Dh1Tl1 Th+

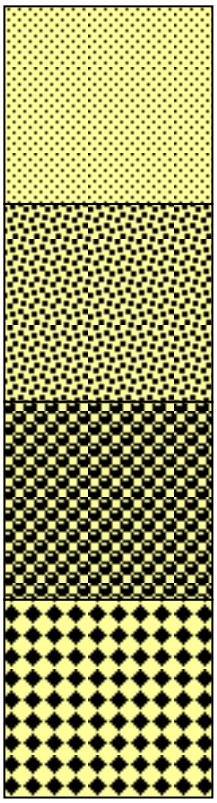
Table 7.20 Cell 10 Core Sample – February 2008

Cell 10	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 67cm Compost	Mid-Brown Coarse Compost	3+	0	2	3	N/A	3	Dl1 Dh1Tl1 Th1 Dg+

VF 1 – Vertical Flow Reed Bed in the following media:

Stratified Sand, Grit, Gravel (10 mm), Gravel (14 mm) (1:1:1:1)

VF 1 – Original Media (July 2007)



Red-Brown Coarse Angular Sand Gs4

20 cm

Red-Brown Fine Sub-Rounded Gravel Gg (min) 4

40 cm

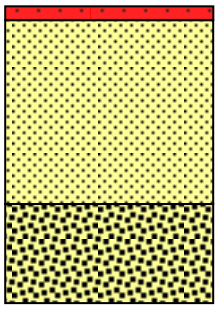
Red-Brown Medium Sub-Rounded Gravel Gg (maj) 4

60 cm

Red-Brown Medium – Coarse, Sub-Rounded Gravel Gg (maj) 4

80 cm

VF 1 – Core Sample (February 2008)



Unit 1 – Iron Pan

Red-Brown Course Angular Sand Gs4 Gg+

Unit 3 – Gg4

30 cm

Figure 7.11 Stratigraphic Log for VF 1

Table 7.21 VF 1 Original Media – July 2007

VF 1	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 20cm Compost	Red-Brown, Coarse Angular Sand	2+	0	0	4	0	N/A	Gs4
Unit 2 20 - 40cm Sand	Red-Brown, Small – Medium, Sub angular – Sub rounded Gravel	2+	0	0	4	3	N/A	Gg (min)
Unit 3 40 – 60cm Compost	Red-Brown, Medium, Sub rounded – Rounded Gravel	2+	0	0	4	3	N/A	Gg (maj)
Unit 4 60 – 80cm Sand	Red-Brown, Medium - Coarse, Sub rounded – Rounded Gravel	2+	0	0	4	3	N/A	Gg (maj)

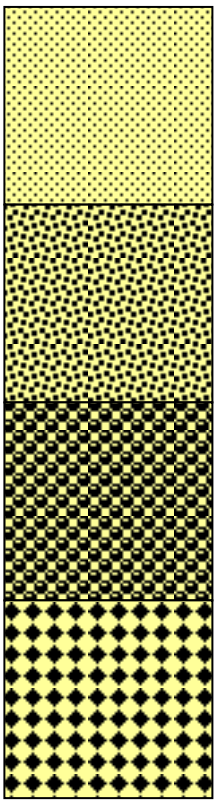
Table 7.22 VF 1 Core Sample – February 2008

VF 1	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface binding top 2cm of sand	3	1	0	3	N/A	N/A	Lf1 Gs3 Dl+
Unit 2 2 - 20m Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	2	N/A	Gs4 Gg+
Unit 3 20- 30cm Gravel	Red-Brown, Medium, Sub rounded – Rounded Gravel	2+	0	0	4	2	N/A	Gg (min) 4 Gs+
	Unable to retrieve a core sample below depth of 30cm due to the loose nature of the gravels							

VF 2 – Vertical Flow Reed Bed in the following media:

Stratified Sand, Grit, Gravel (10 mm), Gravel (14 mm) (1:1:1:1)

VF 2 – Original Media (July 2007)



Red-Brown Coarse Angular Sand Gs4

20 cm

Red-Brown Fine Sub-Rounded Gravel Gg (min) 4

40 cm

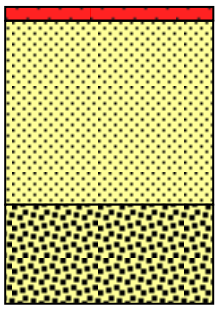
Red-Brown Medium Sub-Rounded Gravel Gg (maj) 4

60 cm

Red-Brown Medium – Coarse, Sub-Rounded Gravel Gg (maj) 4

80 cm

VF 2 – Core Sample (February 2008)



Unit 1 – Iron Pan

Red-Brown Course Angular Sand Gs4 Gg+

Unit 3 – Gg4

30 cm

Figure 7.12 Stratigraphic Log for VF 2

Table 7.23 VF 2 Original Media – July 2007

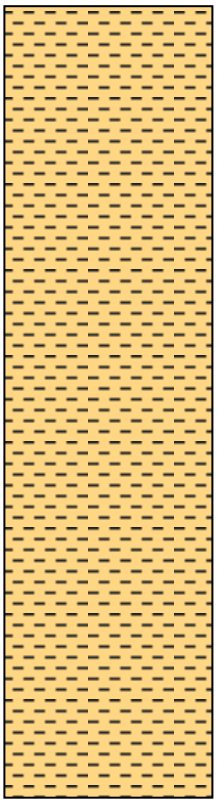
VF 2	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 20cm Compost	Red-Brown, Coarse Angular Sand	2+	0	0	4	0	N/A	Gs4
Unit 2 20 - 40cm Sand	Red-Brown, Small – Medium, Sub angular – Sub rounded Gravel	2+	0	0	4	3	N/A	Gg (min)
Unit 3 40 – 60cm Compost	Red-Brown, Medium, Sub rounded – Rounded Gravel	2+	0	0	4	3	N/A	Gg (maj)
Unit 4 60 – 80cm Sand	Red-Brown, Medium - Coarse, Sub rounded – Rounded Gravel	2+	0	0	4	3	N/A	Gg (maj)

Table 7.24 VF 2 Core Sample – February 2008

VF 2	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 2cm Iron Pan	Red-Brown Iron Pan on surface binding top 2cm of sand	3	1	0	3	N/A	N/A	Lf1 Gs3 Dl+
Unit 2 2 – 20cm Sand	Red-Brown, Coarse Angular Sand	2+	0	0	4	2	N/A	Gs4 Gg+
Unit 3 20- 30cm Gravel	Red-Brown, Medium, Sub rounded – Rounded Gravel	2+	0	0	4	2	N/A	Gg (min) 4 Gs+
	Unable to retrieve a core sample below depth of 32cm due to the loose nature of the gravels							

HF 1 – Horizontal Flow Reed Bed in Sub-Soil (100%)

HF 1 – Original Medium (July 2007)



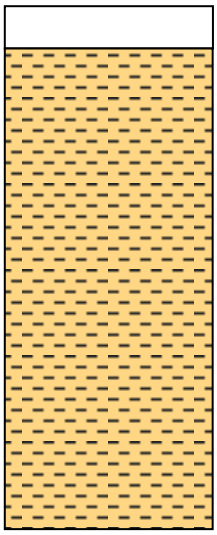
Light Brown, Clayey, Sandy, Silt with fine gravels

Ag2 As1 Gs1 Gg (min) +

2 0 1 3 N/A

80 cm

HF 1 – Core Sample (February 2008)



Section Missing

5 cm

Light-Brown Slightly Sandy, Clayey, Silt with fine gravels

Ag2 As1 Gs1 Gg (min) +

2 0 1 3 N/A

50 cm

Figure 7.13 Stratigraphic Log for HF 1

Table 7.25 HF 1 Original Medium – July 2007

Cell HF 1	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 - 80cm Sub-Soil	Light Brown, Clayey, Sandy, Silt with fine gravels	2	0	1	3	N/A	N/A	Ag2 As1 Gs1 Gg (min) +

Table 7.26 HF 1 Core Sample – February 2008

Cell HF 1	Description	Nig	Strf	Elas	Sicc	Lim	Humo	Classification
Unit 1 0 – 5cm	Section missing							
Unit 2 5 – 50 cm Sub-Soil	Light-Brown Clayey, Sandy, Silt with fine gravels	2	0	1	3	N/A	N/A	Ag2 As1 Gs1 Gg (min) +



Figure 7.14 Cell 1 – Coarse Compost (100%)



Figure 7.15 Cell 2 – Willow Trees set in Coarse Compost (100%)



Figure 7.16 Cell 3 – Stratified Compost, Sand, Compost, Sand (1:1:1:1)



Figure 7.17 Cell 4 – Fine Grade Compost – (100%)



Figure 7.18 Iron Pan on Surface of Cell 4



Figure 7.19 Iron Pan on Surface of Cell 5



Figure 7.20 Cell 6 – Willow Trees set in Sub-Soil (100%)



Figure 7.21 Cell 7 – Sub-Soil (100%)



Figure 7.22 Cell 8 – Mixed Sub-Soil/Sand/Compost (fine grade) 1:1:1

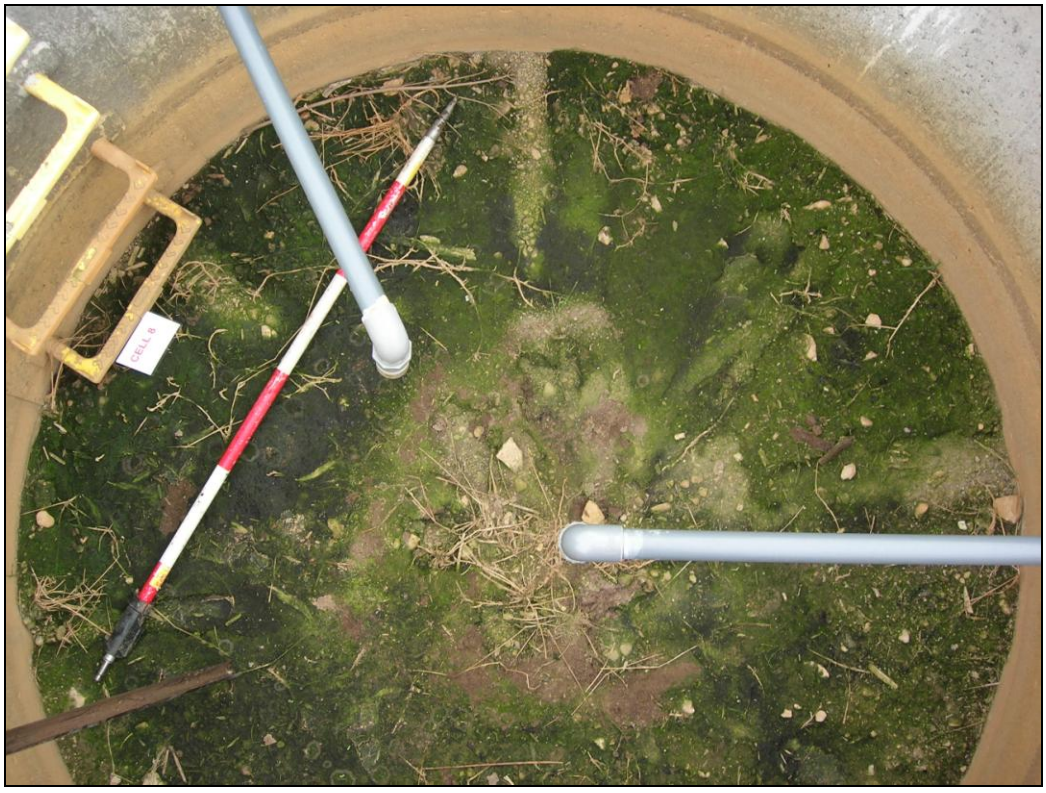


Figure 7.23 Iron Pan on Surface of Cell 8



Figure 7.24 Cell 10 – Coarse Compost (100%)



Figure 7.25 VF 1 – Vertical Flow Reed Bed in Sand / Grit / Gravel Media



Figure 7.26 Iron Pan on Surface of VF 1



Figure 7.27 HF 1 – Horizontal Flow Reed Bed in Sub-Soil (100%)

7.4.4 Conclusions to Physical Analysis of Treatment Units

On examining the stratigraphic units within each core, it was concluded that the iron pan had not developed below the top few centimetres of the surface of each treatment unit and was only a surface cementation of iron (i.e. iron hydroxide ($Fe(OH)_3$)). The media within a number of the units had compacted as was expected. This was particularly evident in Cells 1 and 2 where the original coarse grade compost had compacted to two thirds of its original depth. The fine grade compost unit (Unit 4) in Cell 3 had been squeezed to 50 % of its original thickness.

The iron pan was causing a number of problems; by way of reducing the permeability of the media, causing surface ponding of leachate and restricting the growth of a surface biofilm; all leading to a reduction in treatment efficiency.

The problem was however easily resolved by the physical removal of the iron pan and further loosening up of the media (using a hand shovel) as well as the installation of three gravel beds operating in parallel through which the leachate percolated prior to dosing to the treatment units. The gravel beds acted as a sediment trap and provided surface area for iron oxidation and accumulation. These gravel beds required flushing each month using a power washer to free up the gravels of attached iron and other sediments that had accumulated.

Iron levels within the raw untreated leachate ranged from 5mg/l up to 12mg/l. Testing during the early period of operation, showed that the gravel traps accounted for approximately 25% reduction in iron concentration levels in the leachate stream. The decrease in iron concentration in the leachate being dosed to each treatment unit, together with a reduction in dosing volumes, proved successful in maintaining a surface free of iron cementation, thus creating favourable conditions for the growth and maintenance of a biofilm, whilst maintaining media permeability.

CHAPTER 8

8. RESULTS AND INTERPRETATION

8.1 Introduction

The results achieved throughout the project are outlined in this chapter. Interpretation of the results is set out via phase of operation and by the chemical and biological analysis of key wastewater constituents within the effluent from the respective treatment unit and/or sequence of units.

The interpretation of results achieved for metals and salts, List I and List II Substances, toxicological and bacteriological parameters are dealt with later in the chapter.

In some instances, interpretation of results from treatment units may extend to the succeeding phase of operation depending on the run time of the unit in question.

Appendix 1 contains all results for the trial project.

8.2 Phase 1 and Phase 2 Plant Operations – Results and Interpretation

8.2.1 Introduction

A summary of the treatment efficiencies of individual treatment units (Cells 1, 2, 3, 4, 5, 6, 7 and 8) as well as units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) is outlined in this section. Statistical analysis of the key wastewater constituents together with interpretation of data for iron, manganese and methane are also provided. This was achieved by calculating the mean concentration, standard deviation and range (maximum and minimum) for the influent (i.e. raw leachate) and effluent (i.e. treated leachate) of the pollutant of concern for each treatment unit over the sampling period (all concentration, standard deviation and range data are in mg/l with the exception of conductivity (mS/cm) and pH (expressed as pH units)). The mean loading of each parameter for the influent and effluent to/from the units was also calculated (expressed as $g/m^2/day$ and where applicable as g/unit/day) along with the removal efficiency; expressed as average load removal per m^2 and per unit as well as average load removal as a percentage of influent (see Equation 8.1 and 8.2). All calculations were carried out

using the Microsoft Excel programme, whilst the average areal load removal and average percentage load removal were calculated using equations 8.1 and 8.2 respectively.

It should be noted that some of the loading figures for effluent and influent do not correspond in units operating in sequence (i.e. effluent load from one unit does not match the influent load to the next unit in sequence), in particular Cell 10 – VF 1 – HF 1 and Cell 1 – VF 2 – HF 2. This was due to an error in the timing of the sampling whereby units in the sequence were not necessarily sampled on the same date within the monthly sampling schedule; therefore, it would be incorrect to apply these loading data during statistical analysis. The averaged loading data in these cases are based on a lower sampling number.

Another apparent irregularity occurs in the loading data per m^2 for sequence Cell 10 – VF 1 – HF 1 and Cell 1 – VF 2 – HF 2. This is in fact due to size of the units operating in sequence; Cells 1 and 10 each have a surface area of $2.54m^2$ whereas the VF and HF reed beds have a surface area of $25m^2$.

The range of data for the various wastewater parameters measured within each treatment unit/sequence is represented graphically in the form of a line chart immediately after the tabulated concentration and loading data. Where gaps in the data exist, the data within the chart are interpolated by way of a broken line.

Equation 8.1 Areal pollutant removal rate ($g/m^2/day$)

$$Areal\ Pollutant\ Removal = (PLi - PLo)/A$$

where, PL*i* = Pollutant load of influent (g)

PL*o* = Pollutant load of effluent (g)

A= surface area of treatment unit (m^2)

Equation 8.2 Load removal efficiency (%)

$$Load\ Removal\ Efficiency = 100(PLi - PLo)/PLi$$

(equation notation after Gill *et al*., 2009).

8.2.2 Ammonium Removal

During phase 1 plant operations ammonium (NH_4) was measured at the onsite laboratory. Later during phase 2 operations (July 2008) as a time saving measure, some of the samples were sent to an external laboratory for analysis.

It should be noted that during laboratory analysis of water and wastewater samples, ammonia and ammonium are routinely interchanged whereby results obtained for ammonia may be converted to ammonium by multiplying the result by 1.059 (www.hach.com/wah).

8.2.2.1 Ammonium Removal in Individual Treatment Units

Ammonium concentrations and removal efficiencies for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.1(a) to 8.8(b).

Charts detailing the range of ammonium concentrations and loadings for cells 1 to 8 are presented in Figures 8.1(a) to 8.8(b).

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.1(a) Summary of Ammonium Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[a] ($g/m^2/day$)
Ammonium	Influent	7	322 - 440	390 (± 52)	361
Ammonium	Effluent	3	174 - 284	245 (± 61)	231

Note: [a] Based on average daily flow of 2400L/cell/day ($945L/m^2/day$)
n = number of samples; sd = standard deviation
Area of cells = $2.54m^2$

Table 8.1(b) Summary of Ammonium Load Removal for Cell 1

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Ammonium	130	36

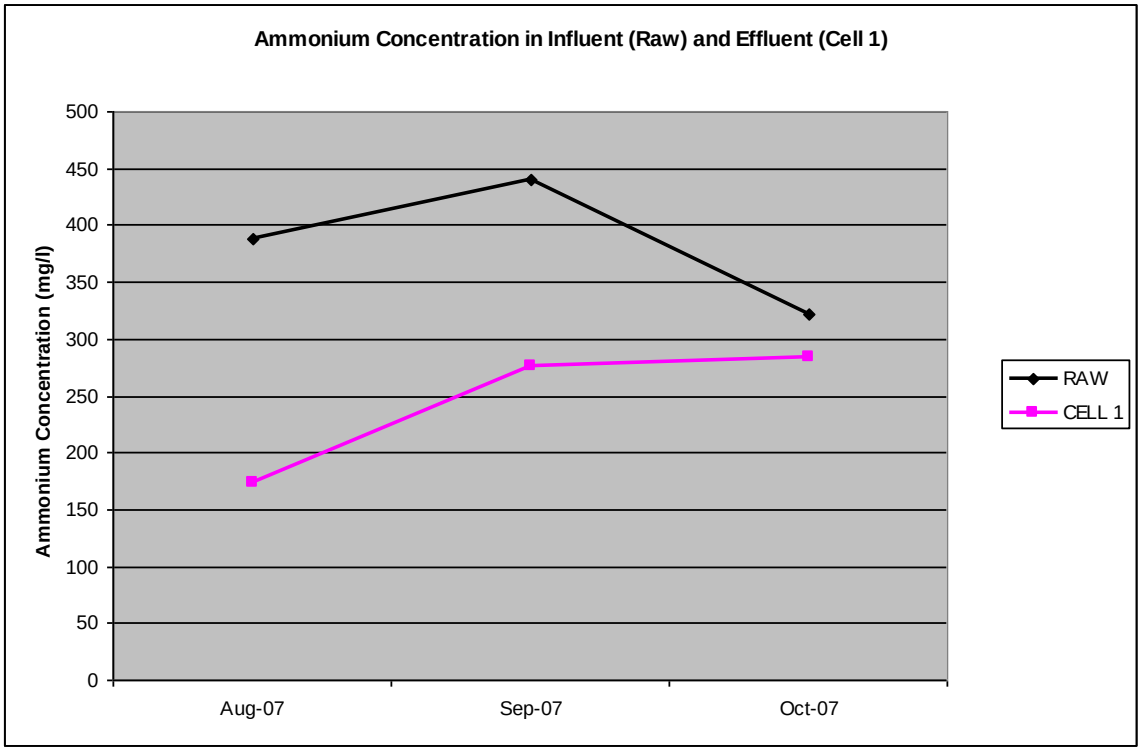


Figure 8.1(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 1)

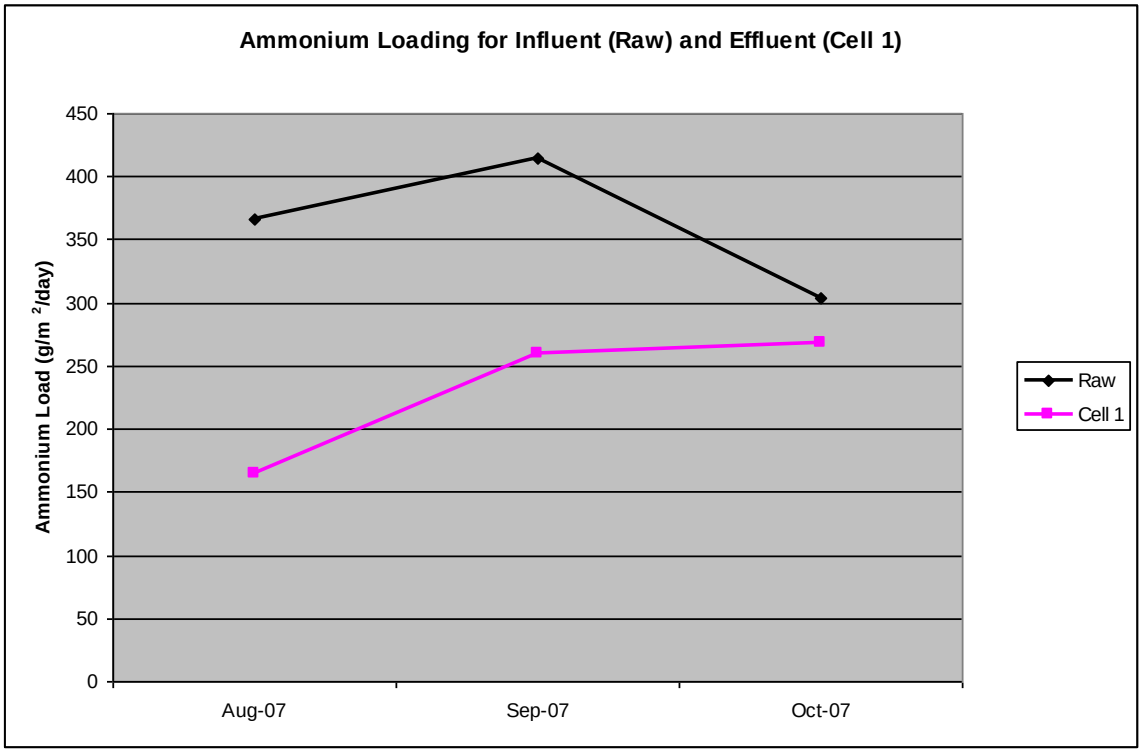


Figure 8.1(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 1)

Cell 2 – Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.2(a) Summary of Ammonium Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[b] ($g/m^2/day$)
Ammonium	Influent	16	130 - 440	319 (± 99)	310
Ammonium	Effluent	7	66 - 396	246 (± 138)	232

[b] Based on average daily flow of 2400L/cell/day ($945L/m^2/day$)

Table 8.2(b) Summary of Ammonium Load Removal for Cell 2

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Ammonium	78	25

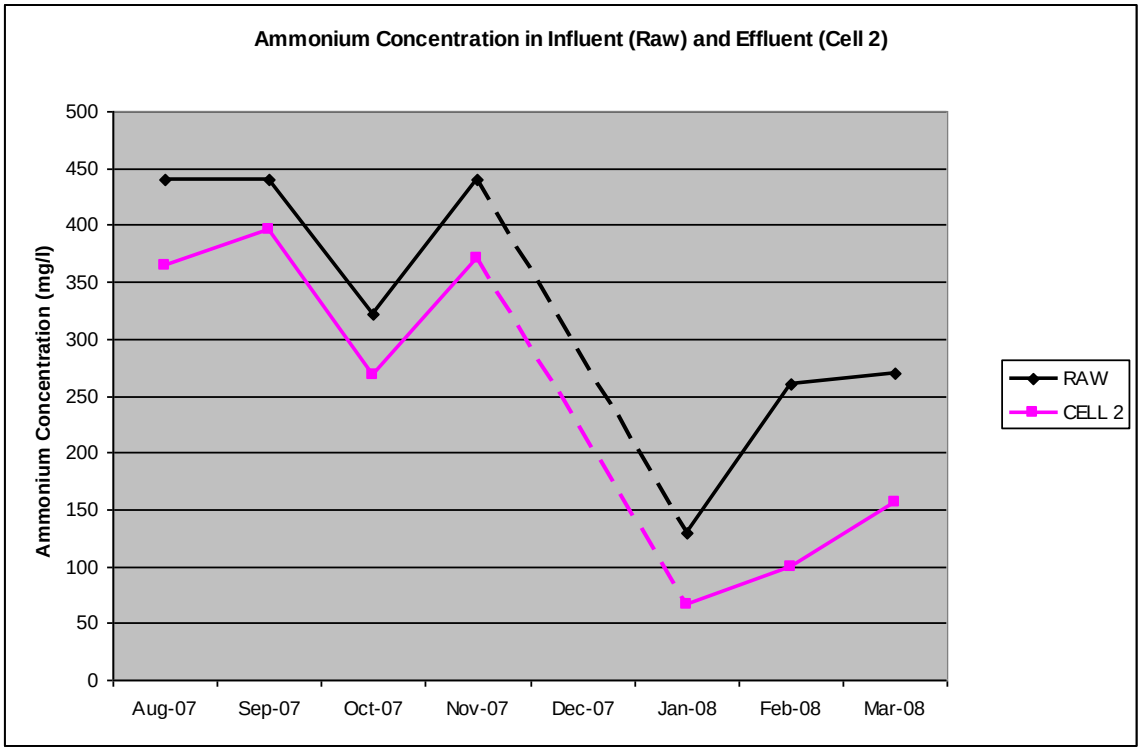


Figure 8.2(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 2)

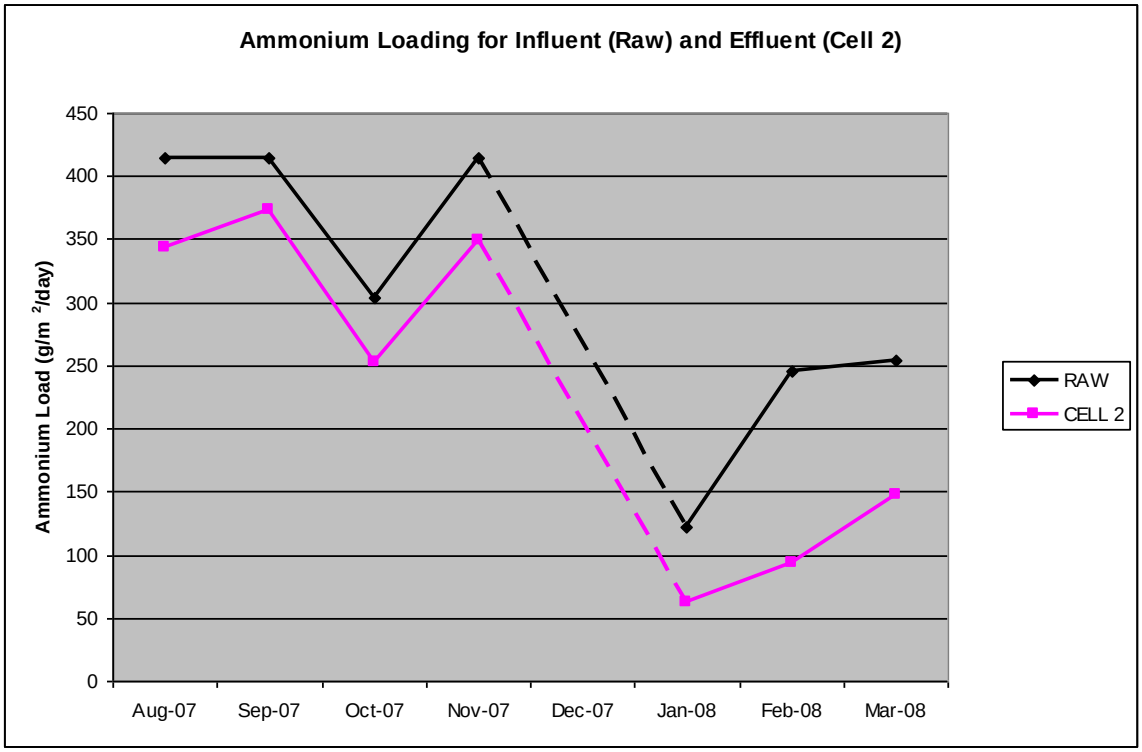


Figure 8.2(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August – December 2007

Table 8.3(a) Summary of Ammonium Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[c] (g/m^2/day)
Ammonium	Influent	10	240 - 440	366 (± 78)	375
Ammonium	Effluent	4	240 - 400	334 (± 67)	315

[c] Based on average daily flow of 2400L/unit/day ($945L/m^2$/day)

Table 8.3(b) Summary of Ammonium Load Removal for Cell 3

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Ammonium	60	15

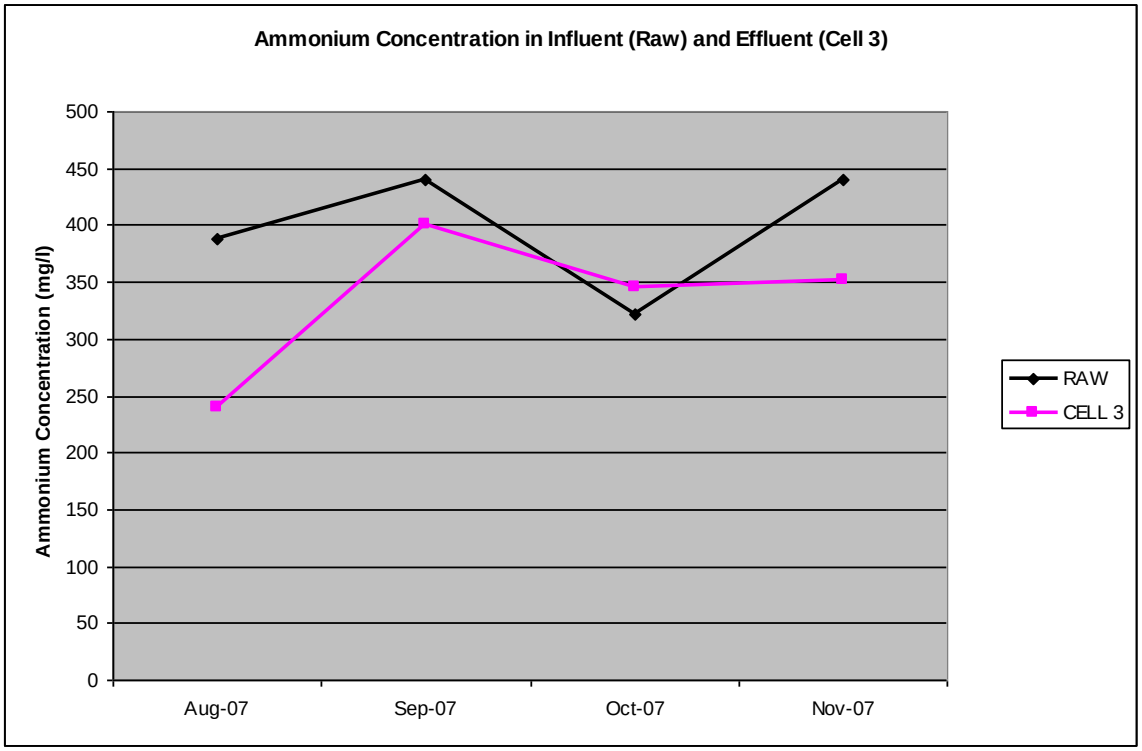


Figure 8.3(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 3)

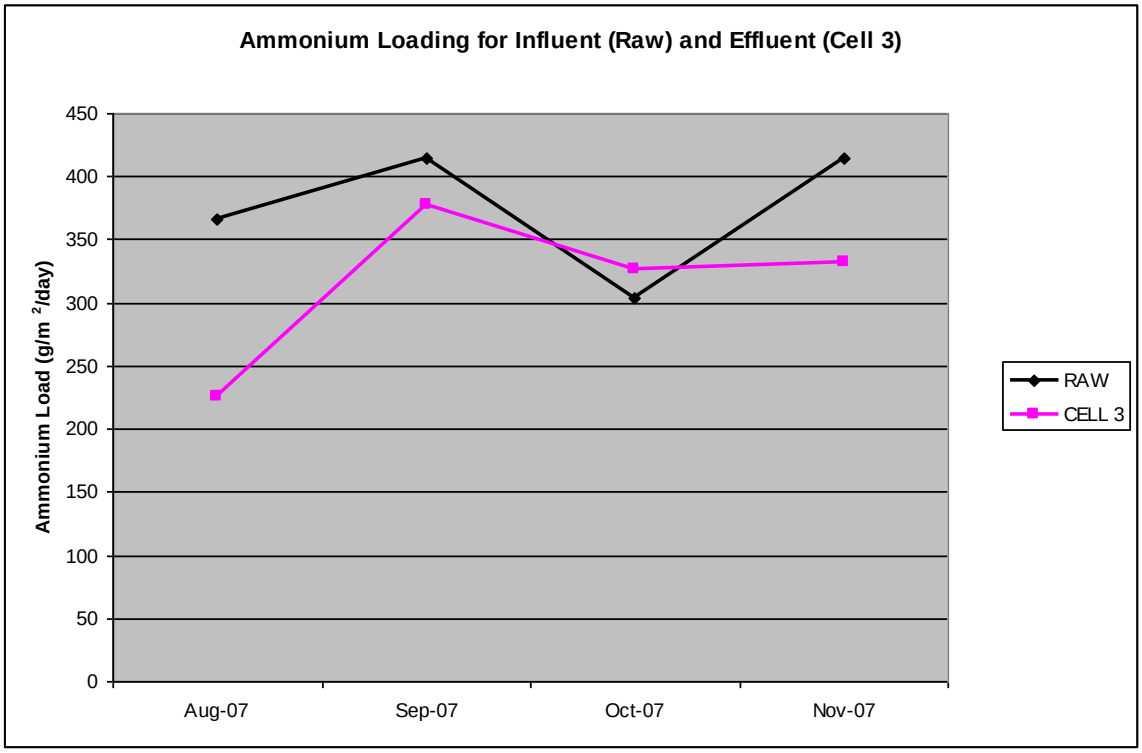


Figure 8.3(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 - April 2008

Table 8.4(a) Summary of Ammonium Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[d] ($g/m^2/day$)
Ammonium	Influent	18	130 - 440	325 (± 95)	326
Ammonium	Effluent	8	110 - 440	310 (± 112)	293

[d] Based on average daily flow of 2400L/unit/day ($945L/m^2/day$)

Table 8.4(b) Summary of Ammonium Load Removal for Cell 4

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Ammonium	33	11

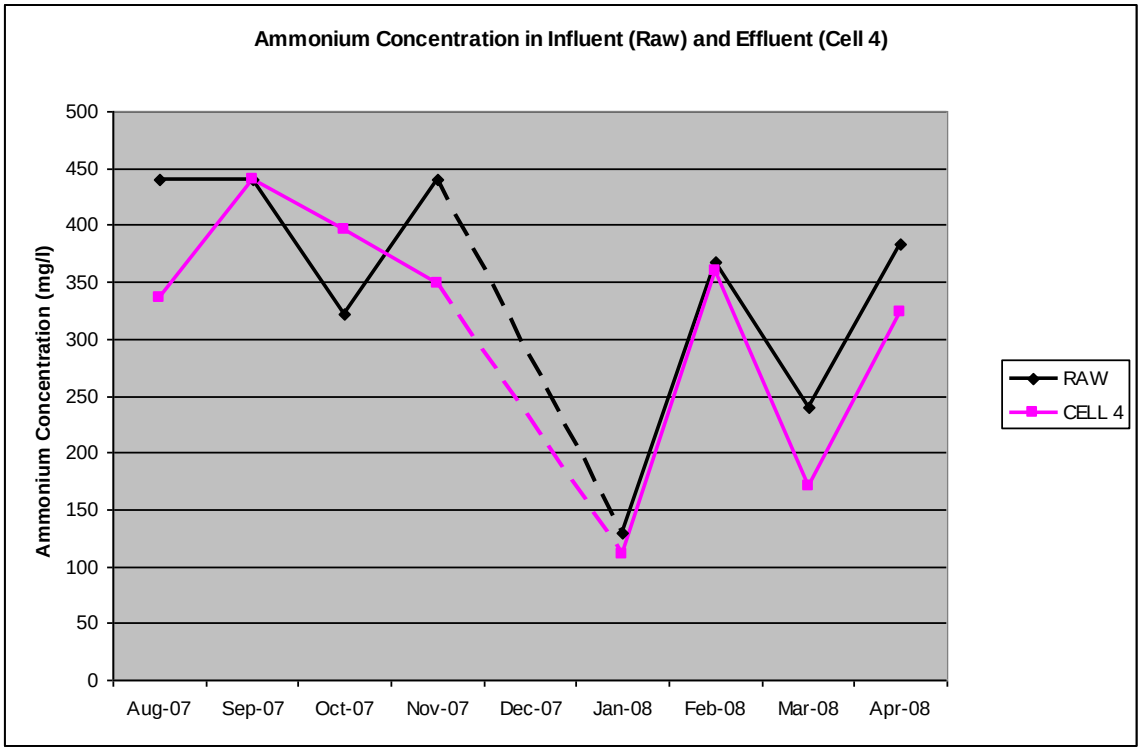


Figure 8.4(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 4)

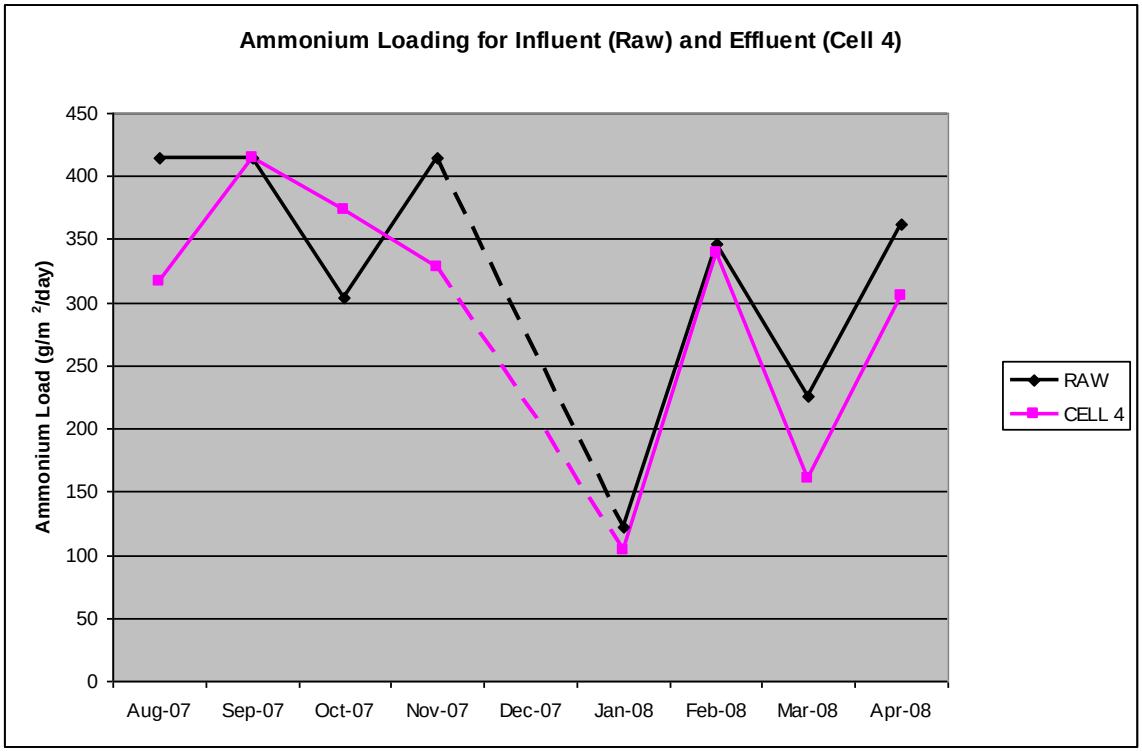


Figure 8.4(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 4)

Cell 5 – Media: Stratified Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.5(a) Summary of Ammonium Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[e] (g/m^2/day)
Ammonium	Influent	23	130 - 440	330 (± 90)	52
Ammonium	Effluent	8	68 - 256	209 (± 113)	37

[e] Based on an average daily flow of 408L/unit/day (161L/m^2/day)

Table 8.5(b) Summary of Ammonium Load Removal for Cell 5

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Ammonium	14	33

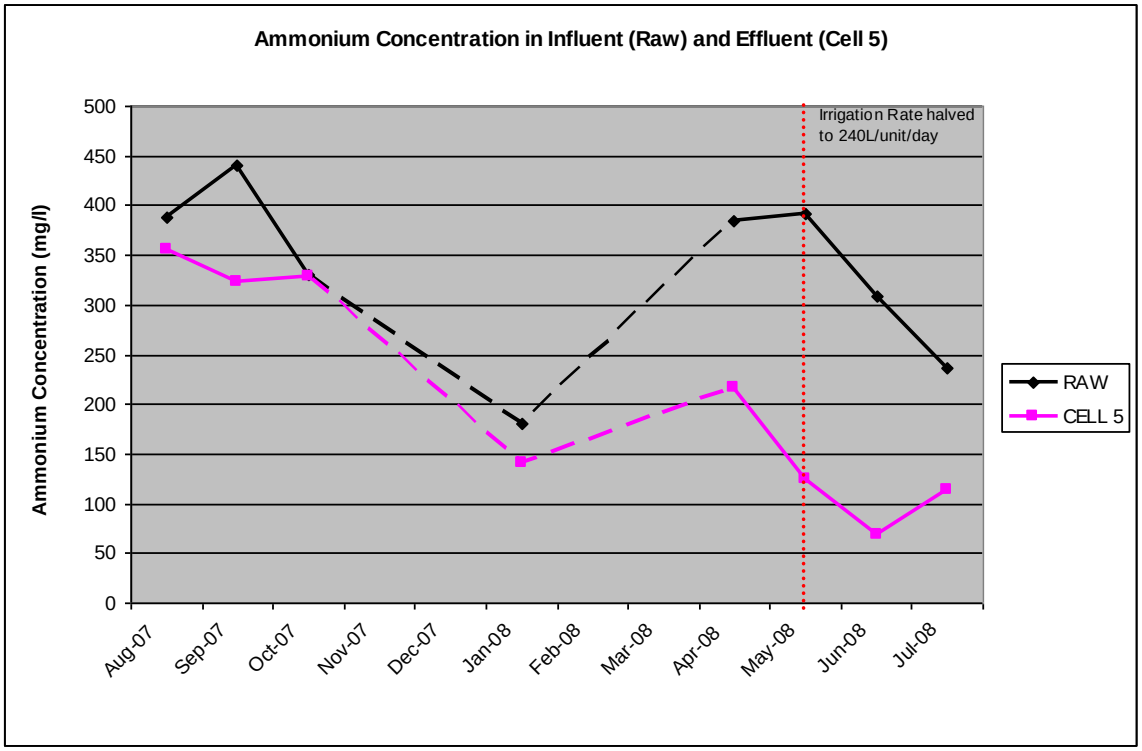


Figure 8.5(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 5)

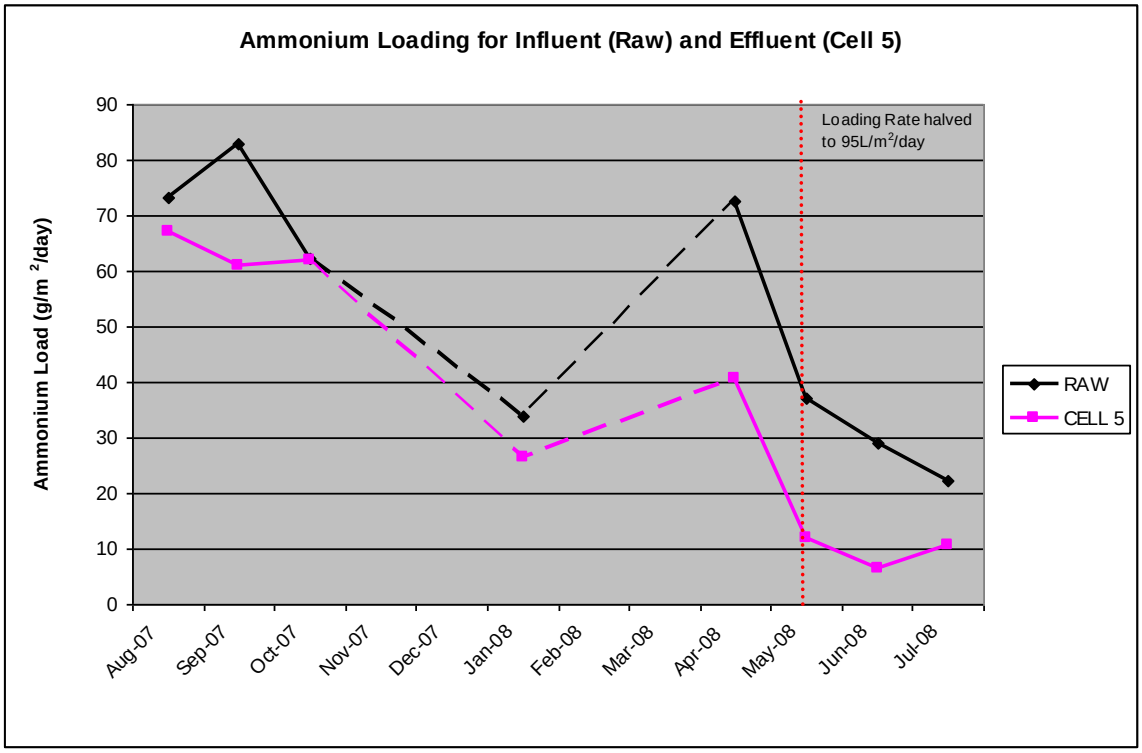


Figure 8.5(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.6(a) Summary of Ammonium Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[f] ($g/m^2/day$)
Ammonium	Influent	22	130 - 440	334 (± 90)	146
Ammonium	Effluent	9	150 - 440	287 (± 110)	127

[f] Based on an average daily flow of 1145L/unit/day ($451L/m^2/day$)

Table 8.6(b) Summary of Ammonium Load Removal for Cell 6

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Ammonium	19	13

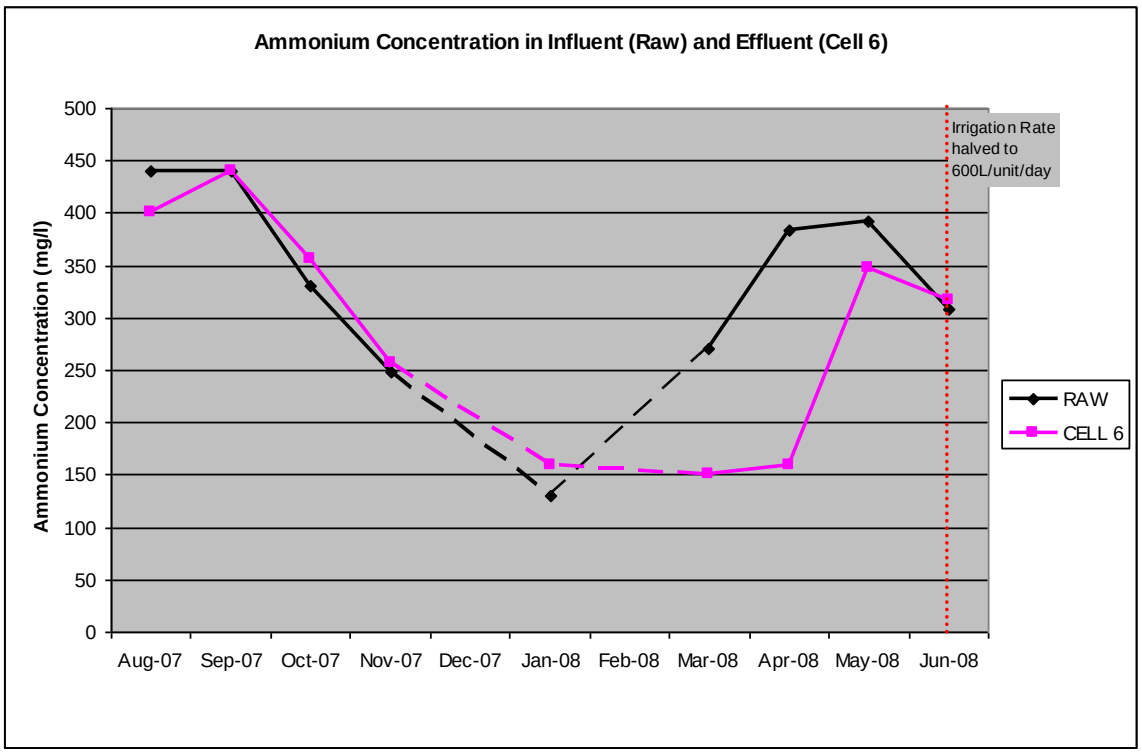


Figure 8.6(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 6)

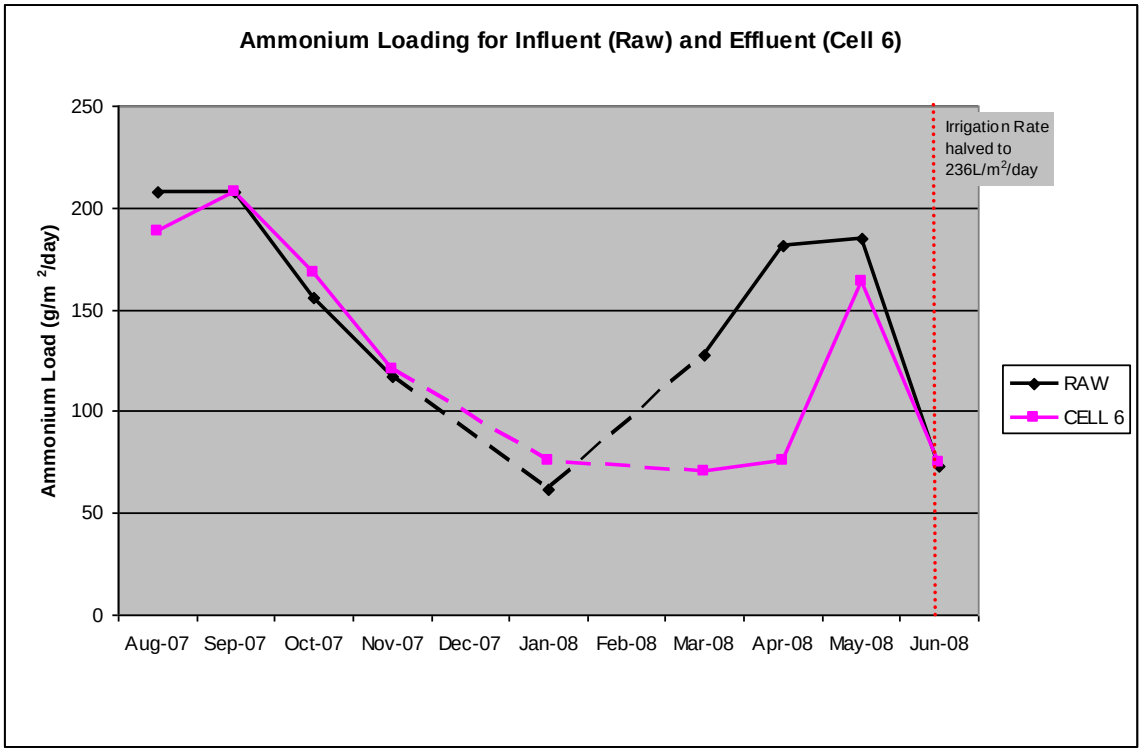


Figure 8.6(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 6)

Cell 7 – Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.7(a) Summary of Ammonium Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[g] ($g/m^2/day$)
Ammonium	Influent	25	130 - 440	323 (± 90)	231
Ammonium	Effluent	13	120 - 400	274 (± 91)	205

[g] Based on an average daily flow of 1971/unit/day ($775L/m^2/day$)

Table 8.7(b) Summary of Ammonium Load Removal for Cell 7

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Ammonium	26	11

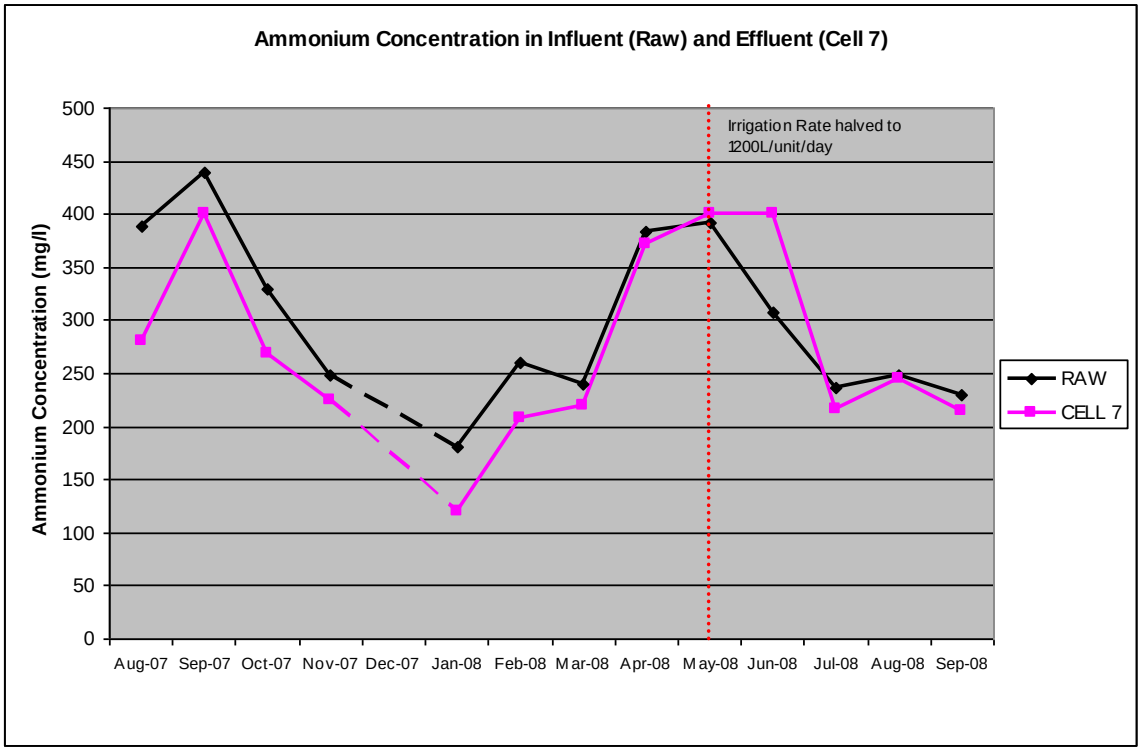


Figure 8.7(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 7)

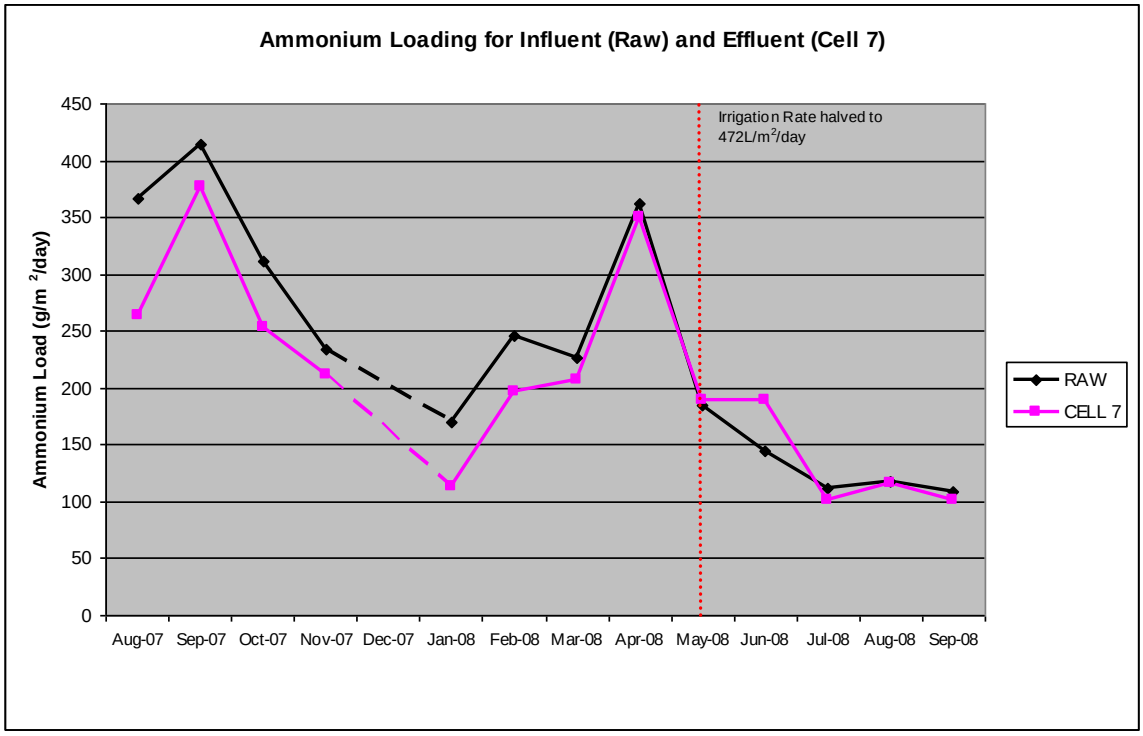


Figure 8.7(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 7)

Cell 8 – Media: Mixed Soil/Sand/Compost

Operational Period: August 2007 - October 2008

Table 8.8(a) Summary of Ammonium Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load[h] ($g/m^2/day$)
Ammonium	Influent	26	130 - 440	323 (± 90)	129
Ammonium	Effluent	10	190 - 440	325 (± 90)	128

[h] Based on an average daily flow of 960L/unit/day ($378L/m^2/day$)

Table 8.8(b) Summary of Ammonium Load Removal for Cell 8

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Ammonium	1	0.01

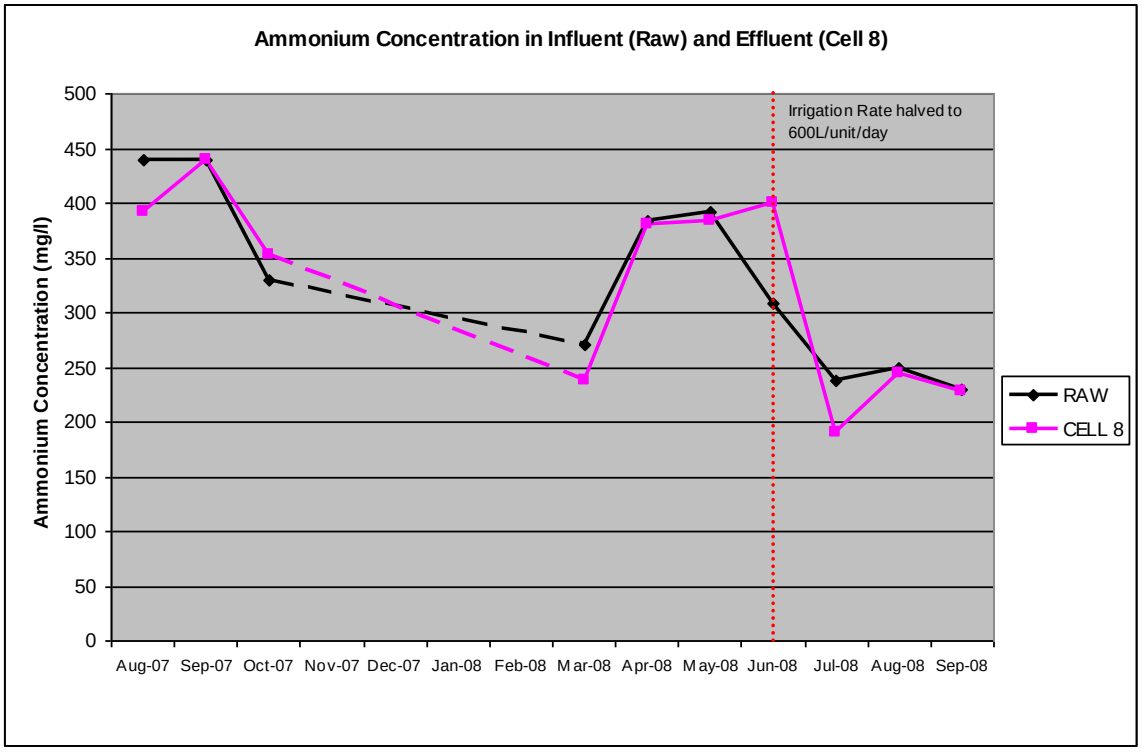


Figure 8.8(a) Ammonium Concentration in Influent (Raw) and Effluent (Cell 8)

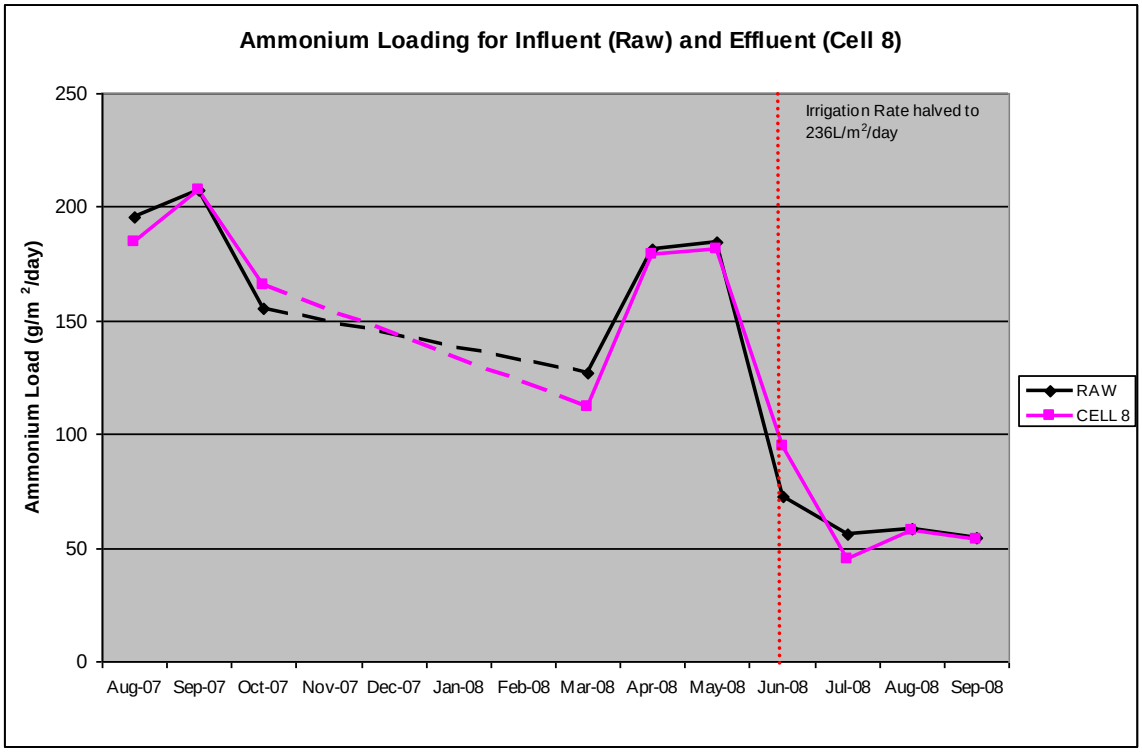


Figure 8.8(b) Ammonium Loading for Influent (Raw) and Effluent (Cell 8)

8.2.2.2 Interpretation of Ammonium Removal in Individual Treatment Units

Inspection of the results obtained for ammonium load removal rates for cells 1 to 8 displays a wide variance between the units.

In general there is a tendency for greater treatment efficiencies within units containing coarse grade compost (Cell 1) and willow trees in compost (Cell 2); with an average load removal of 130g/m^2/day and 78g/m^2/day respectively (36% and 25%).

Cell 3, containing stratified sand and compost, performed well removing 60g/m^2/day of NH_4, where as the lower than expected removal rate for Cell 4 (fine grade compost) was most likely the result of medium compaction and humification of the fine grade compost.

Results for cell 5, containing stratified sand, grit and gravel were modest with an average load removal rate of 14g/m^2/day (33% removal), despite the much lower initial influent load (~ 15% of Cell 1 and Cell 2 influent loading).

Results achieved for ammonium removal within the units containing subsoil and subsoil compounds were relatively poor to moderate; ranging from 1g/m^2/day (1% removal) for

Cell 8, 19g/m^2/day (13% removal) for Cell 6 and 26g/m^2/day (11% removal) for cell 7. It is likely that media compaction and ponding of effluent on the surface of the treatment units coupled with a poor development of a biofilm contributed to the reduced rates of ammonium load removal. On reflection, it is the author's view that the subsoil sourced for the medium in Cells 6 and 7 and that used as part of the media mixture for Cell 8 was too high in silt, causing surface sealing and media compaction.

Analysis of Charts for Ammonium Loading to Cells 1 to 8

Charts detailing the range of ammonium concentrations and loadings to cells 1 to 8 are presented in Figures 8.1(a) to 8.8(b).

The chart displaying load removal for cell 1 (Figure 8.1(b)) reveals positive load removal throughout, with the load removal rate ranging from 202g/m^2/day in August 2007 at project start-up to 36g/m^2/day in October 2007.

The influent load to cell 2 displays a wide range from a low of 123g/m^2/day in January 2008 to 415g/m^2/day in August, September and November 2007. Load removal for cell 2 (Figure 8.2(b)) reveals positive load removal throughout with a maximum load removal of 151g/m^2/day in February 2008.

Cell 3 load removal rates range from 38g/m^2/day in to September 2007 to 140g/m^2/day in August 2007 (Figure 8.3(b)). Results for October 2007 display negative load removal of -22g/m^2/day.

Influent load to Cell 4 was highly variable ranging from 123g/m^2/day to 415g/m^2/day (Figure 8.4(b)). Cell 4 load removal rates range from 8g/m^2/day in February 2008 to 98g/m^2/day in August 2007. Results for October 2007 display negative load removal of -69g/m^2/day.

Load removal in cell 5 ranges from zero in October 2007 to 32g/m^2/day in April 2008 (Figure 8.5(b)). The hydraulic loading rate (HLR) was halved to 95l/m^2/day in May 2008 in an effort to increase treatment efficiency. This resulted in moderate success with load removal rates of 25, 23 and 12g/m^2/day achieved in the months thereafter.

Load removal for cell 6 ranged from -12g/m^2/day in October 2007 to 106g/m^2/day in April 2008 (Figure 8.6(b)). The HLR was reduced by 50% in June 2008 in an effort to

increase unit treatment efficiency. However, this resulted in negative load removal of -2g/m^2/day.

Cell 7 displayed positive load removal rates ranging from 2g/m^2/day in August 2008 to 102g/m^2/day in August 2007 (Figure 8.7(b)). There were two instances of negative load removal recorded in the data set; -4g/m^2/day in May 2008 and -43g/m^2/day in June 2008. The HLR was reduced by 50% in May 2008 in an effort to increase unit treatment efficiency. However, this achieved limited success.

Load removal from cell 8 was low ranging from zero (September 2007 and September 2008) to 15g/m^2/day in March 2008. Two negative load removal results were recorded; -10/m^2/day in October 2007 and -22g/m^2/day in June 2008. The HLR was reduced by 50% in June 2008 to 236l/m^2/day with the aim of increasing unit rest time and increasing unit treatment efficiency. However, results achieved at the lower HLR were moderate to poor displaying both positive and negative load removal.

8.2.2.3 Ammonium Removal in Treatment Units Operating in Sequence

Ammonium concentrations and removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.9(a) to 8.10(c).

Charts detailing the range of ammonium concentrations and loadings for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.9(a) to 8.10(c).

Due to the differences in surface area between units in each sequence (cells 1 and 10 have a surface area of 2.54m^2, where as the VF and HF reed beds each have a surface area of 25m^2) the loading data are presented in two separate charts, one displaying loading (g) per m^2/day and the other loading (g) per unit/day.

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Table 8.9(a) Summary of Ammonium Concentrations for sequence Cell 1 – VF 2 – HF 2

Ammonium Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	Influent	4	180 - 440	280 (± 112)
Ammonium	Effluent Cell 1	4	140 - 324	211 (± 79)
Ammonium	Effluent VF 2	4	6.0 - 84	31 (± 36)
Ammonium	Effluent HF 2	4	10 - 84	35 (± 34)

Table 8.9(b) Summary of Ammonium Load Removal per m^2 for Cell 1 – VF 2 – HF 2[(i)]

Ammonium	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/m^2/day	264	20	3
Effluent Load g/m^2/day	199	3	3.3
Load Removal g/m^2/day	65	17	-0.3
Cumulative Load Removal g/m^2/day	65	82	81.7

Note:
[i] Based on an average daily flow of 2400L/unit/day
Area of cells = 2.54m^2
Area of reed beds = 25m^2

Table 8.9(c) Summary of Ammonium Load Removal per unit for Cell 1 – VF 2 – HF 2

Ammonium	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/unit/day	671	504	75
Effluent Load g/unit/day	504	75	81
Load Removal g/unit/day	167	429	-6
Cumulative Load Removal g/unit/day	167	596	590
Cumulative Load Removal as % per unit	25	89	88

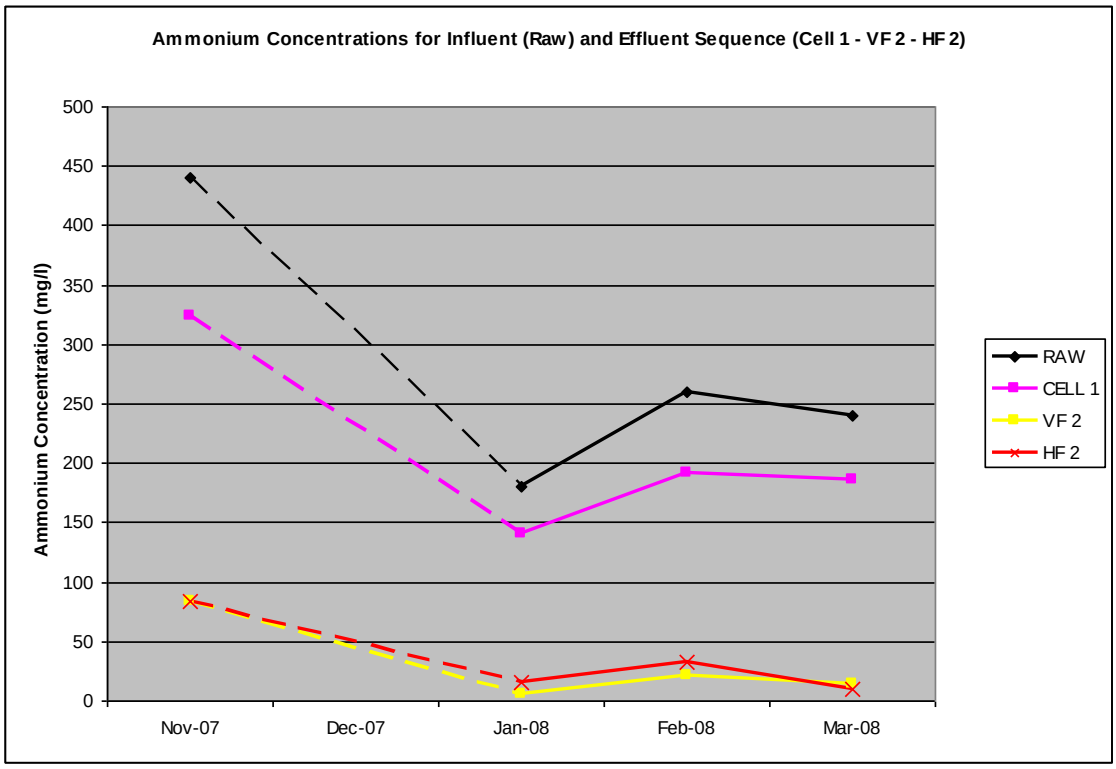


Figure 8.9(a) Ammonium Concentrations for Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

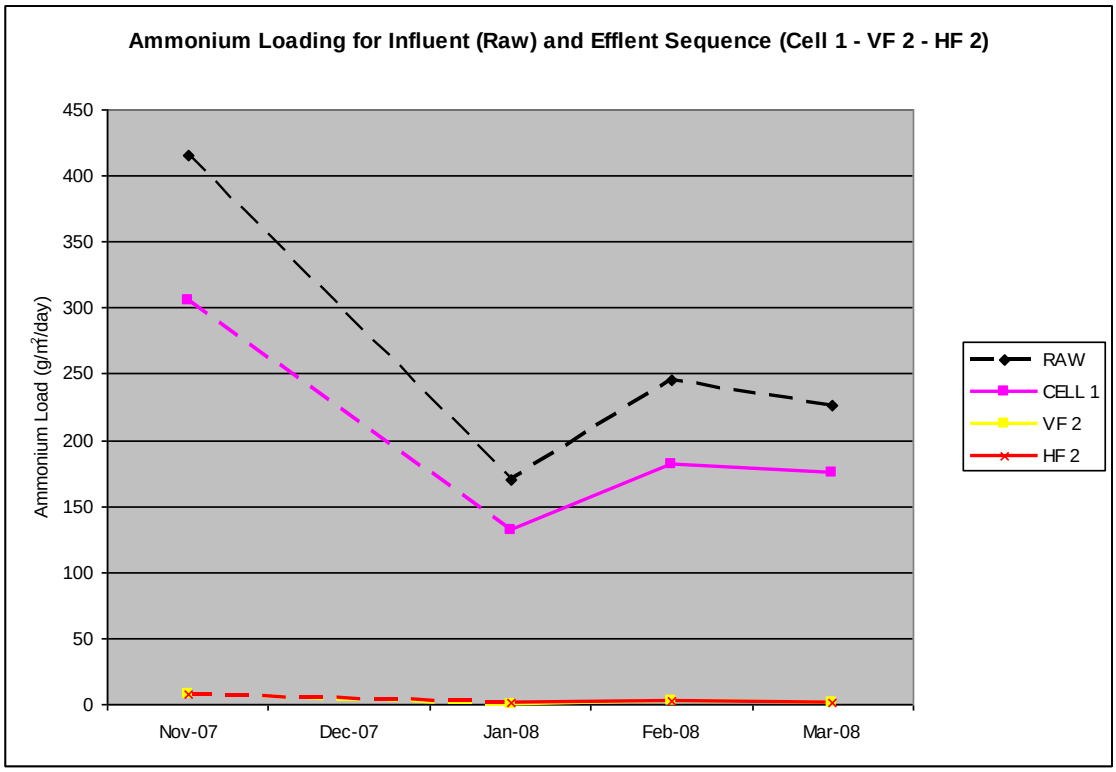


Figure 8.9(b) Ammonium Loading for Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

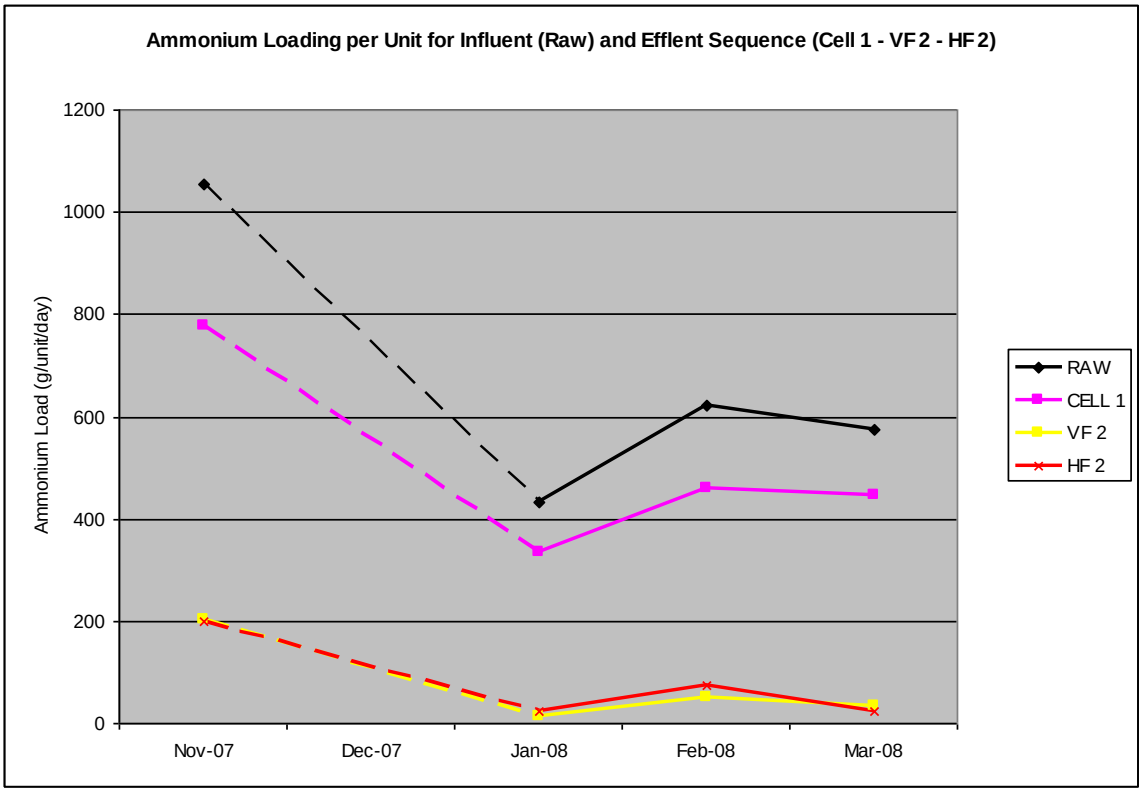


Figure 8.9(c) Ammonium Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Table 8.10(a) Summary of Ammonium Concentrations for sequence Cell 10 – VF 1 – HF 1

Ammonium Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	Influent	4	130 - 368	247 (± 97)
Ammonium	Effluent Cell 10	4	110 - 347	221 (± 106)
Ammonium	Effluent VF 1	4	9 - 208	95 (± 101)
Ammonium	Effluent HF 1	4	21 - 160	98 (± 60)

Table 8.10(b) Summary of Ammonium Load Removal per m^2 for Cell 10 – VF 1 – HF 1[(j)]

Ammonium	Cell 10	VF 1	HF 1
Influent Load g/m^2/day	232	21.1	9.1
Effluent Load g/m^2/day	208	9.1	9.5
Load Removal g/m^2/day	24	12	-0.4
Cumulative Load Removal g/m^2/day	24	36.3	35.9

Table 8.10(c) Summary of Ammonium Load Removal per unit for Cell 10 – VF 1 – HF 1

Ammonium	Cell 10	VF 1	HF 1
Influent Load g/unit/day	590	529	228
Effluent Load g/unit/day	529	228	236
Load Removal g/unit/day	62	300	-8
Cumulative Load Removal g/unit/day	62	362	354
Cumulative Load Removal as % per unit	10	61	60

Note:
[j] Based on an average daily flow of 2400L/unit/day

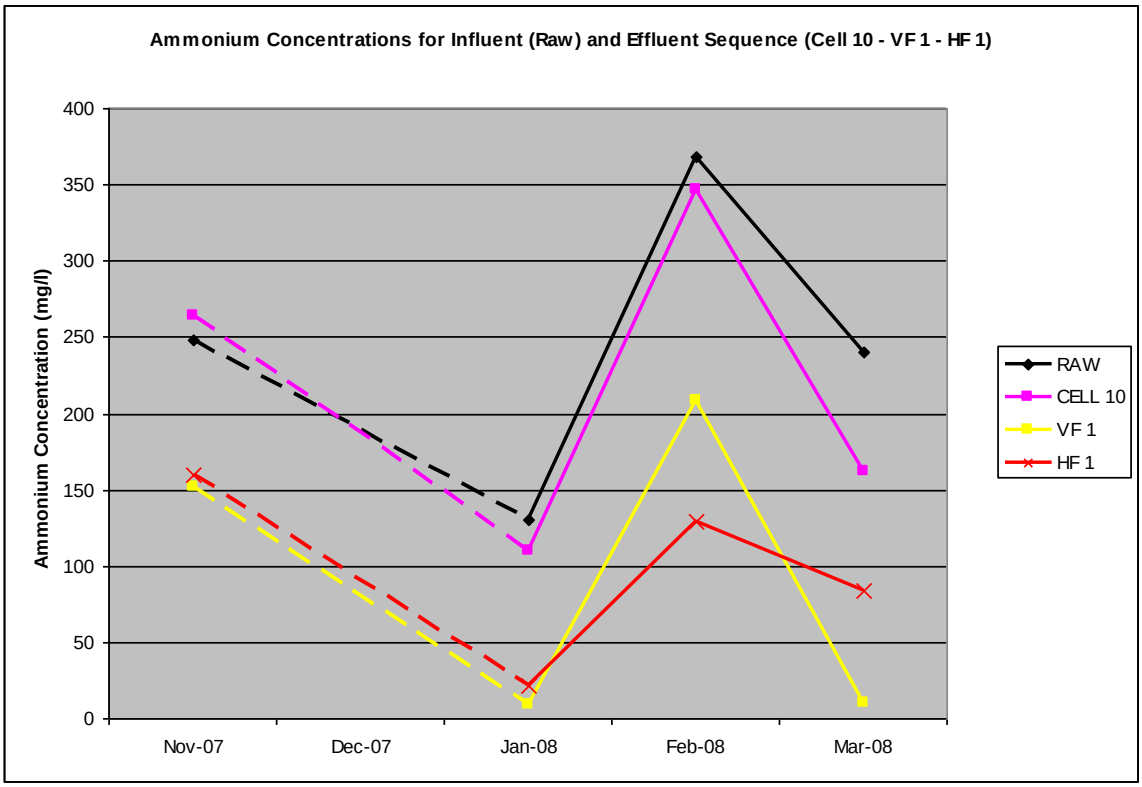


Figure 8.10(a) Ammonium Concentrations for Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

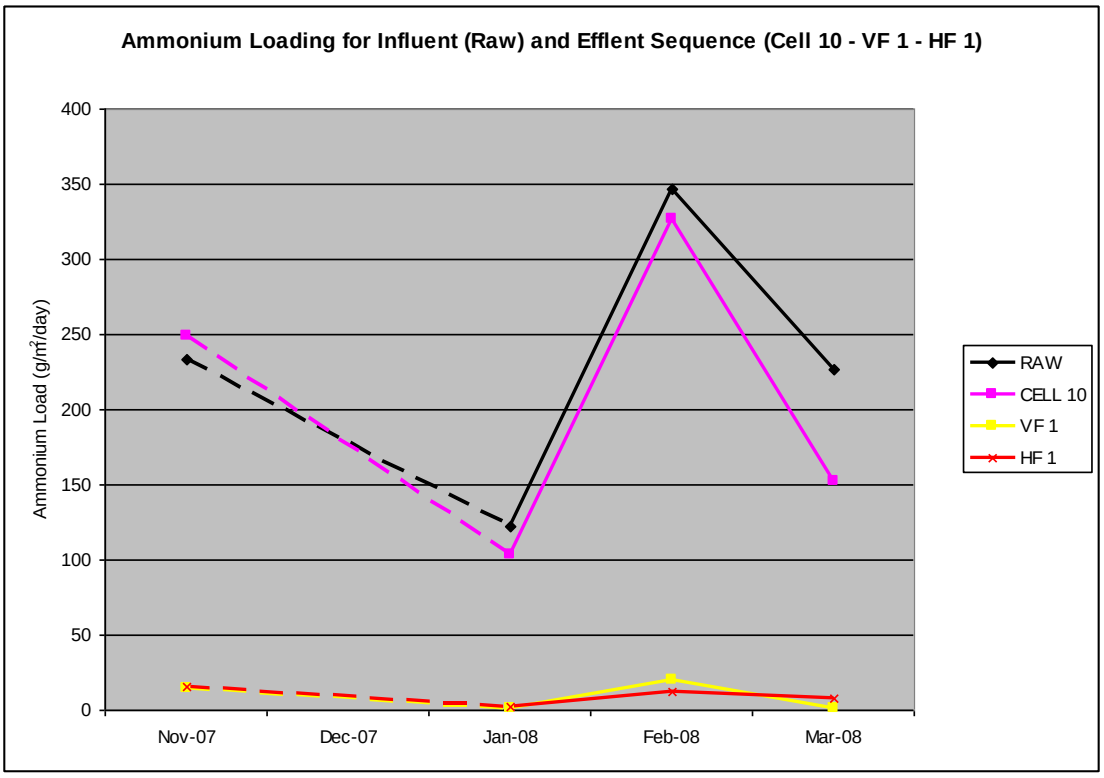


Figure 8.10(b) Ammonium Loading for Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

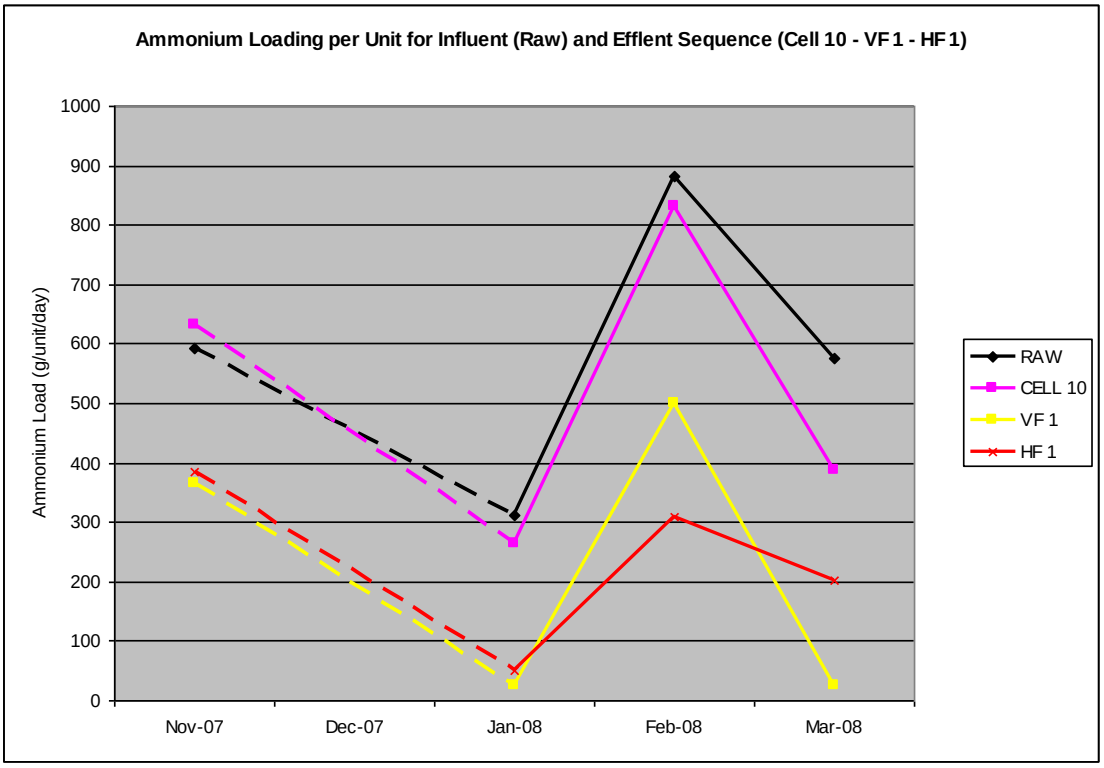


Figure 8.10(c) Ammonium Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 10 – VF 2 – HF 1)

8.2.2.4 Interpretation of Ammonium Removal in Treatment Units Operating in Sequence

Inspection of the results obtained for ammonium load removal rates for treatment units Cell 1 – VF 2 – HF 2 reveals a high degree of treatment efficiency between Cell 1 and VF 2 with an average load removal of 65g/m^2/day and 17g/m^2/day respectively. The load removal per unit was 167g/day and 429g/day respectively for Cell 1 and VF 2.

These promising results do not carry over to the next unit in the sequence, HF 2. Instead this unit displays a negative value for treatment efficiency, with a load removal of -0.3g/m^2/day (-6g/unit/day). The explanation for the negative load removal is most likely due to seasonal reed die back and the subsequent release of ammonium back in to the system from decaying organic matter, composed mainly of plant litter.

Ammonium load removal rates for treatment units Cell 10 – VF 1 – HF 1 reveals a high degree of treatment efficiency between Cell 10 and VF 1 with an average load removal of 24g/m^2/day and 12g/m^2/day respectively. The load removal per unit was 62g/day and 362g/day respectively for Cell 1 and VF 2.

The average load removal per unit was 10%, 61% and 60% respectively. The tables outline a steady positive removal of ammonium through the sequence of treatment units, with a slight negative for HF 1. The average NH_4 load removal for HF 1 was -0.4g/m^2/day (-8g/unit/day)

A possible explanation for the disparity between the HF reed bed results is the higher influent concentrations and loads to HF 1, whereby VF 1 was not operating to the same degree of treatment efficiency as VF 2, leaving HF 1 reed bed with a lot more work to do to bring down the loadings to a comparable level to that of HF 2. The difference in media substrate between the HF units may have also played a role. The subsoil medium in HF 1 compacted over time and led to a reduced permeability within the reed bed, often leading to an increase in water level above the desired freeboard depth. The delay in effluent transport through the reed bed would have given rise to anaerobic conditions unsuitable for further nitrification. Conversely, the gravel matrix of HF 2 would have provided a free flowing bed and allowed for the retention of aerobic conditions (and further nitrification) to a much greater degree.

It should be noted that there was a lag between influent and effluent in the HF units. This amounted to a hydraulic residence time (HRT) of 4.7 days in HF 1 (allowing for an initial

55% volume displacement by the subsoil medium) and a HRT of 5.75 days in HF 2 (allowing for 56% volume displacement by the gravel medium with 200mm of standing water above the gravels). This lag effect creates an inbuilt error in HF reed beds when calculating influent and effluent loadings from flow and real time pollutant concentrations.

Analysis of Charts for Ammonium Loading to Units Operating in Sequence

Charts detailing the range of ammonium concentrations and loadings to Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.9(a) to 8.10(c).

The chart displaying loading data per unit for Cell 1 – VF 2 – HF 2 displays an influent loading range of 1054g/unit/day at trial commencement in November 2007 to 431g/unit/day in January 2008 (Figure 8.9(c)).

Cell 1 performed well recording NH_4 load removal rates of 38 – 109g/m^2/day (96 – 278g/unit/day). VF 2 also displayed high load removal rates of 321 – 574g/unit/day (5 – 12g/m^2/day).

Unit HF 2 displays both positive and negative load removal during the trial period, ranging from positive load removal of 10g/unit/day for March 2008 to negative load removal of -25g/unit/day for February 2008.

The chart displaying loading data per unit for Cell 10 – VF 1 – HF 1 displays an influent loading range of 311g/unit/day in January 2008 to 881g/unit/day in February 2008 (Figure 8.10(c)).

When compared to cell 1 for the same period, cell 10 recorded very moderate NH_4 load removal rates of -15 to 74g/m^2/day (-38 to 187g/unit/day). VF 1 displayed high load removal rates of 238 – 364g/unit/day (4 – 12g/m^2/day).

Unit HF 1 displayed negative removal for the majority of the trial with the exception of February 2008 where load removal of 190g/unit/day was recorded.

Ammonium Removal Mechanisms

The majority of ammonium removal from the effluent can most likely be attributed to nitrification through surface contact and oxygen diffusion, although the absence of nitrate data for phases 1 and 2 operations means that an N balance cannot be calculated. However, N balance calculations in phases 3 and 4 operations (where nitrate concentrations were recorded) supports the nitrification explanation for phases 1 and 2 data.

Nitrification of ammonium and subsequent plant uptake of nitrate could present a further pathway for N removal (specifically Cell 2 and Cell 6 containing willow trees) although this cannot be quantified due to the lack of nitrate data for phase 1 and 2 plant operations.

Anammox of NH_4-N to nitrogen gas may be another potential mechanism. Where anoxic conditions persist, for example during periods of surface ponding or within anoxic zones within the media column, NH_4-N is stable and may be adsorbed by the substrate or used by plants and microorganisms (Sikora *et al*., 1995).

Removal of nitrogen from the reed beds was most likely achieved through nitrification/denitrification (through microbial process within the rhizosphere), volatilisation of ammonium (NH_4) stored in detritus and sediment, reed uptake and accumulation in plant biomass (Brix, 1993).

8.2.3 Organics Removal

The removal of organics from the system in the form of Biological Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) is detailed in this section. A series of tables outlining BOD_5 and COD removal in individual treatment units is presented below in sections 8.2.3.1 and 8.2.3.2 respectively with interpretation in 8.2.3.3.

Similar tables for BOD_5 and COD removal within treatment units operating in sequence are presented in sections 8.2.3.4 and 8.2.3.5 followed by interpretation.

8.2.3.1 BOD_5 Removal in Individual Treatment Units

BOD concentrations and removal efficiencies for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.11(a) to 8.18(b).

Charts detailing the range of BOD concentrations and loadings for cells 1 to 8 are presented in Figures 8.11(a) to 8.18(b).

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.11(a) Summary of BOD Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
BOD	Influent	7	29 - 128	53 (± 42)	65
BOD	Effluent	2	64 - 66	65 (± 2)	62

Table 8.11(b) Summary of BOD Load Removal for Cell 1

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
BOD	3	5

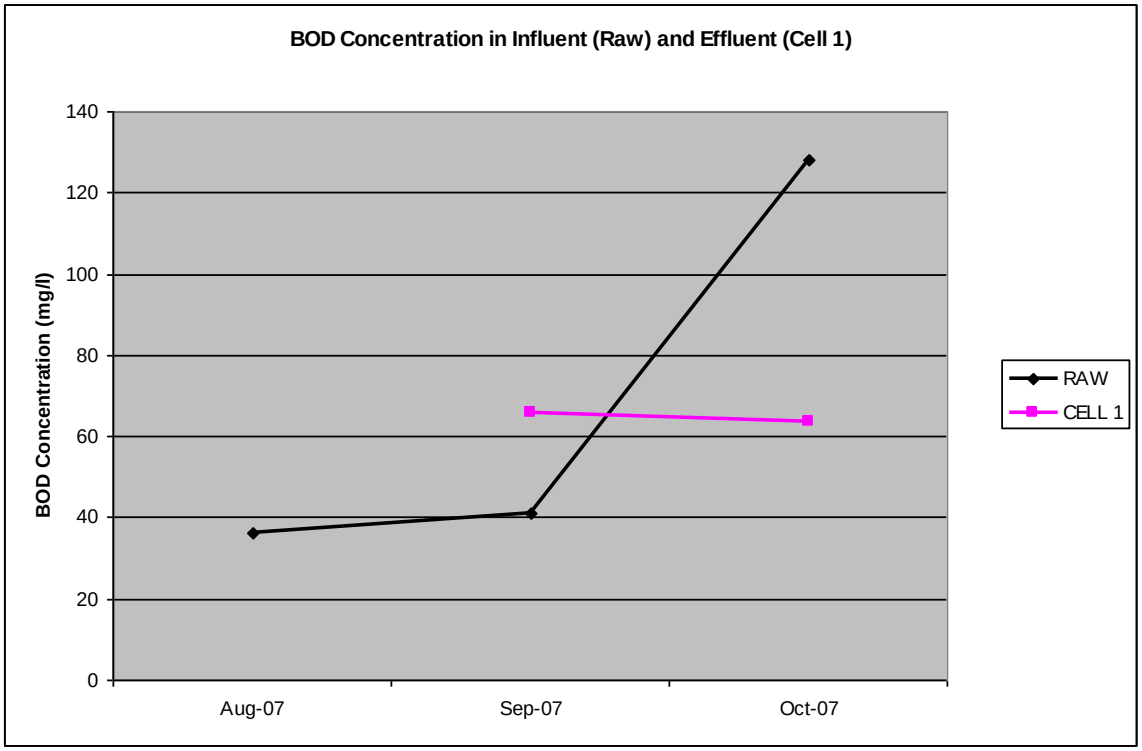


Figure 8.11(a) BOD Concentration in Influent (Raw) and Effluent (Cell 1)

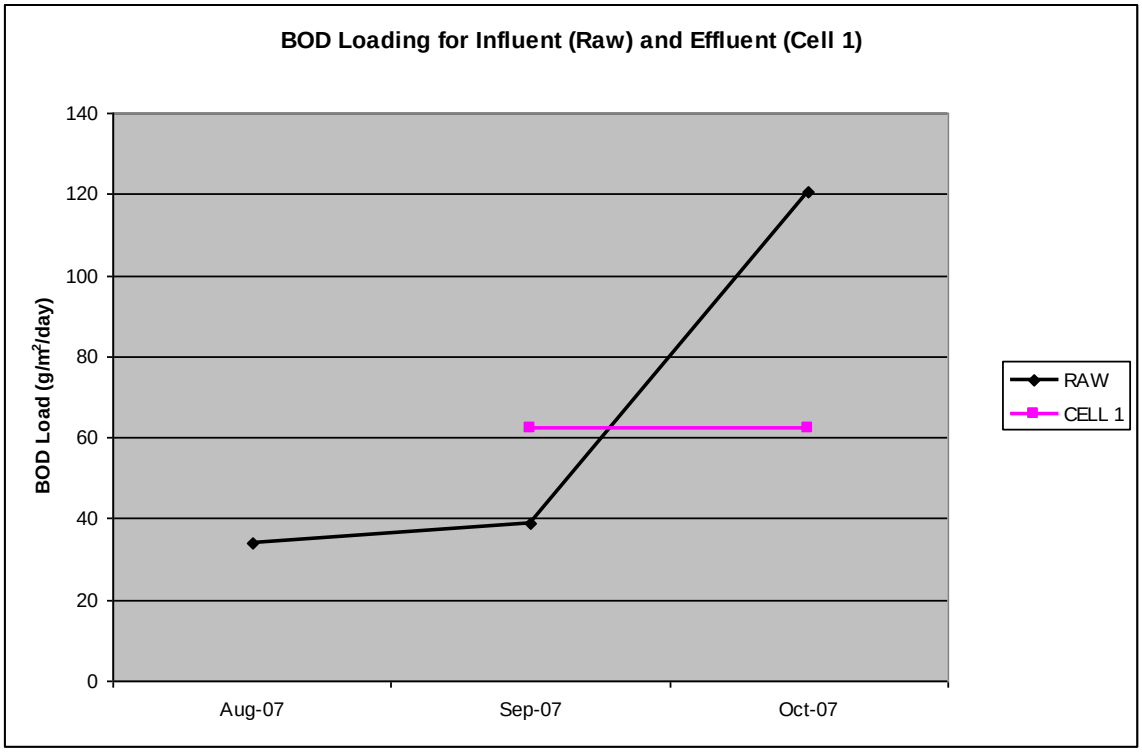


Figure 8.11(b) BOD Loading for Influent (Raw) and Effluent (Cell 1)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.12(a) Summary of BOD Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
BOD	Influent	17	10 - 129	31 (± 29)	37
BOD	Effluent	7	16 - 63	47 (± 16)	45

Table 8.12(b) Summary of BOD Load Removal for Cell 2

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
BOD	-8	-21

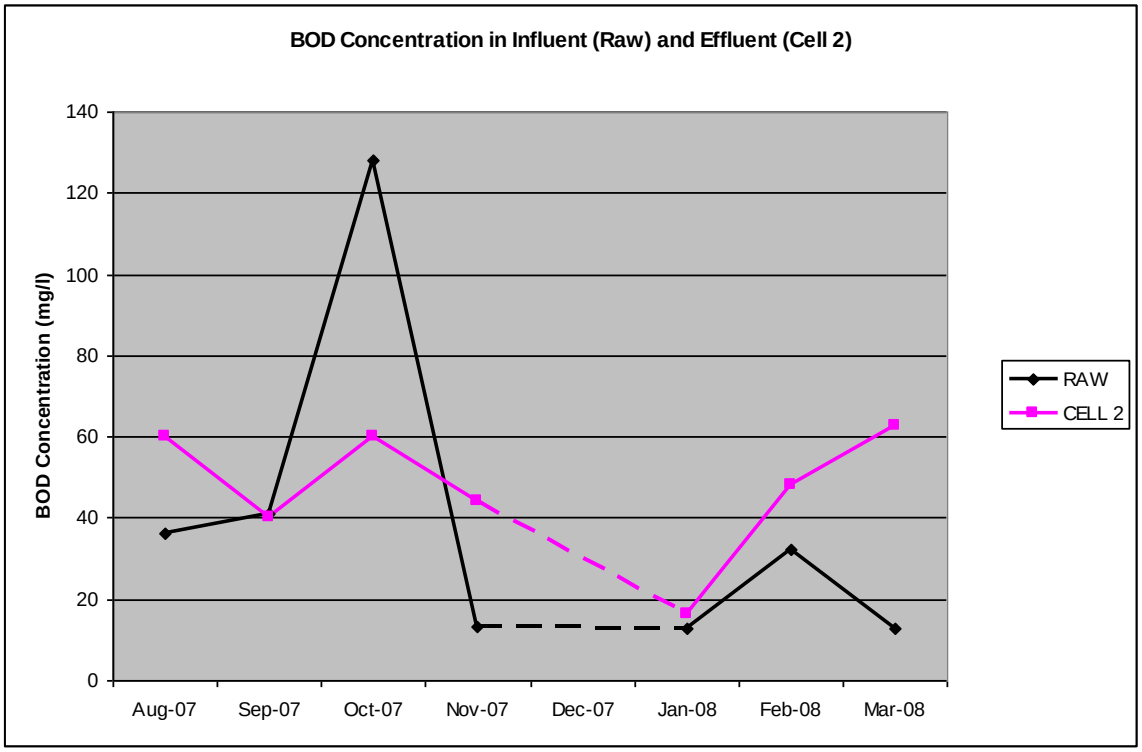


Figure 8.12(a) BOD Concentration in Influent (Raw) and Effluent (Cell 2)

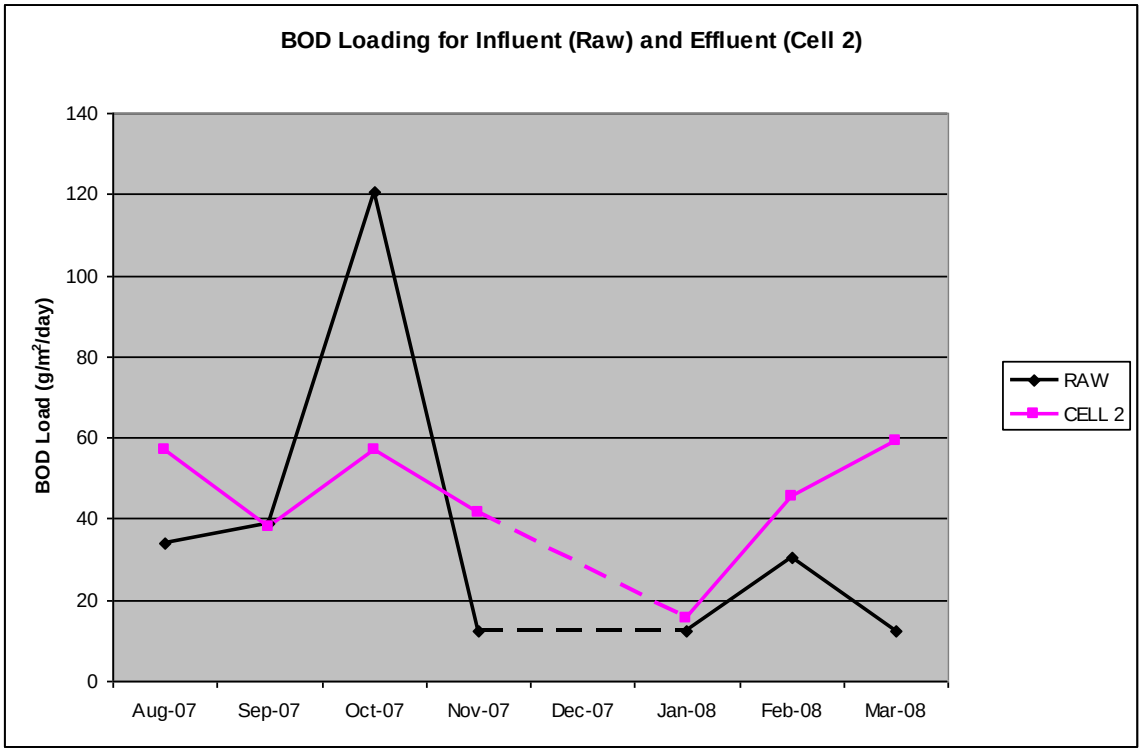


Figure 8.12(b) BOD Loading for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.13(a) Summary of BOD Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
BOD	Influent	8	13 - 128	41 (± 36)	52
BOD	Effluent	3	29 - 129	73 (± 51)	69

Table 8.13(b) Summary of BOD Load Removal for Cell 3

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
BOD	-17	-33

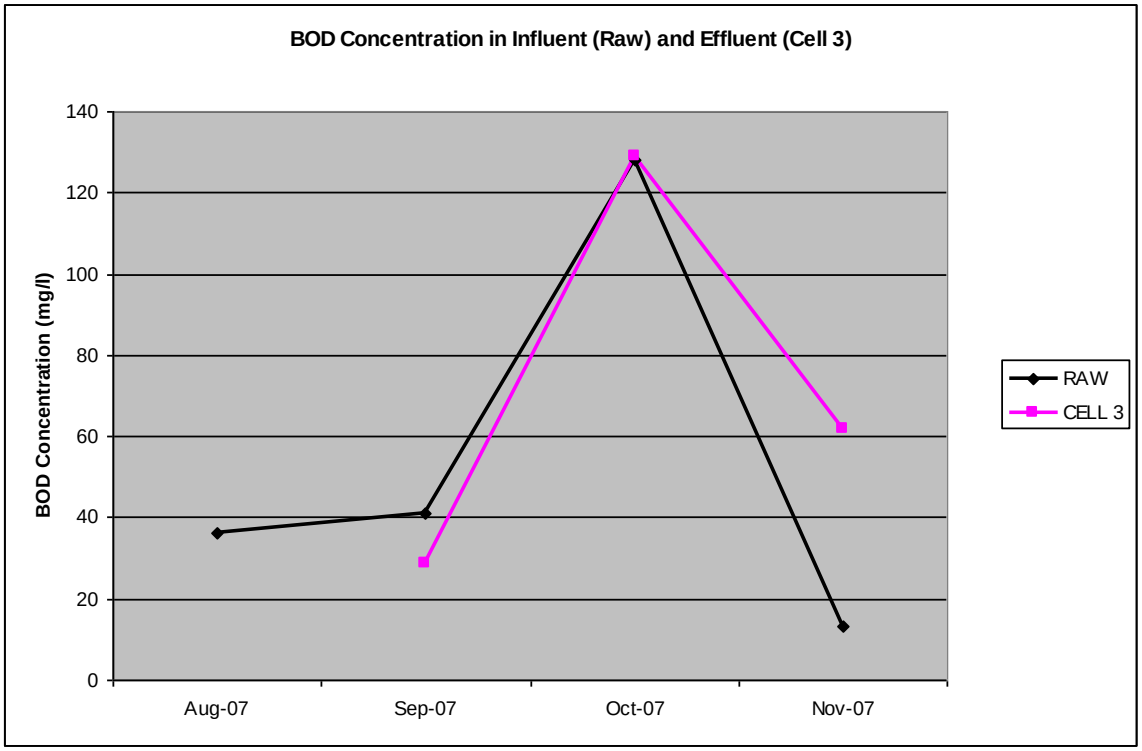


Figure 8.13(a) BOD Concentration in Influent (Raw) and Effluent (Cell 3)

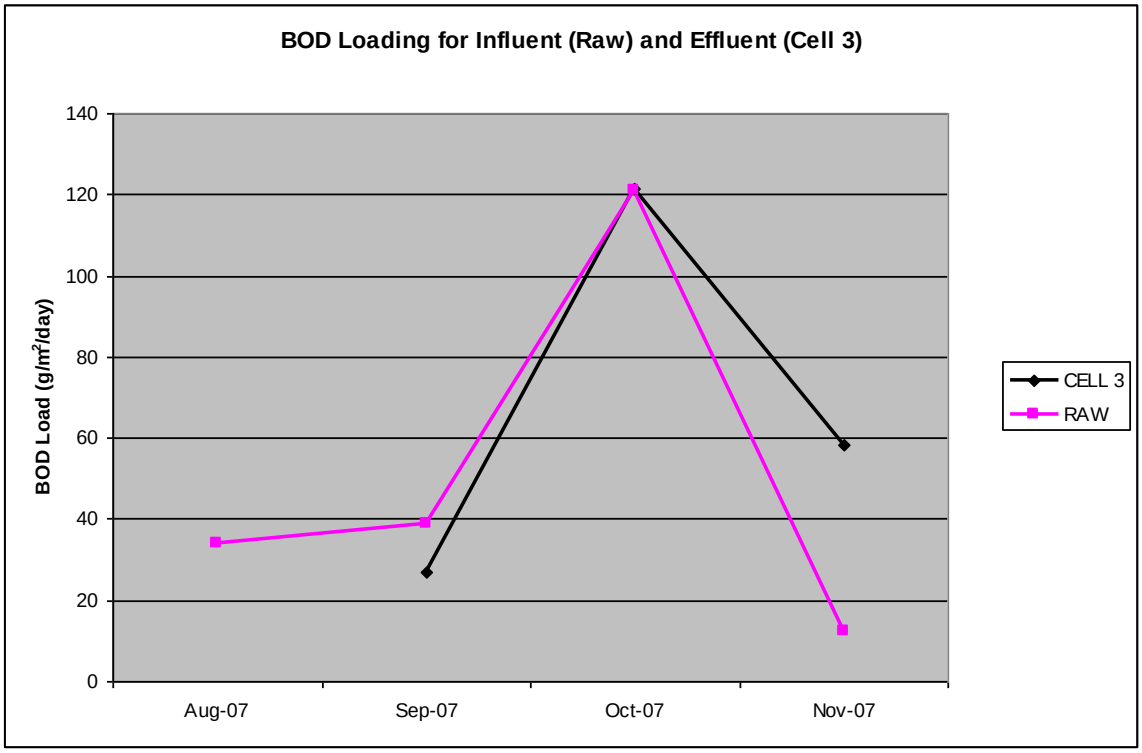


Figure 8.13(b) BOD Loading for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.14(a) Summary of BOD Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
BOD	Influent	17	10 - 128	31 (± 27)	36
BOD	Effluent	8	32 - 130	62 (± 35)	59

Table 8.14(b) Summary of BOD Load Removal for Cell 4

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
BOD	-23	-64

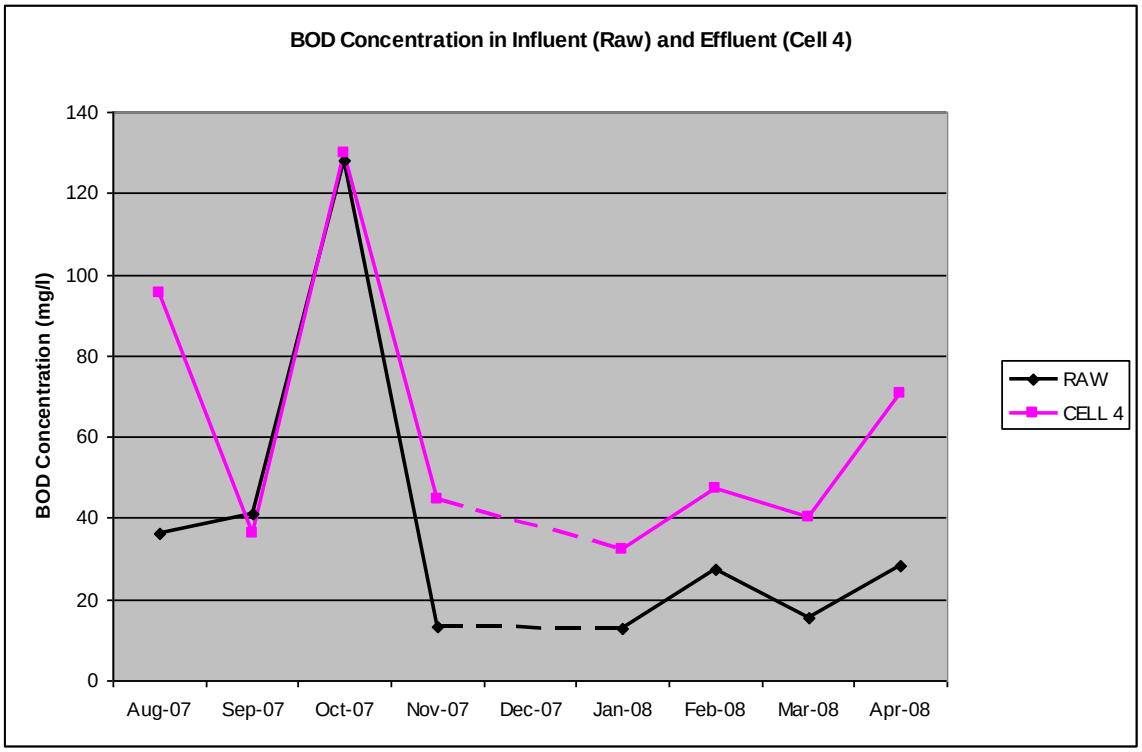


Figure 8.14(a) BOD Concentration in Influent (Raw) and Effluent (Cell 4)

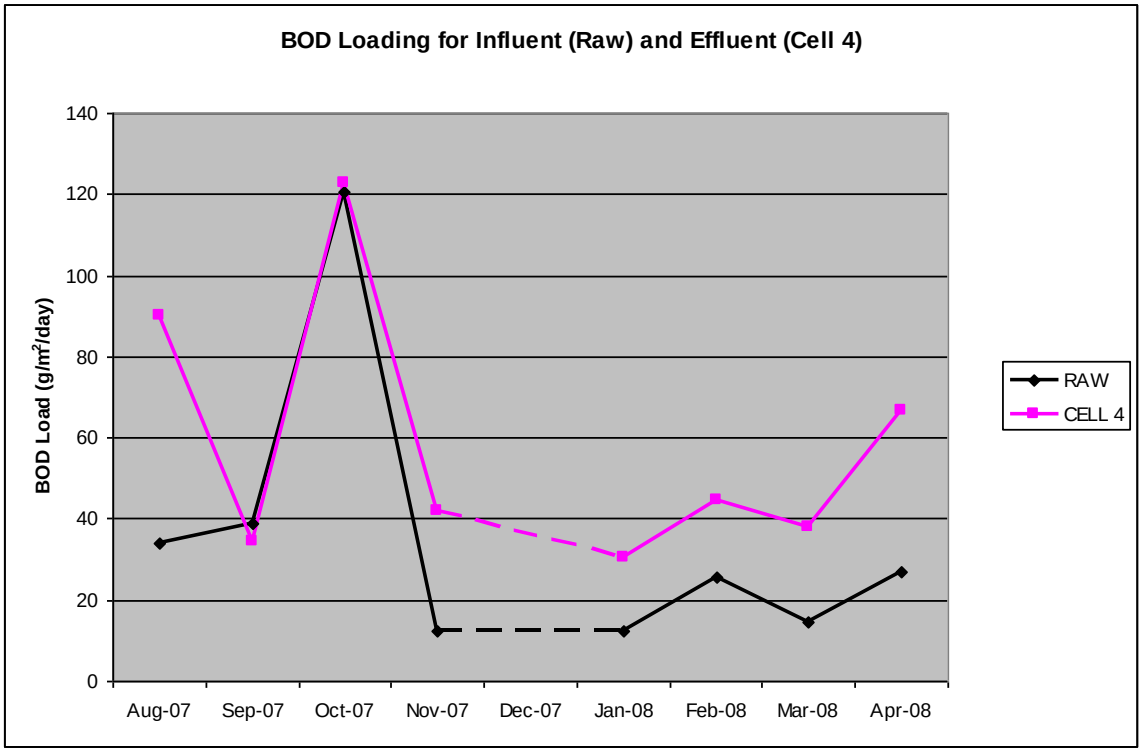


Figure 8.14(b) BOD Loading for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.15(a) Summary of BOD Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
BOD	Influent	22	10 - 128	29 (± 24)	4
BOD	Effluent	7	13 - 71	29 (± 20)	5

Table 8.15(b) Summary of BOD Load Removal for Cell 5

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
BOD	-1	-25

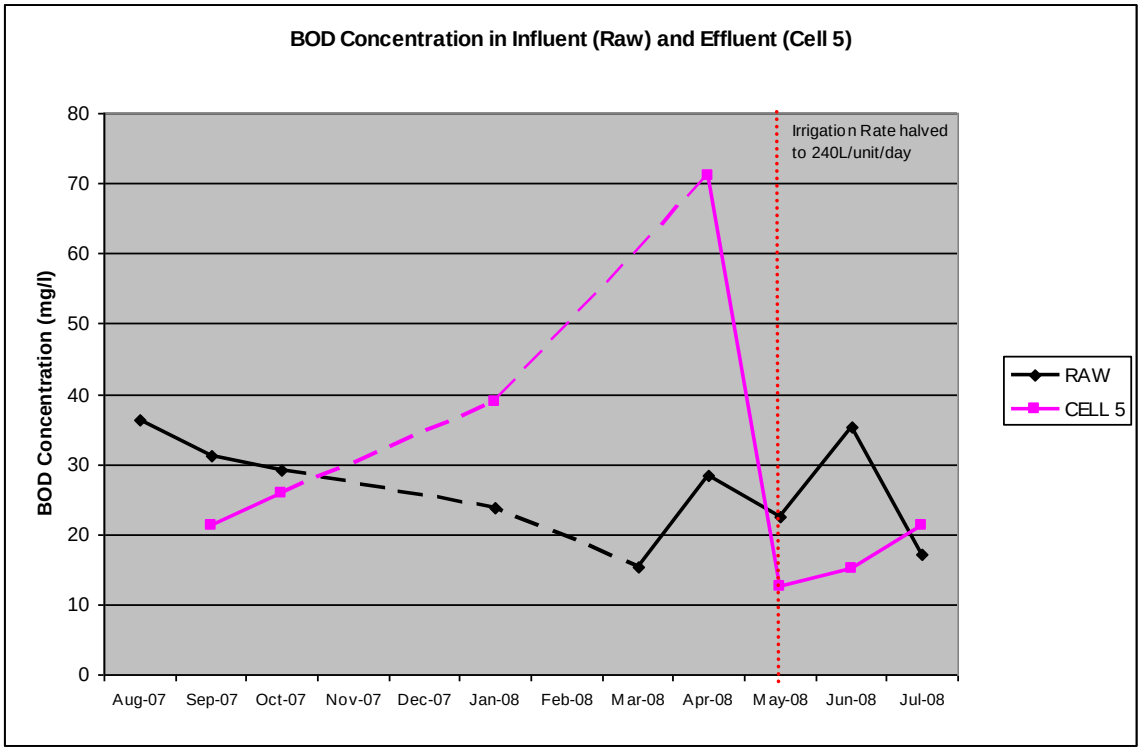


Figure 8.15(a) BOD Concentration in Influent (Raw) and Effluent (Cell 5)

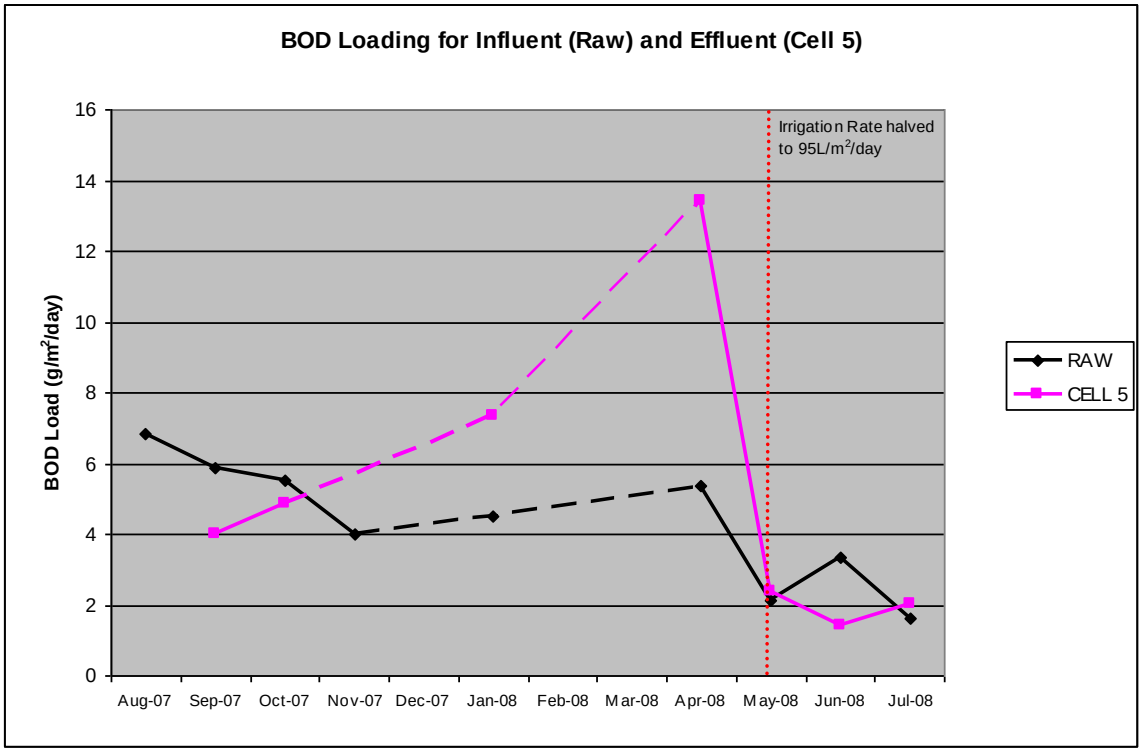


Figure 8.15(b) BOD Loading for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.16(a) Summary of BOD Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
BOD	Influent	23	10 - 128	30 (± 24)	11
BOD	Effluent	9	7 - 89	41 (± 25)	17

Table 8.16(b) Summary of BOD Load Removal for Cell 6

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
BOD	-6	-55

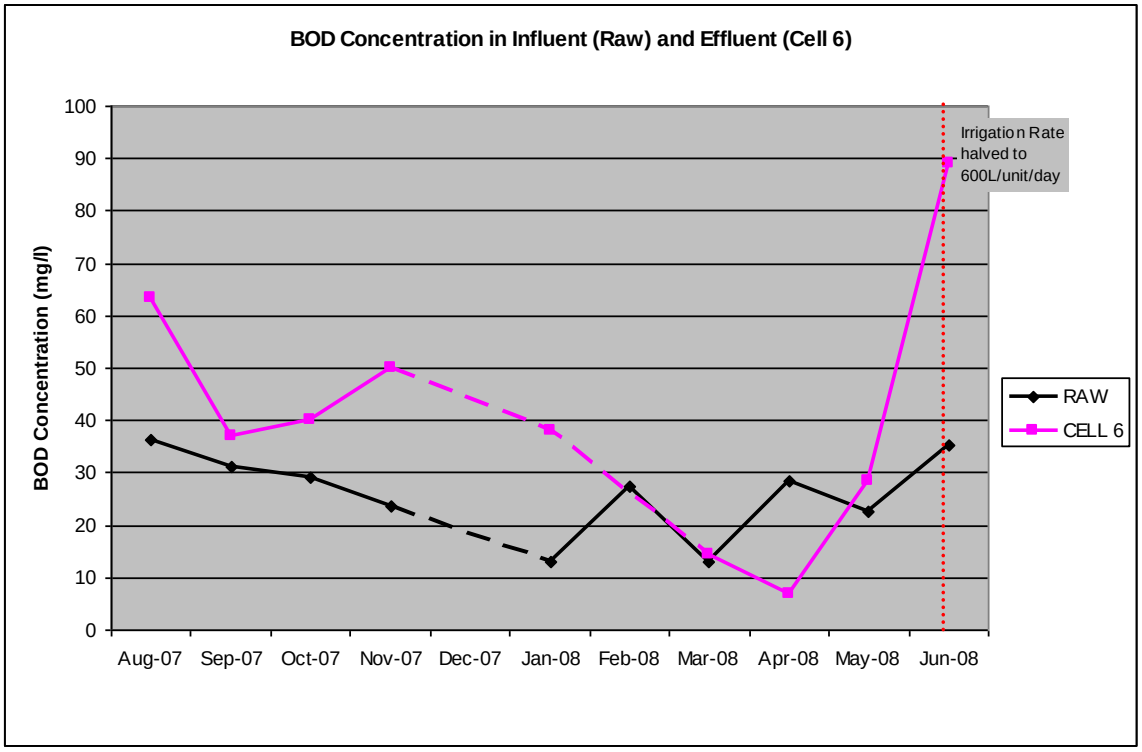


Figure 8.16(a) BOD Concentration in Influent (Raw) and Effluent (Cell 6)

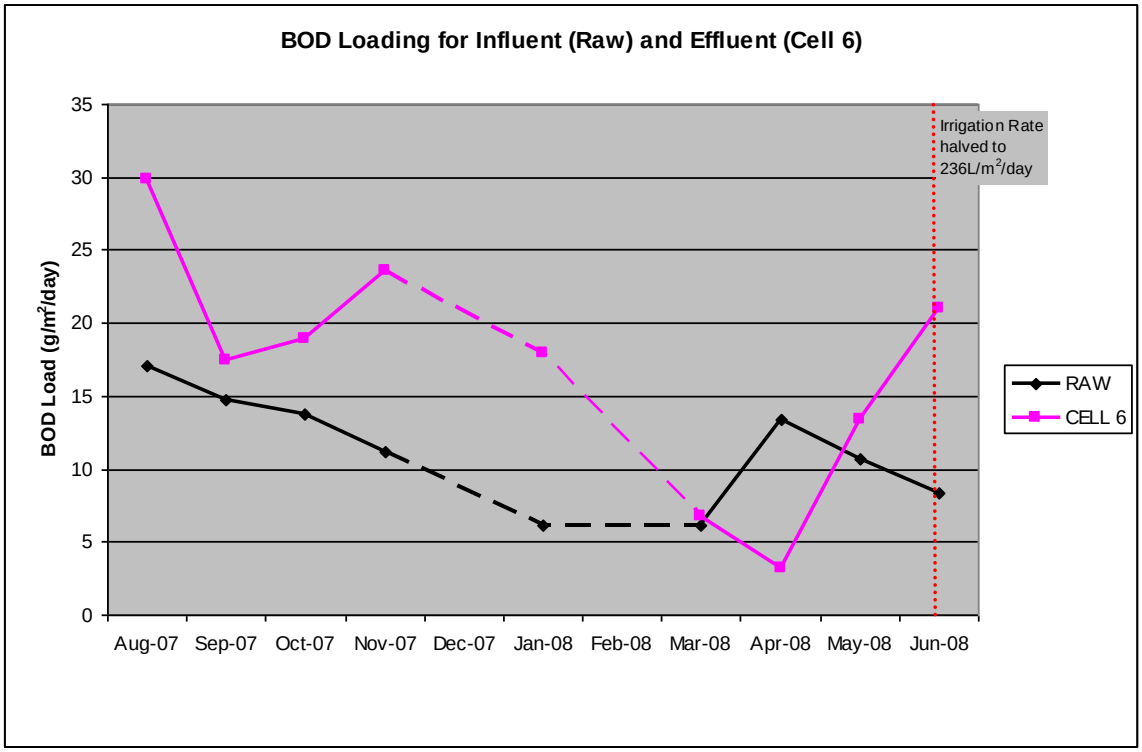


Figure 8.16(b) BOD Loading for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.17(a) Summary of BOD Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
BOD	Influent	24	10 - 128	28 (± 23)	21
BOD	Effluent	11	8 - 81	39 (± 26)	30

Table 8.17(b) Summary of BOD Load Removal for Cell 7

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
BOD	-9	-43

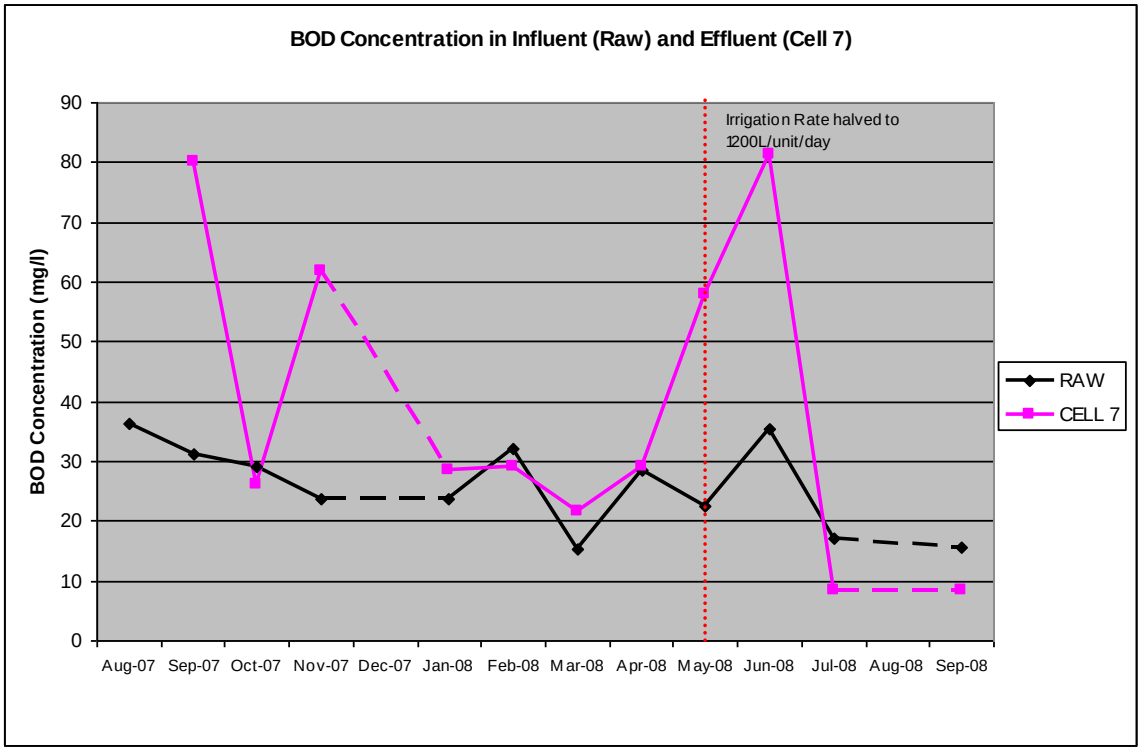


Figure 8.17(a) BOD Concentration in Influent (Raw) and Effluent (Cell 7)

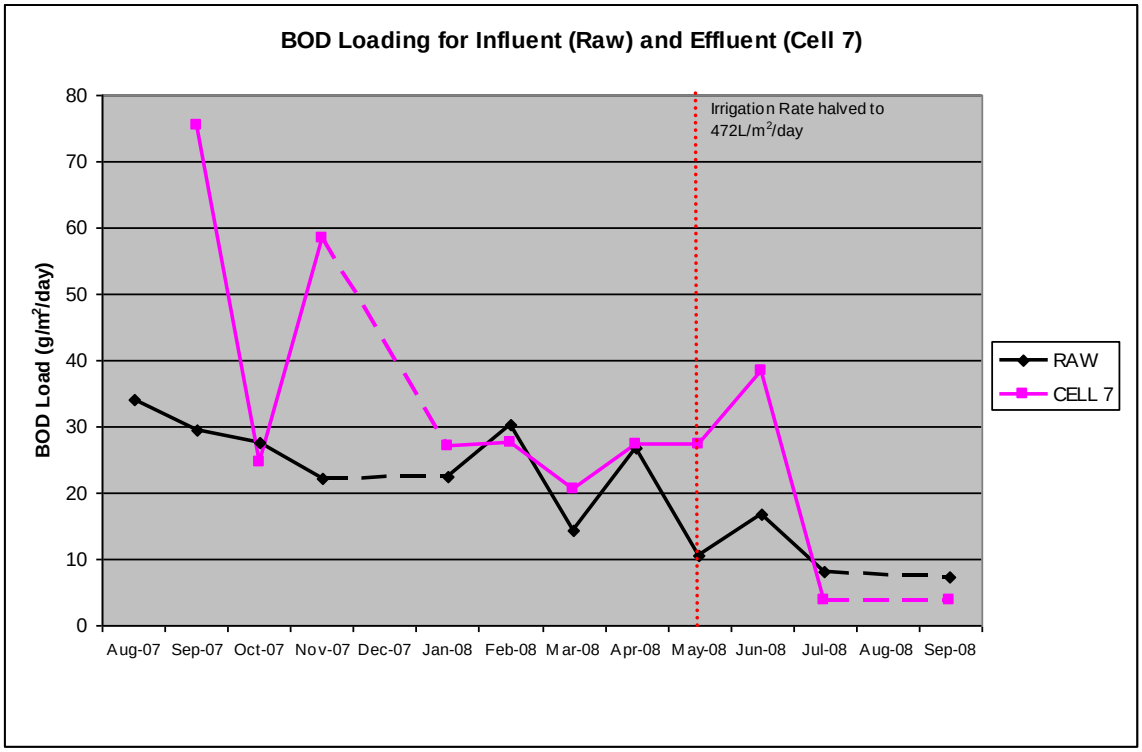


Figure 8.17(b) BOD Loading for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.18(a) Summary of BOD Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
BOD	Influent	24	10 - 228	28 (± 23)	10
BOD	Effluent	9	12 - 98	39 (± 29)	13

Table 8.18(b) Summary of BOD Load Removal for Cell 8

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
BOD	-3	-30

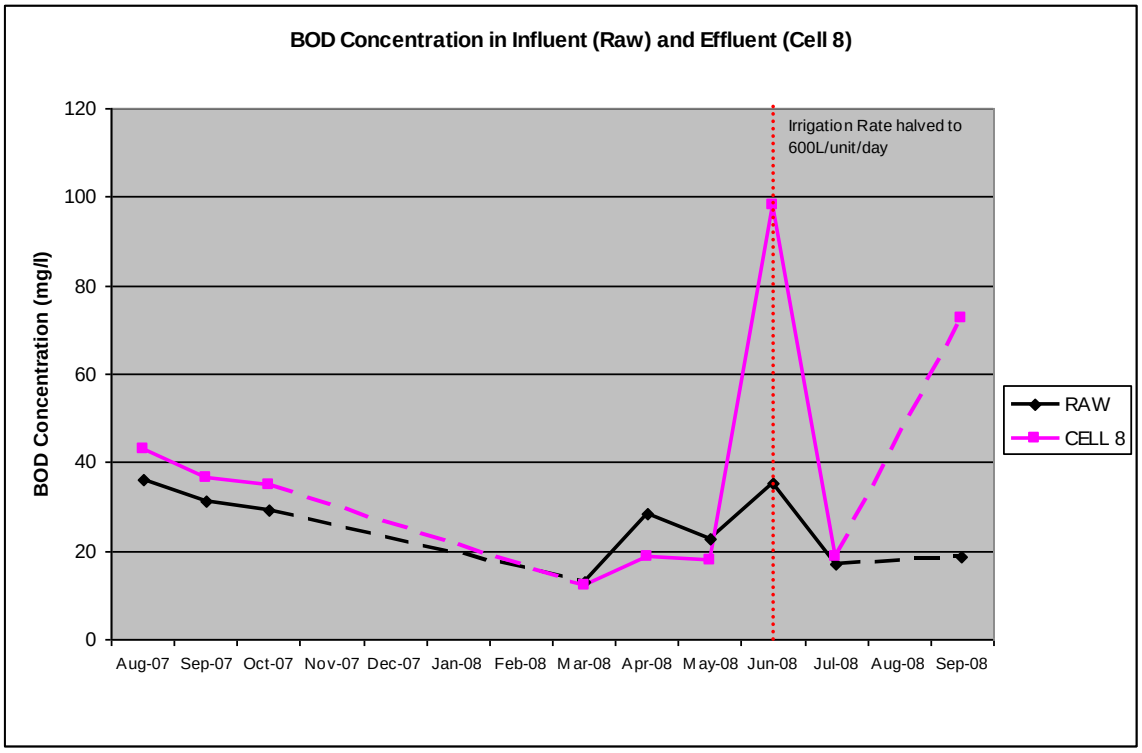


Figure 8.18(a) BOD Concentration in Influent (Raw) and Effluent (Cell 8)

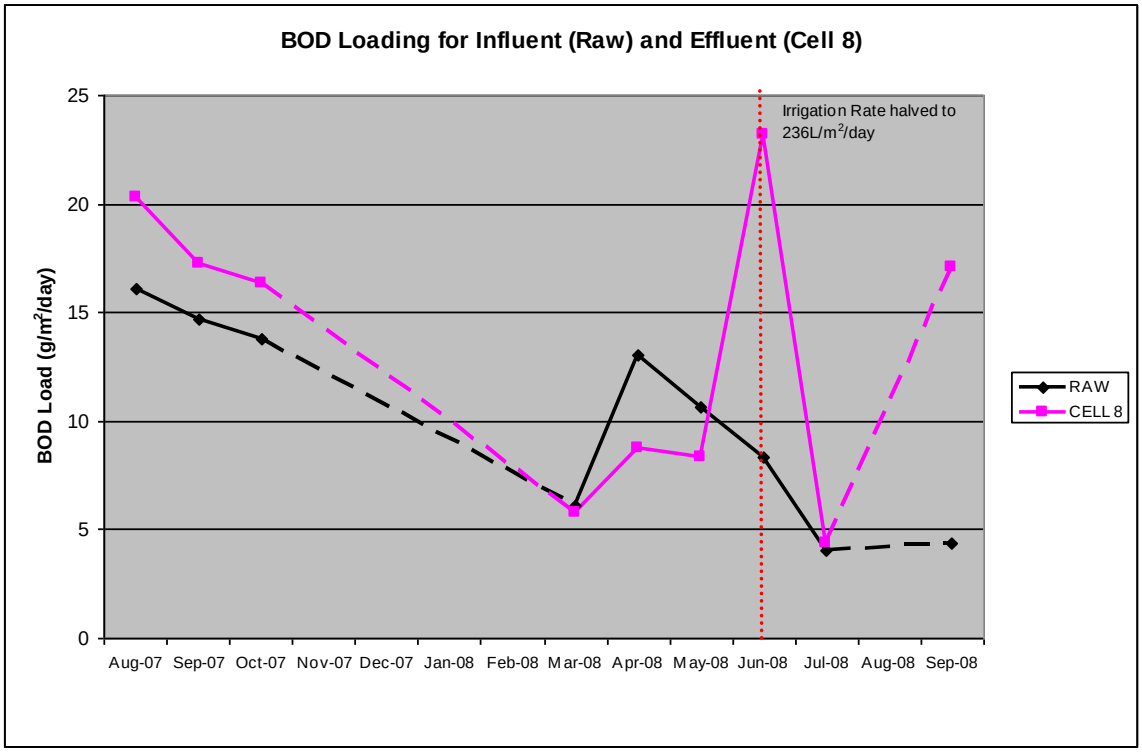


Figure 8.18(b) BOD Loading for Influent (Raw) and Effluent (Cell 8)

8.2.3.2 COD Removal in Individual Treatment Units

COD concentrations and removal efficiencies for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.19(a) to 8.26(b).

Charts detailing the range of COD concentrations and loadings for cells 1 to 8 are presented in Figures 8.19(a) to 8.26(b).

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.19(a) Summary of COD Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
COD	Influent	7	259 - 559	367 (± 120)	326
COD	Effluent	3	260 - 344	311 (± 45)	293

Table 8.19(b) Summary of COD Load Removal for Cell 1

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
COD	33	10%

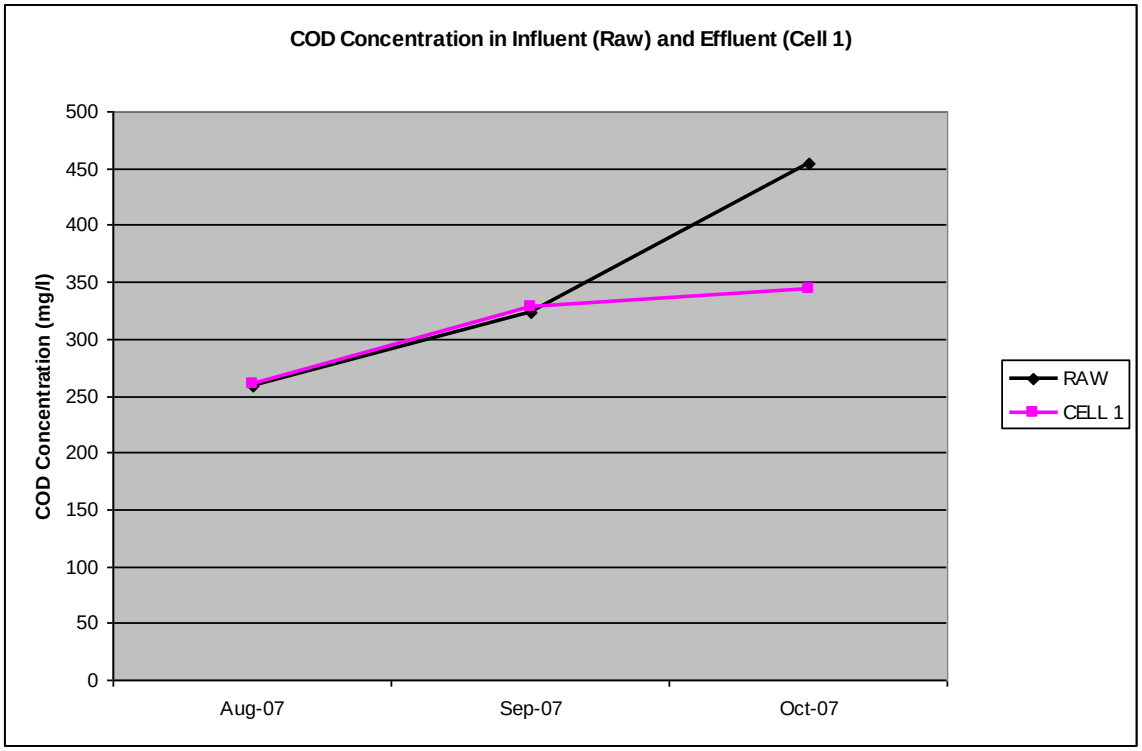


Figure 8.19(a) COD Concentration in Influent (Raw) and Effluent (Cell 1)

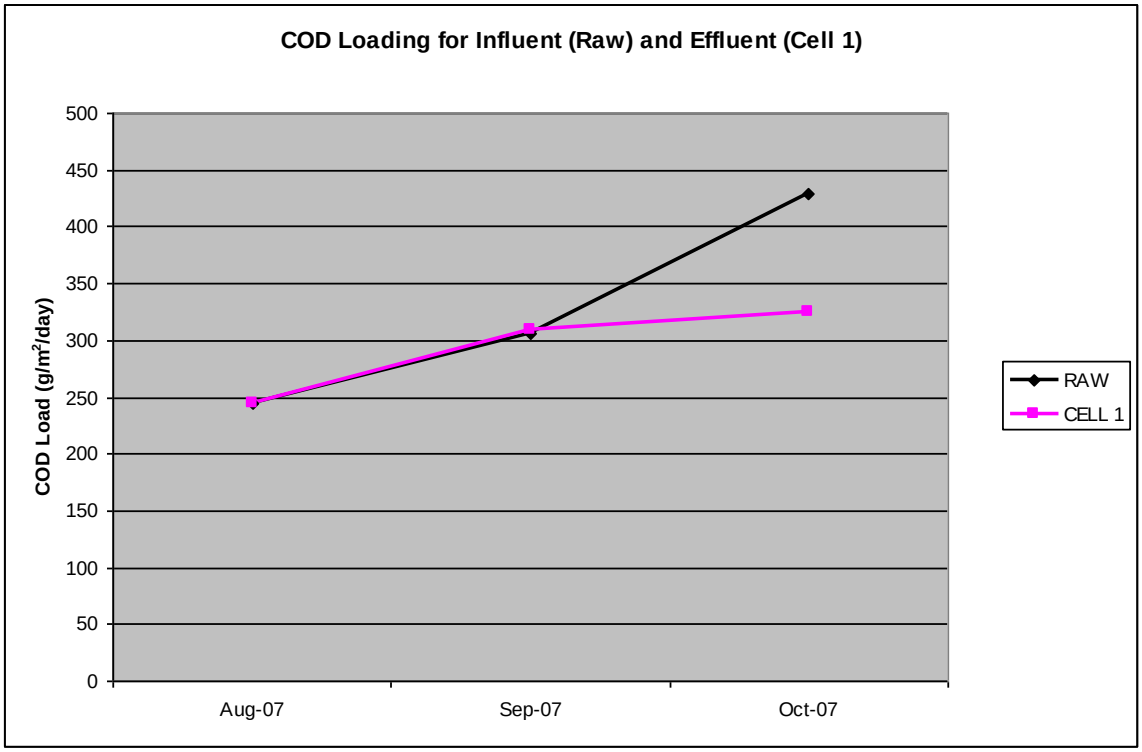


Figure 8.19(b) COD Loading for Influent (Raw) and Effluent (Cell 1)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.20(a) Summary of COD Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
COD	Influent	17	121 - 599	259 (± 124)	254
COD	Effluent	7	107 - 308	236 (± 83)	223

Table 8.20(b) Summary of COD Load Removal for Cell 2

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
COD	32	13

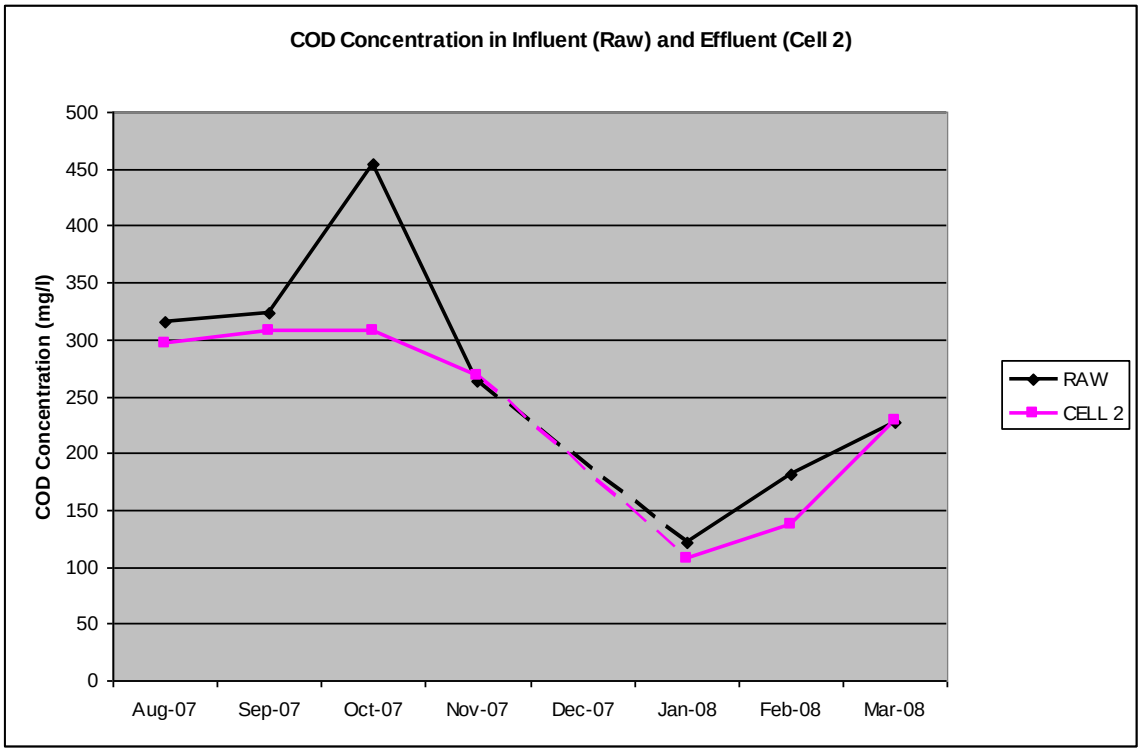


Figure 8.20(a) COD Concentration in Influent (Raw) and Effluent (Cell 2)

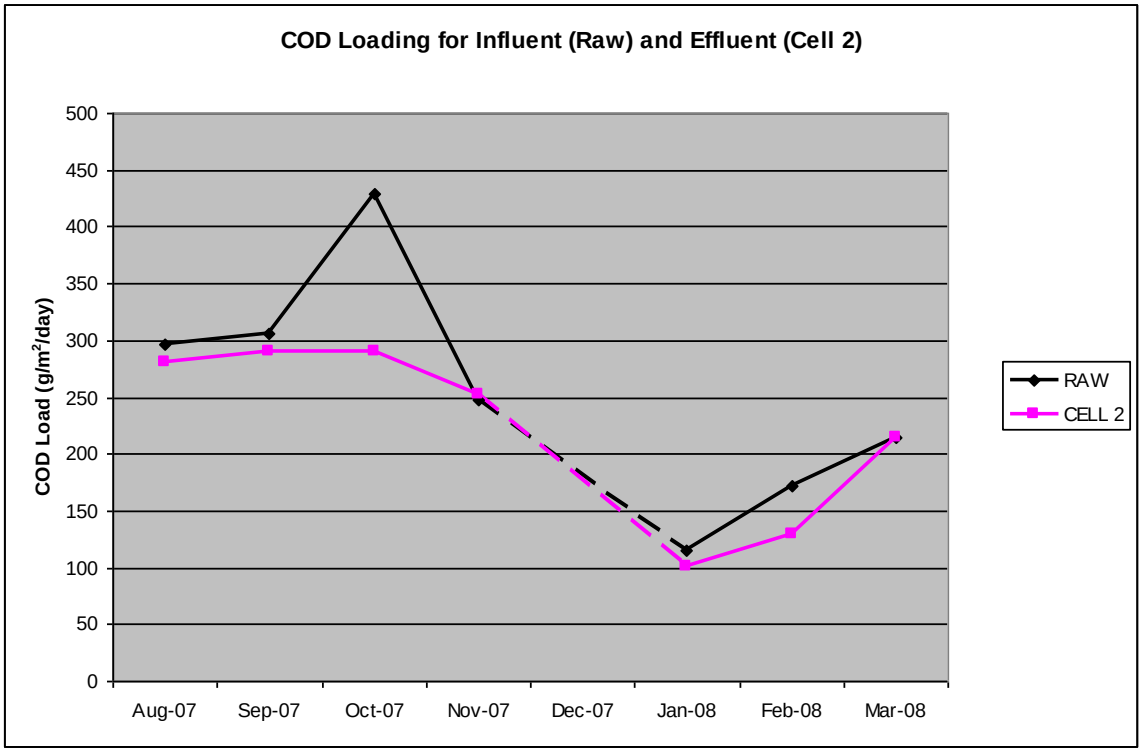


Figure 8.20(b) COD Loading for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.21(a) Summary of COD Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
COD	Influent	10	193 - 599	322 (± 123)	307
COD	Effluent	4	253 - 478	300 (± 105)	311

Table 8.21(b) Summary of COD Load Removal for Cell 3

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
COD	-4	-1

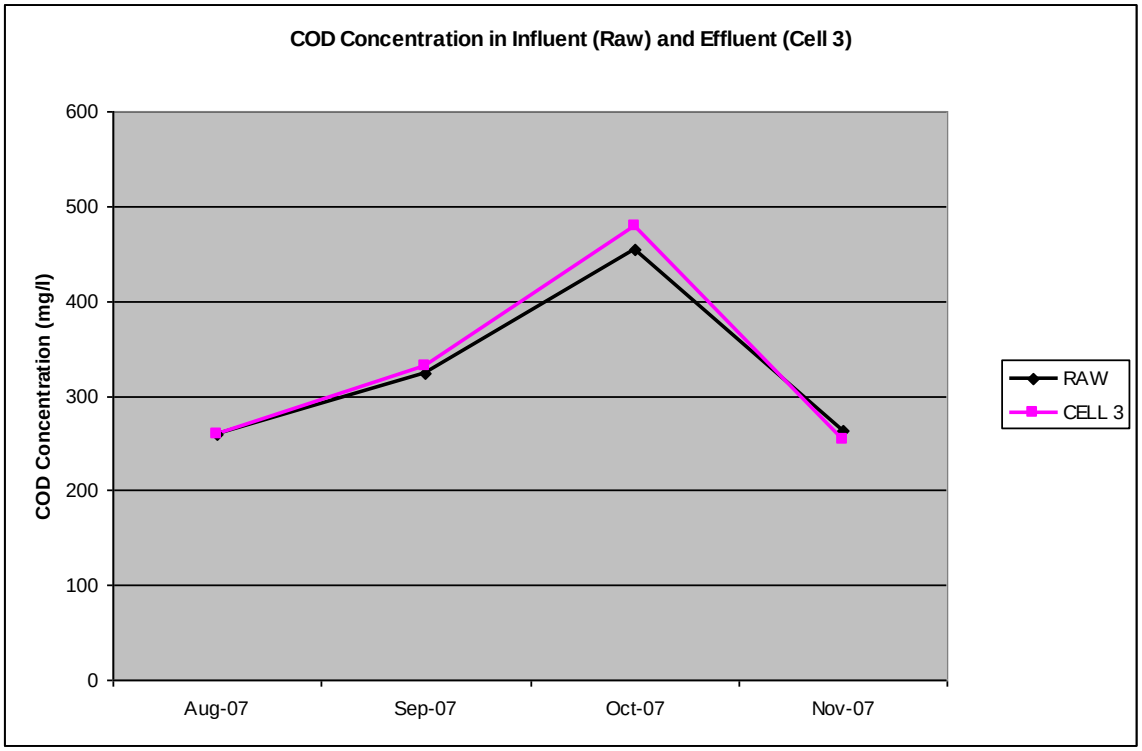


Figure 8.21(a) COD Concentration in Influent (Raw) and Effluent (Cell 3)

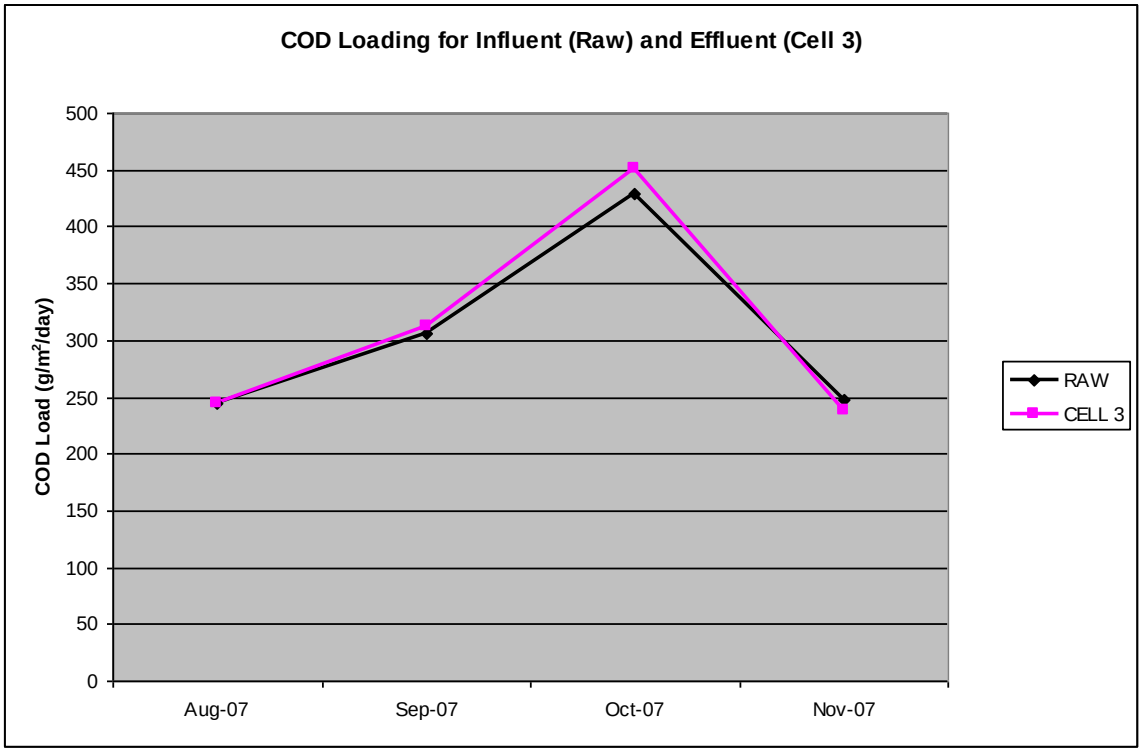


Figure 8.21(b) COD Loading for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.22(a) Summary of COD Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
COD	Influent	19	121 - 599	262 (± 118)	254
COD	Effluent	8	111 - 481	259 (± 116)	253

Table 8.22(b) Summary of COD Load Removal for Cell 4

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
COD	1	0.4

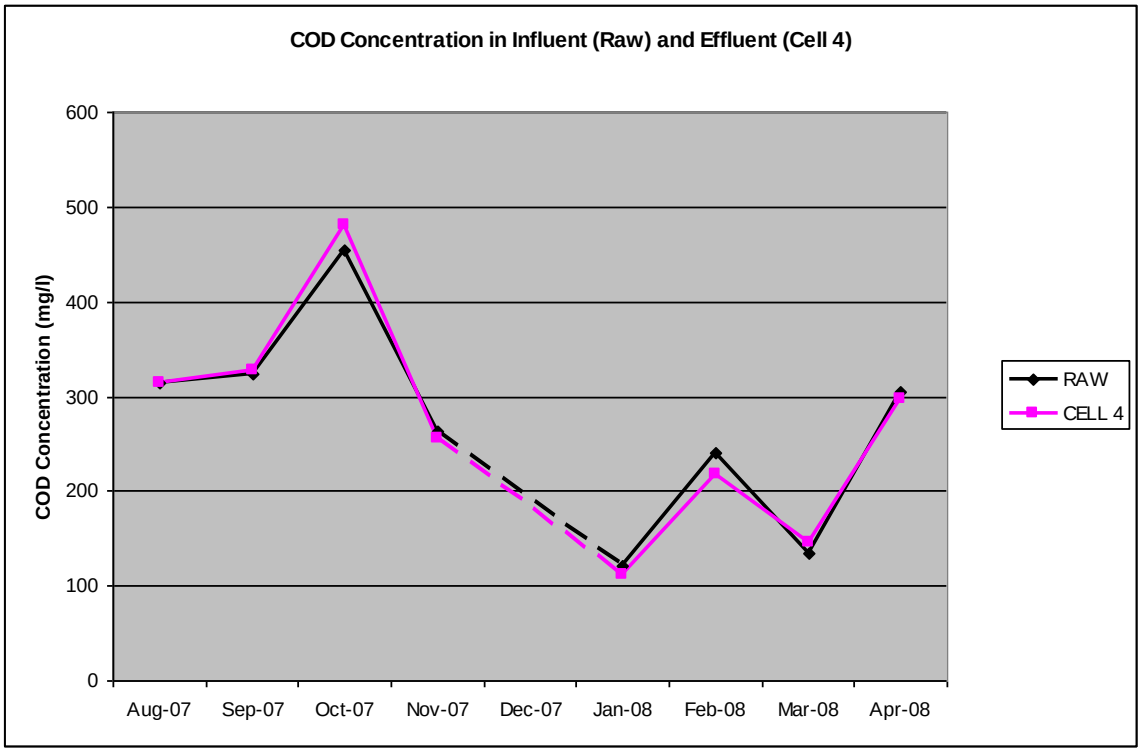


Figure 8.22(a) COD Concentration in Influent (Raw) and Effluent (Cell 4)

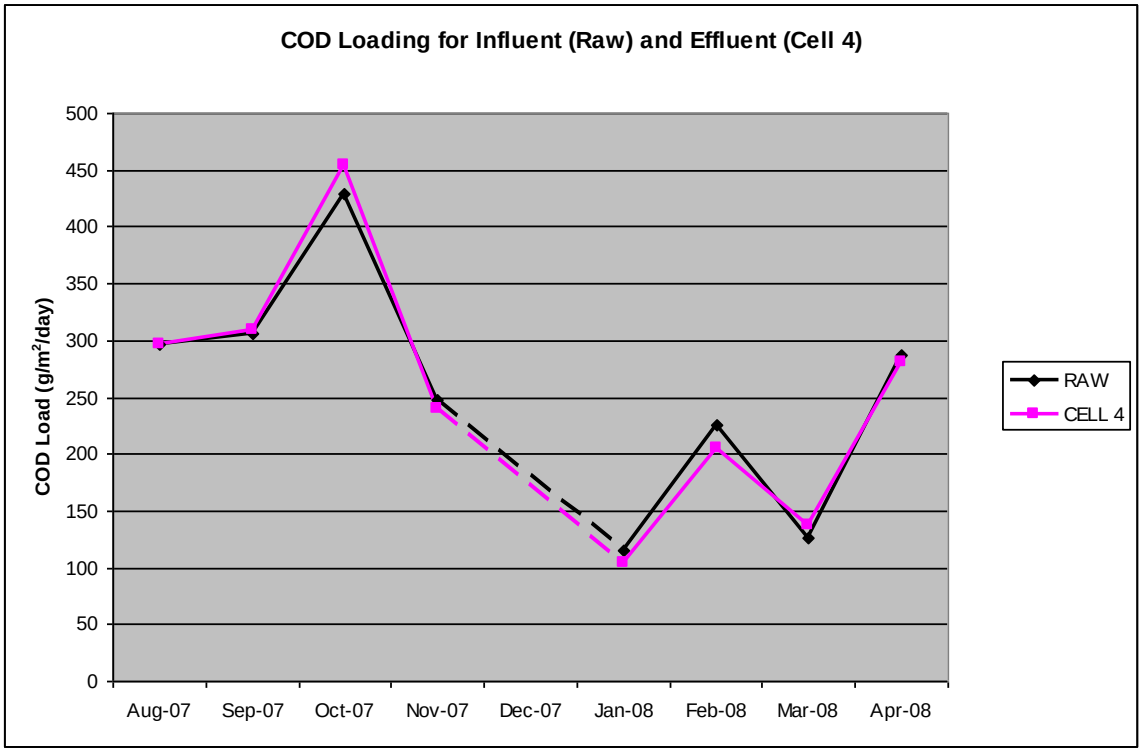


Figure 8.22(b) COD Loading for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.23(a) Summary of COD Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
COD	Influent	23	121 - 599	257 (± 106)	39
COD	Effluent	8	174 - 306	245 (± 51)	38

Table 8.23(b) Summary of COD Load Removal for Cell 5

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
COD	1	3

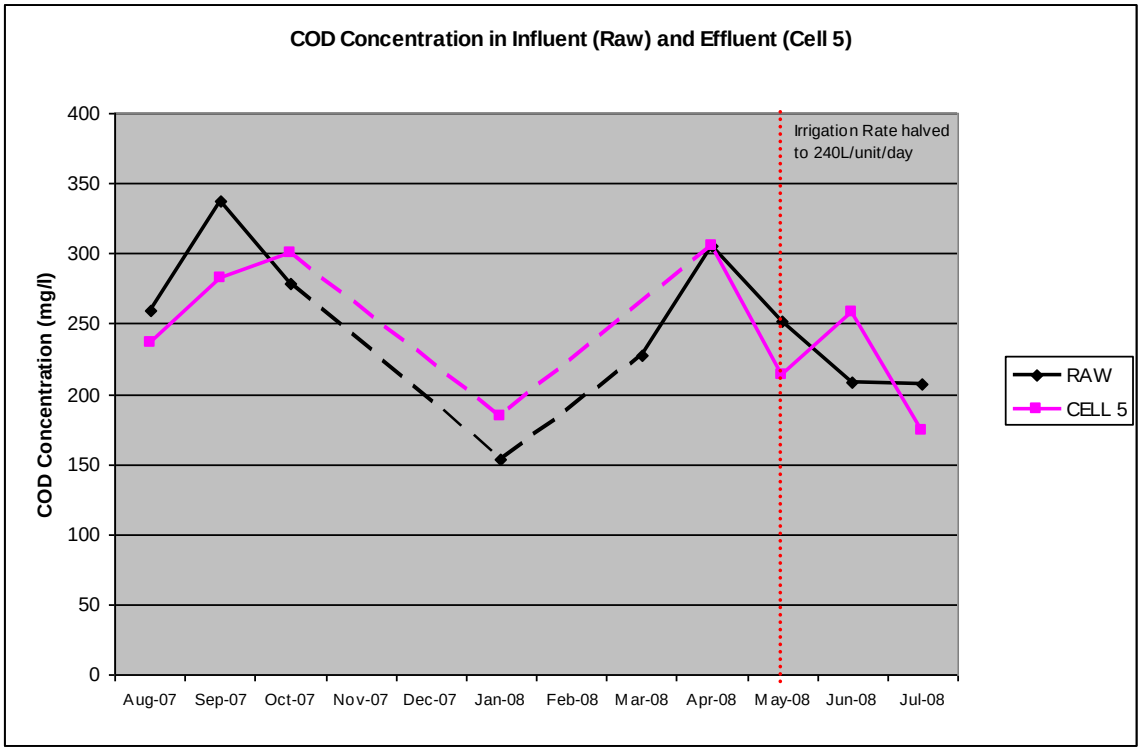


Figure 8.23(a) COD Concentration in Influent (Raw) and Effluent (Cell 5)

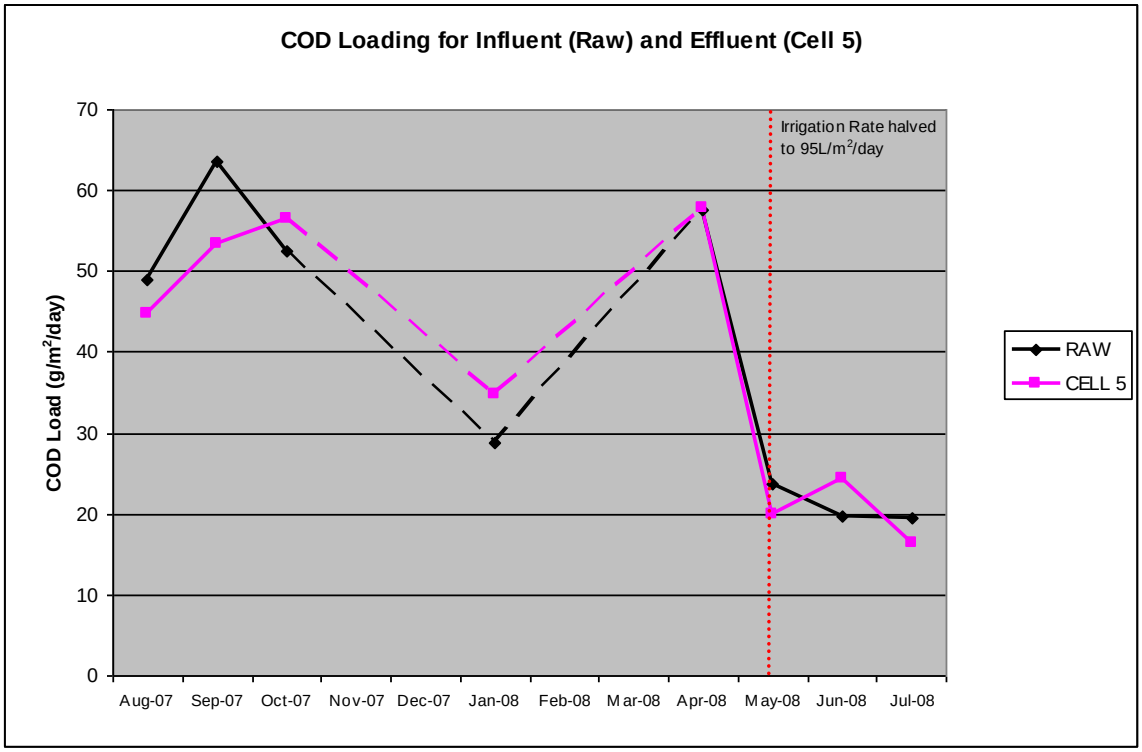


Figure 8.23(b) COD Loading for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.24(a) Summary of COD Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
COD	Influent	23	121 - 599	259 (± 108)	112
COD	Effluent	9	123 - 324	236 (± 75)	105

Table 8.24(b) Summary of COD Load Removal for Cell 6

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
COD	7	6

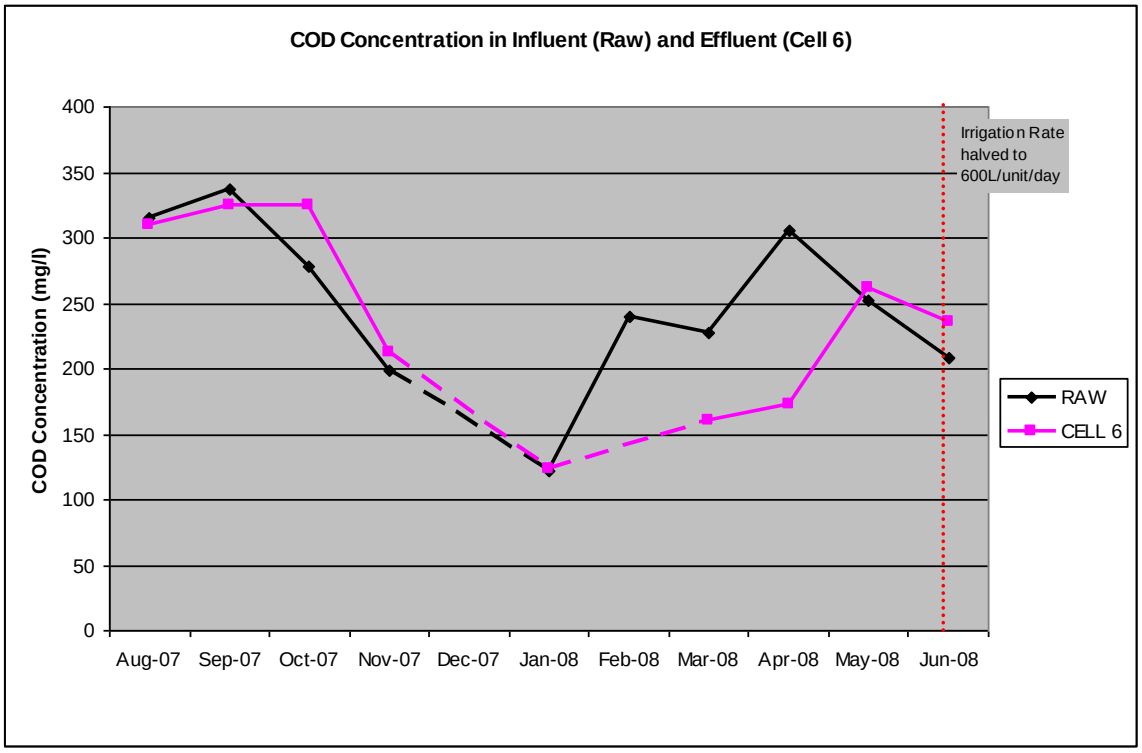


Figure 8.24(a) COD Concentration in Influent (Raw) and Effluent (Cell 6)

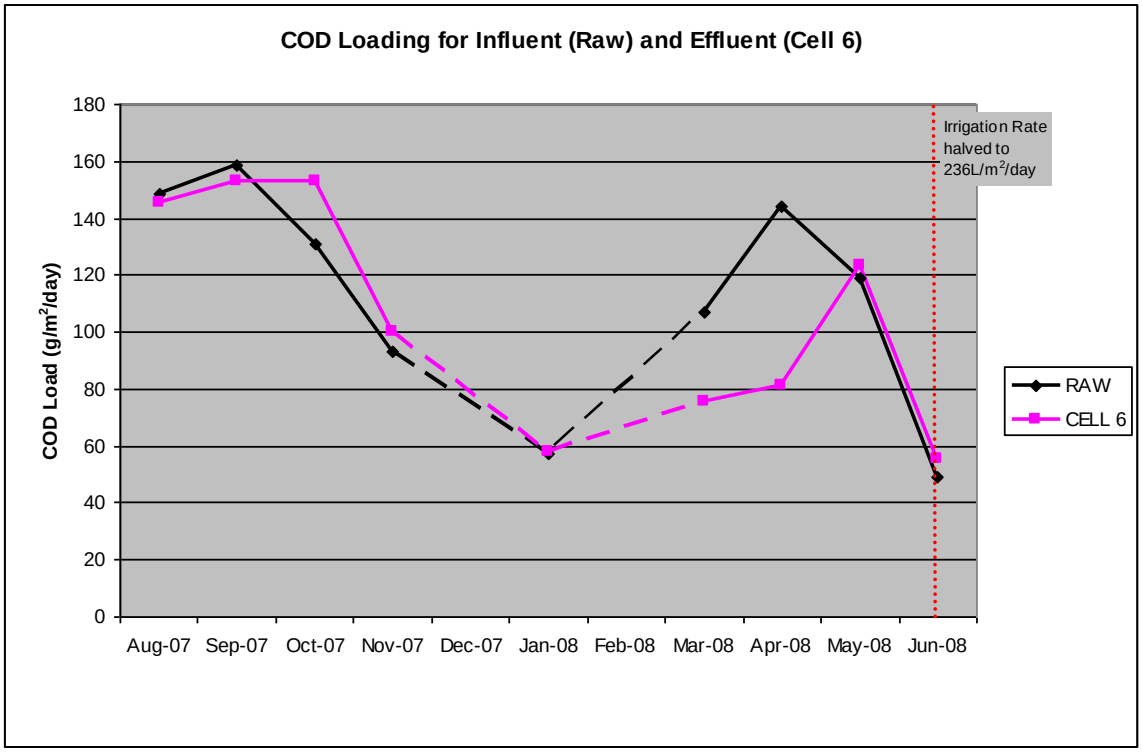


Figure 8.24(b) COD Loading for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.25(a) Summary of COD Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
COD	Influent	26	121 - 599	256 (± 103)	179
COD	Effluent	12	132 - 355	235 (± 61)	188

Table 8.25(b) Summary of COD Load Removal for Cell 7

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
COD	-9	-5

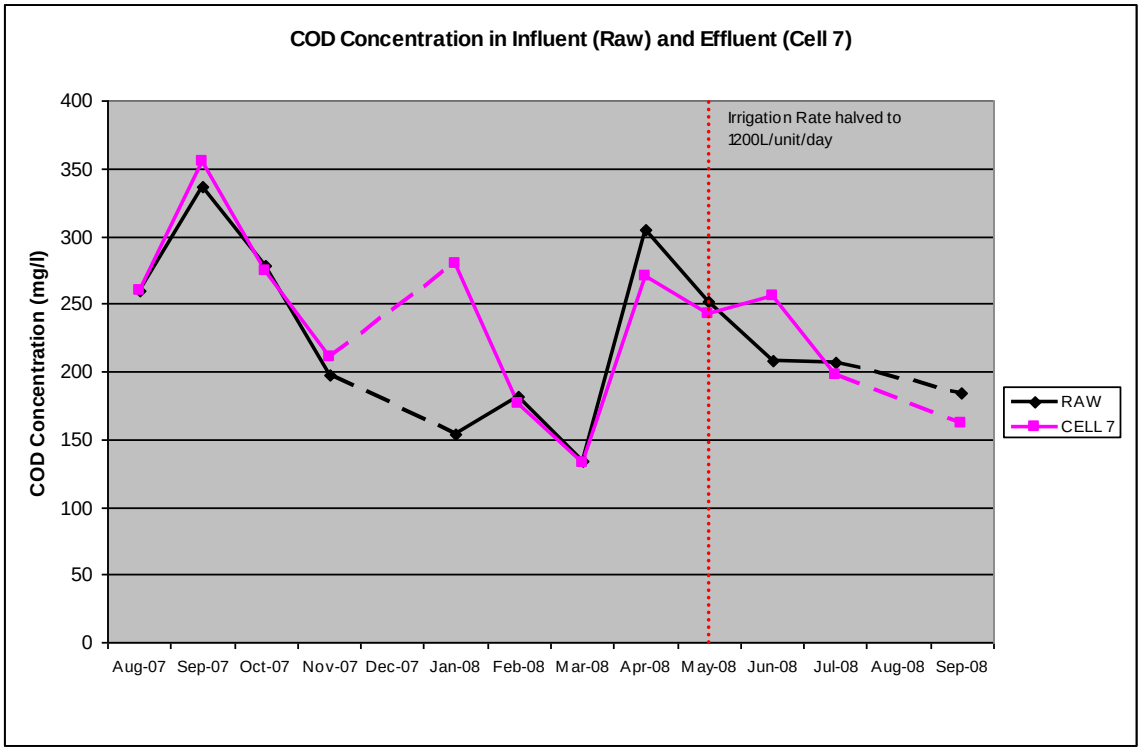


Figure 8.25(a) COD Concentration in Influent (Raw) and Effluent (Cell 7)

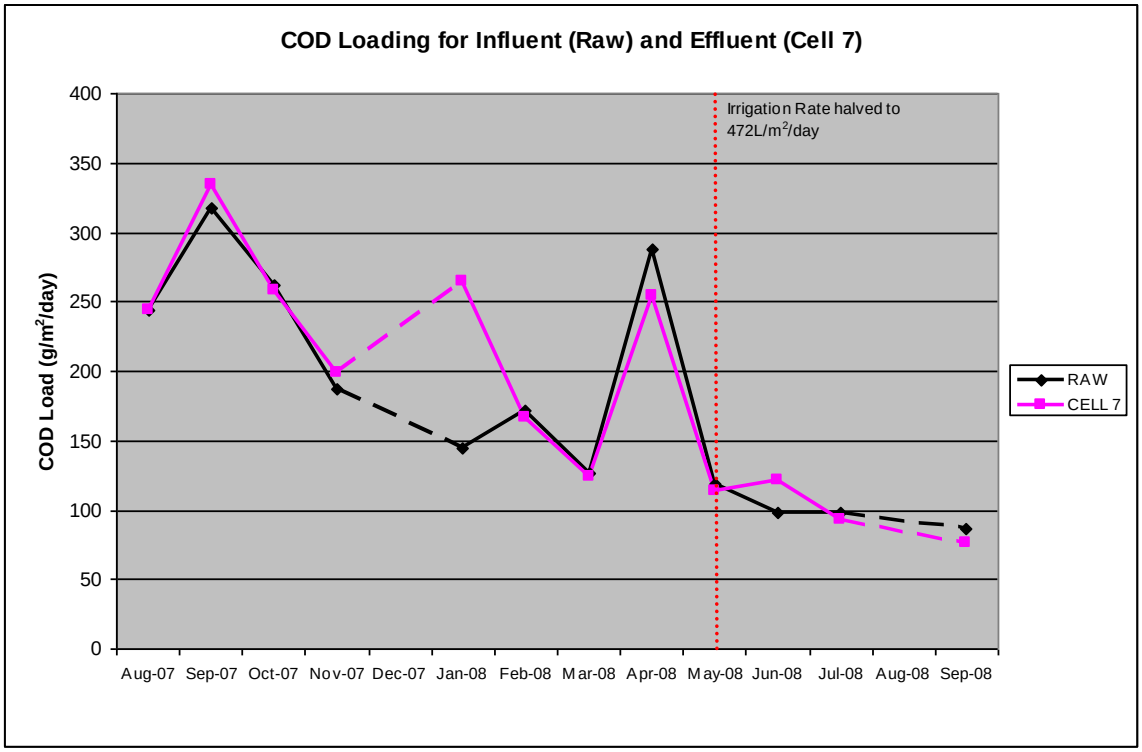


Figure 8.25(b) COD Loading for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.26(a) Summary of COD Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
COD	Influent	26	121 - 599	256 (± 103)	108
COD	Effluent	9	169 - 326	257 (± 53)	104

Table 8.26(b) Summary of COD Load Removal for Cell 8

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
COD	4	4

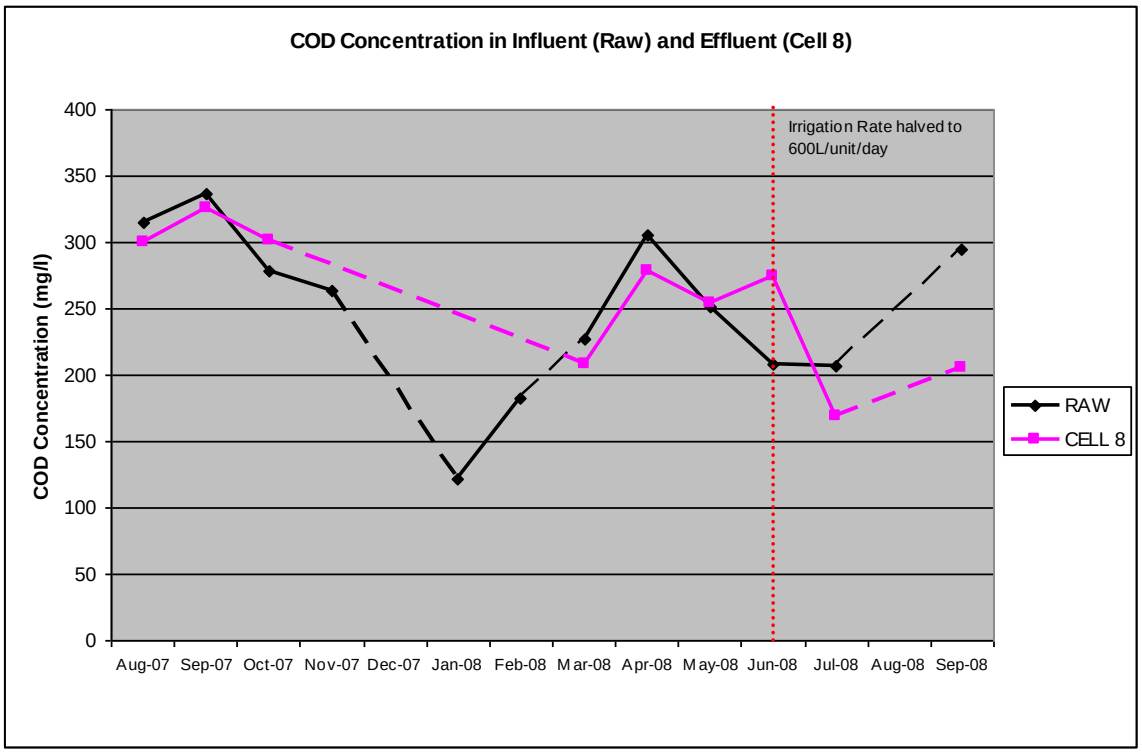


Figure 8.26(a) COD Concentration in Influent (Raw) and Effluent (Cell 8)

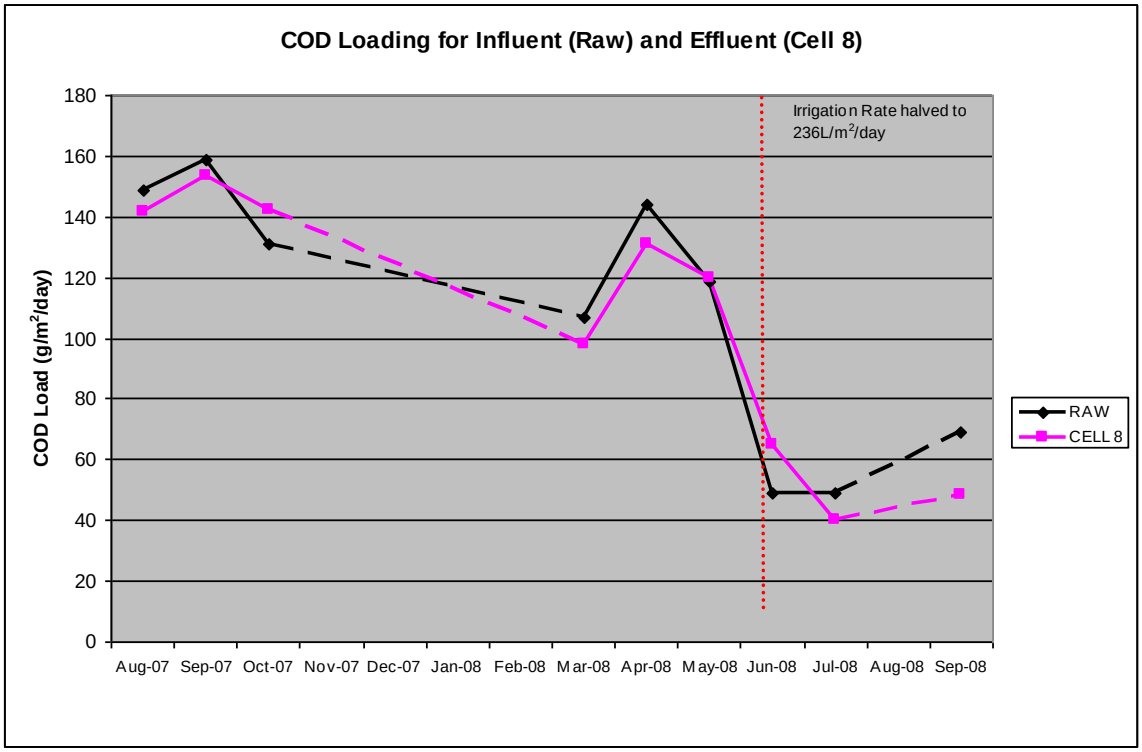


Figure 8.26(b) COD Loading for Influent (Raw) and Effluent (Cell 8)

8.2.3.3 Interpretation of Organics Removal in Individual Treatment Units

Inspection of the results obtained for load removal rates for organics within cells 1 to 8 displays a wide variance both between the units and within the sampling period of each individual unit.

A broad analysis of BOD_5 results shows negative load removal and an increase in effluent concentrations. Cell 1 was the exception to this (Figure 8.11(b)), displaying a positive average load removal of 3g/m^2/day (removal rate of 5%). However due to the low sampling number (two samples over the three months of operation) no statistical significance could be attributed to the results.

Cells 2, 3, 4 and 6 displayed almost entirely negative BOD_5 load removal throughout the sampling period (Figures 8.12(b) – 8.14(b) and 8.16(b)),

Cells 5, 7 and 8, while still showing a minus average for BOD_5 load removal, the results were somewhat more erratic with occasional positive load removal coupled with high negative load removal (Figures 8.15(b), 8.17(b) and 8.18(b).

A 50% reduction in the loading rate in the latter stages of operation for cells 5, 6, 7 and 8 did not have any discernable impact in terms of increased treatment efficiency; the result was instead a mixture of positive and negative load removal rates.
The data are too erratic to discern a pattern, seasonal or otherwise and in some instances, missing data sets further confuse the issue.

Analysis of COD data also show a mixed set of results across the treatment units. Cells 1, 2, 5, 6 and 8 all display positive COD average load removals of 33g/m^2/day, 32g/m^2/day, 7g/m^2/day, 1g/m^2/day and 4g/m^2/day respectively (10%, 13%, 3%, 6% and 4% load removal respectively) (Figures 8.19(b), 8.20(b), 8.23(b), 8.24(b) and 8.26(b)). Cell 4 had an average load removal of 0.4% (8.22(b)).
Of the cells displaying positive load removal, cell 2 was most consistent, with two slightly negative load removal results from seven samples (-5g/m^2/day and -1g/m^2/day in November 2007 and March 2008 respectively).
Cell 6 displays a possible seasonal flux in treatment efficiency (positive load removal in late summer and early spring); however, a longer temporal span of sampling would be required to confirm this. It should be noted that the flow and influent load to cells 6 and 8 was approximately half that of the other cells (with the exception of cell 5). This is considered significant in terms of effluent areal distribution as well as the rest periods between dosing events.

Negative average COD load removal was recorded for Cells 3 and 7 (Figures 8.21(b) and 8.25(b)). Each of the cells displayed erratic results for the sampling period alternating between positive and negative load removal, with cell 3 load removal ranging from -22 to 9g/m^2/day and cell 7 load removal ranging from -120 to 33g/m^2/day.
Once a again, a 50% reduction in the loading rate in the latter stages of operation for cells 5, 6, 7 and 8 did not have any discernable impact in terms of increased treatment efficiency; the result was instead a mixture of positive and negative load removal rates.

8.2.3.4 BOD_5 Removal in Treatment Units Operating in Sequence

BOD_5 concentrations, loading and removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.27(a) to 8.28(c).

Charts detailing the range of BOD_5 concentrations and loadings for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.27(a) to 8.28(c).

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.27(a) Summary of BOD Concentrations for sequence Cell 1 – VF 2 – HF 2

BOD Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
BOD	Influent	4	13 - 32	21 (± 9)
BOD	Effluent Cell 1	4	25 - 44	32 (± 9)
BOD	Effluent VF 2	4	5 − 43	20 (± 17)
BOD	Effluent HF 2	4	4 − 25	12 (± 9)

Table 8.27(b) Summary of BOD Load Removal per m^2 for Cell 1 – VF 2 – HF 2

BOD	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/m^2/day	22	3	2
Effluent Load g/m^2/day	31	2	1
Load Removal g/m^2/day	-10	1	1
Cumulative Load Removal g/m^2/day	-10	-8	-8

Table 8.27(c) Summary of BOD Load Removal per unit for Cell 1 – VF 2 – HF 2

BOD	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/unit/day	55	80	45
Effluent Load g/unit/day	80	45	32
Load Removal g/unit/day	-25	35	13
Cumulative Load Removal g/unit/day	-25	10	23
Cumulative Load Removal as % per unit	-45	18	42

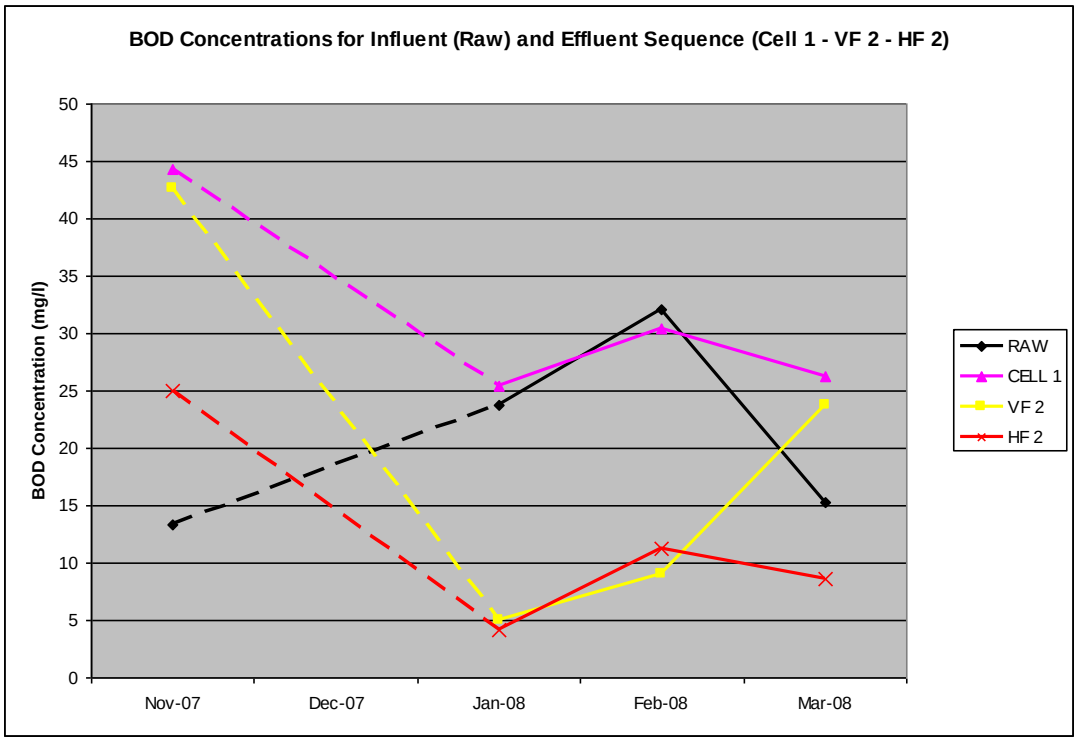


Figure 8.27(a) BOD Concentrations in Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

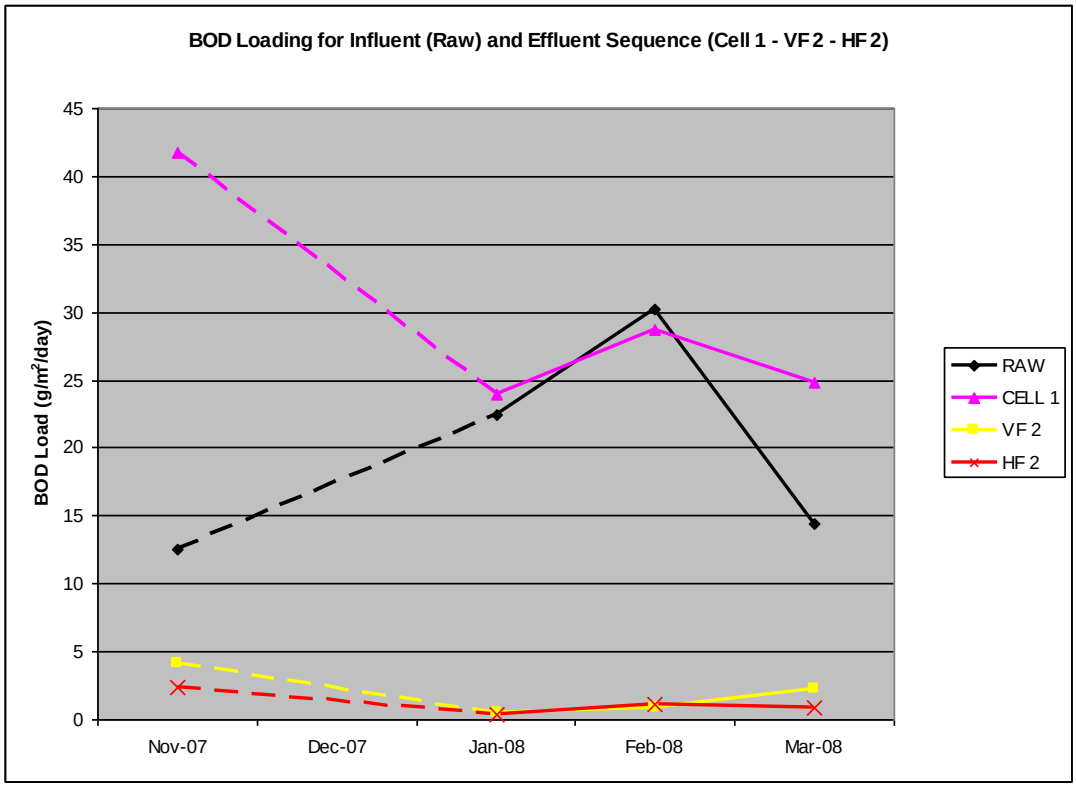


Figure 8.27(b) BOD Loading for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

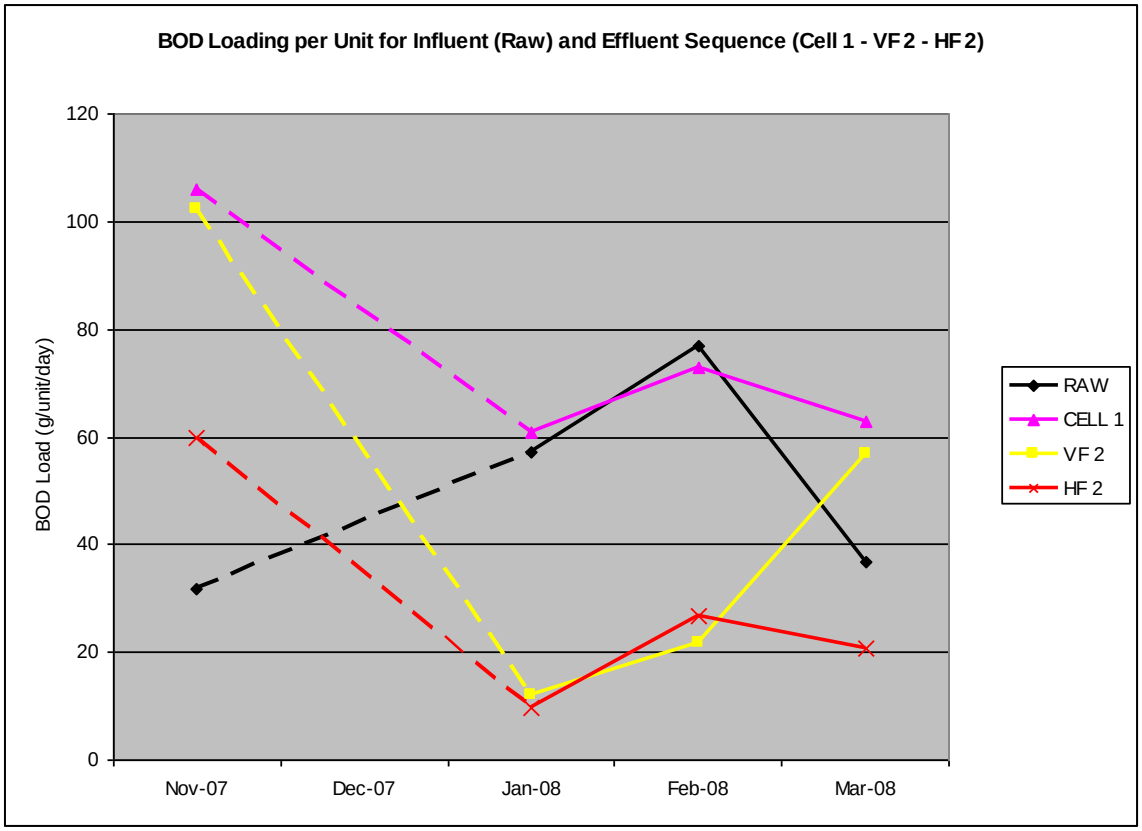


Figure 8.27(c) BOD Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.28(a) Summary of BOD Concentrations for sequence Cell 10 – VF 1 – HF 1

BOD Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
BOD	Influent	4	13 − 27	20 (± 7)
BOD	Effluent Cell 10	4	19 - 53	31 (± 15)
BOD	Effluent VF 1	4	14 - 90	40 (± 36)
BOD	Effluent HF 1	4	19 − 53	34 (± 15)

Table 8.28(b) Summary of BOD Load Removal per m^2 for Cell 10 – VF 1 – HF 1

BOD	Cell 10	VF 1	HF 1
Influent Load g/m^2/day	20	3	5
Effluent Load g/m^2/day	32	5	4
Load Removal g/m^2/day	-12	-1	1
Cumulative Load Removal g/m^2/day	-12	-13	-12

Table 8.28(c) Summary of BOD Load Removal per unit for Cell 10 – VF 1 – HF 1

BOD	Cell 10	VF 1	HF 1
Influent Load g/unit/day	51	81	115
Effluent Load g/unit/day	81	115	95
Load Removal g/unit/day	-30	-34	20
Cumulative Load Removal g/unit/day	-30	-64	-44
Cumulative Load Removal as % per unit	-59	-125	-86

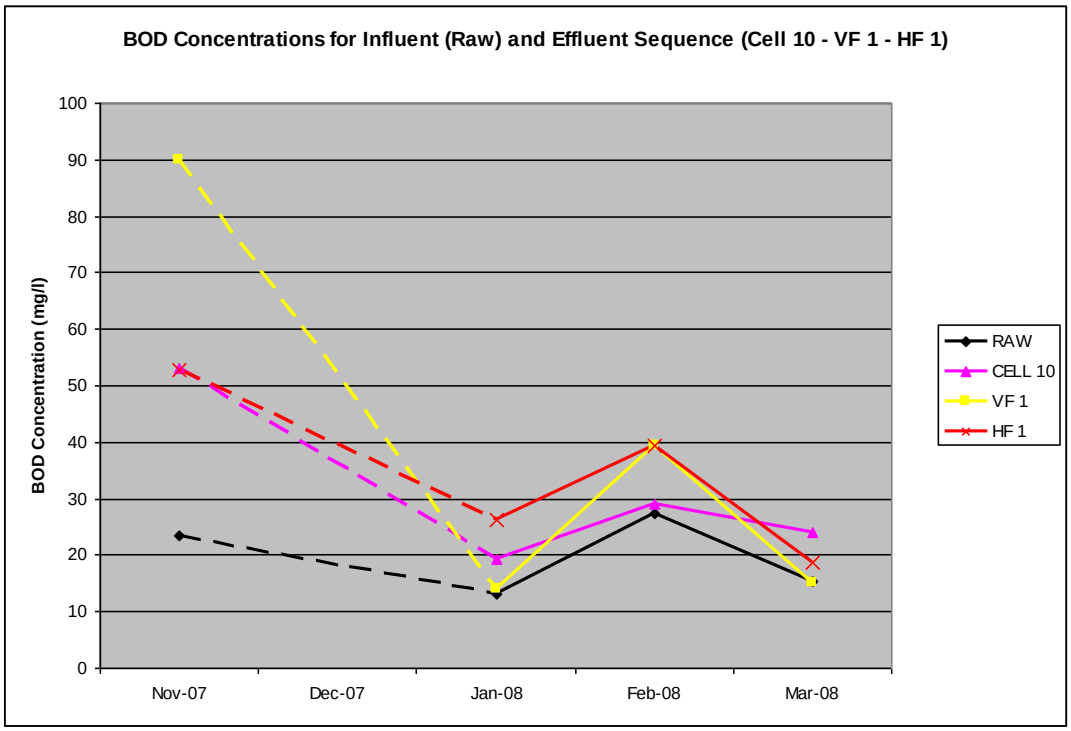


Figure 8.28(a) BOD Concentrations in Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

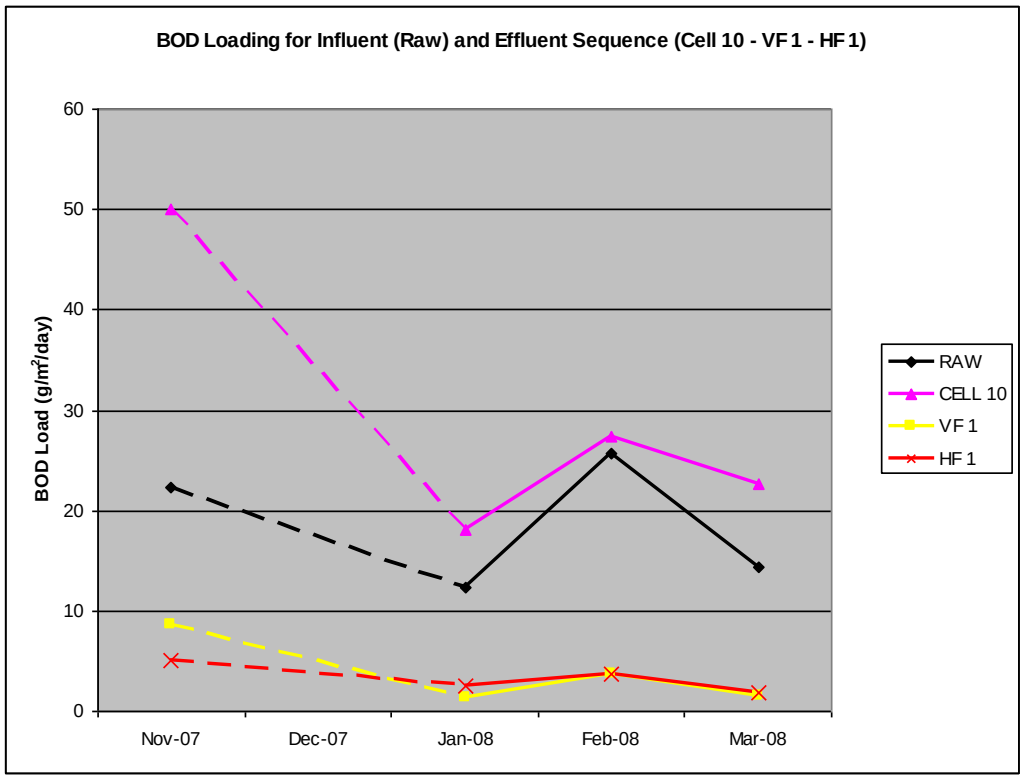


Figure 8.28(b) BOD Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

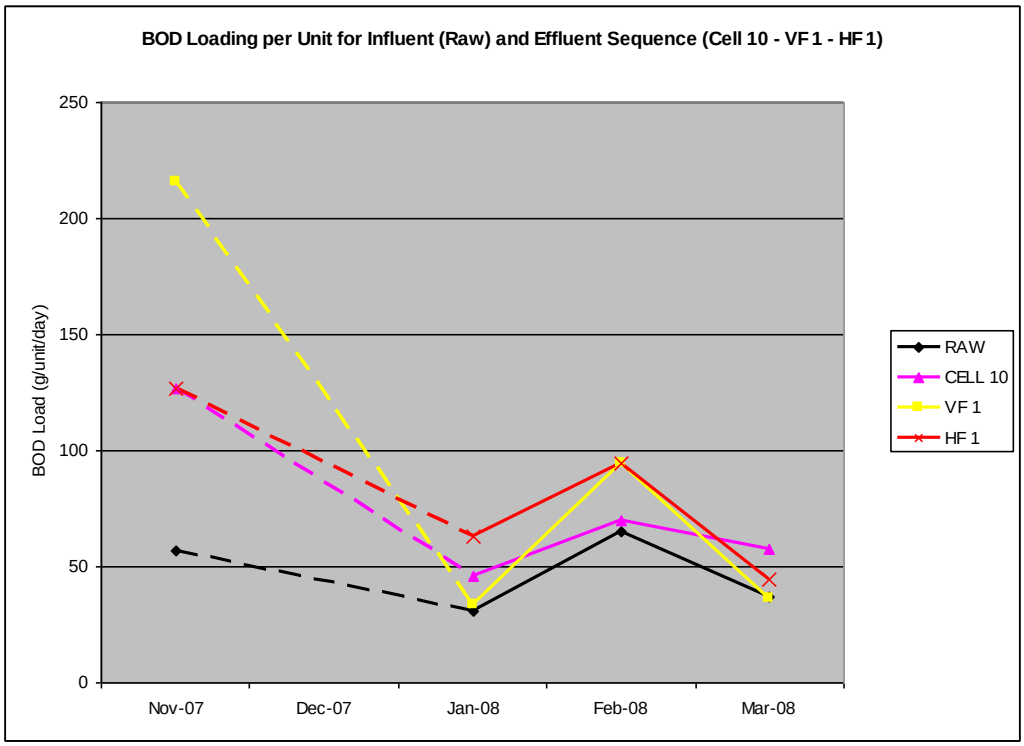


Figure 8.28(c) BOD Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.3.5 COD Removal in Treatment Units Operating in Sequence

COD concentrations and removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.29(a) to 8.30(c).

Charts detailing the range of COD concentrations and loadings for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.29(a) to 8.30(c).

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.29(a) Summary of COD Concentrations for sequence Cell 1 – VF 2 – HF 2

COD Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
COD	Influent	4	134 - 263	183 (± 57)
COD	Effluent Cell 1	4	133 – 266	176 (± 61)
COD	Effluent VF 2	4	114 - 234	168 (± 56)
COD	Effluent HF 2	4	116 - 179	145 (± 32)

Table 8.29(b) Summary of COD Load Removal per m^2 for Cell 1 – VF 2 – HF 2

COD	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/m^2/day	173	17	16
Effluent Load g/m^2/day	166	16	14
Load Removal g/m^2/day	6	1	2
Cumulative Load Removal g/m^2/day	6	7	9

Table 8.29(c) Summary of COD Load Removal per unit for Cell 1 – VF 2 – HF 2

COD	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/unit/day	438	422	403
Effluent Load g/unit/day	422	403	347
Load Removal g/unit/day	16	19	56
Cumulative Load Removal g/unit/day	16	35	91
Cumulative Load Removal as % per unit	4	8	21

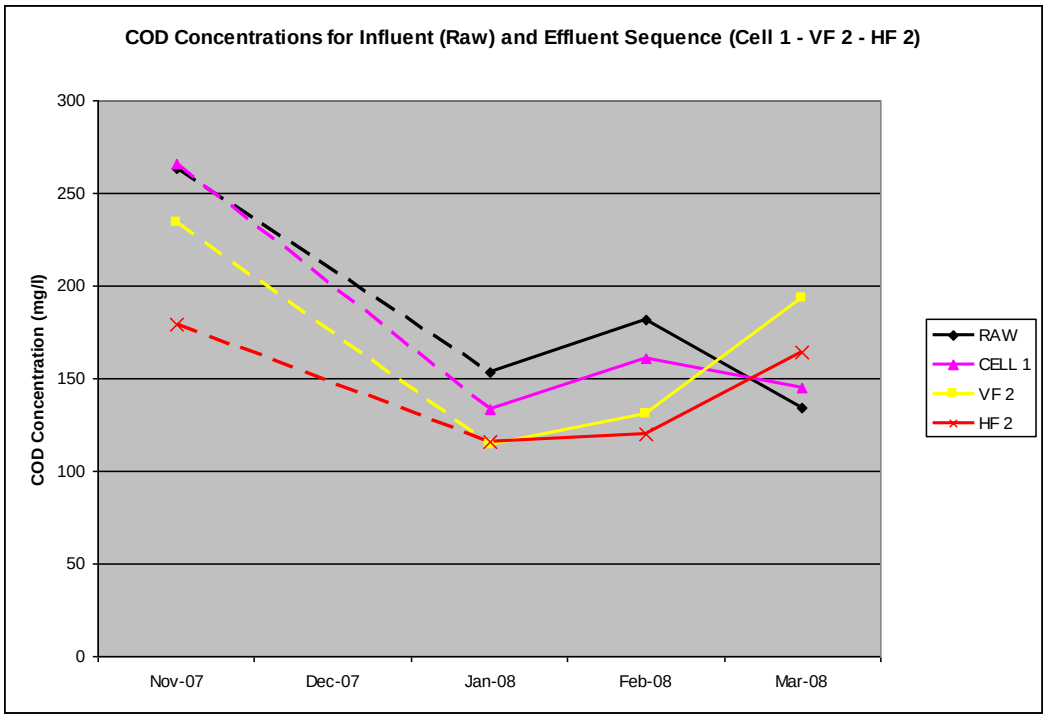


Figure 8.29(a) COD Concentrations in Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

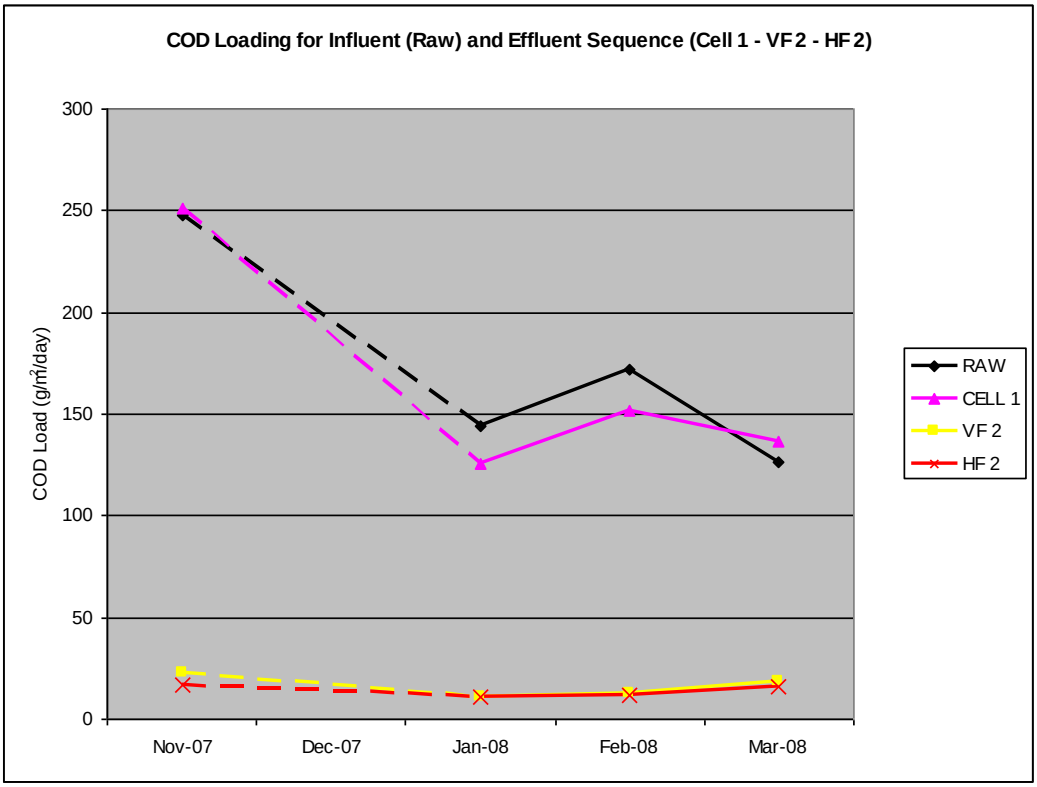


Figure 8.29(b) COD Loading for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

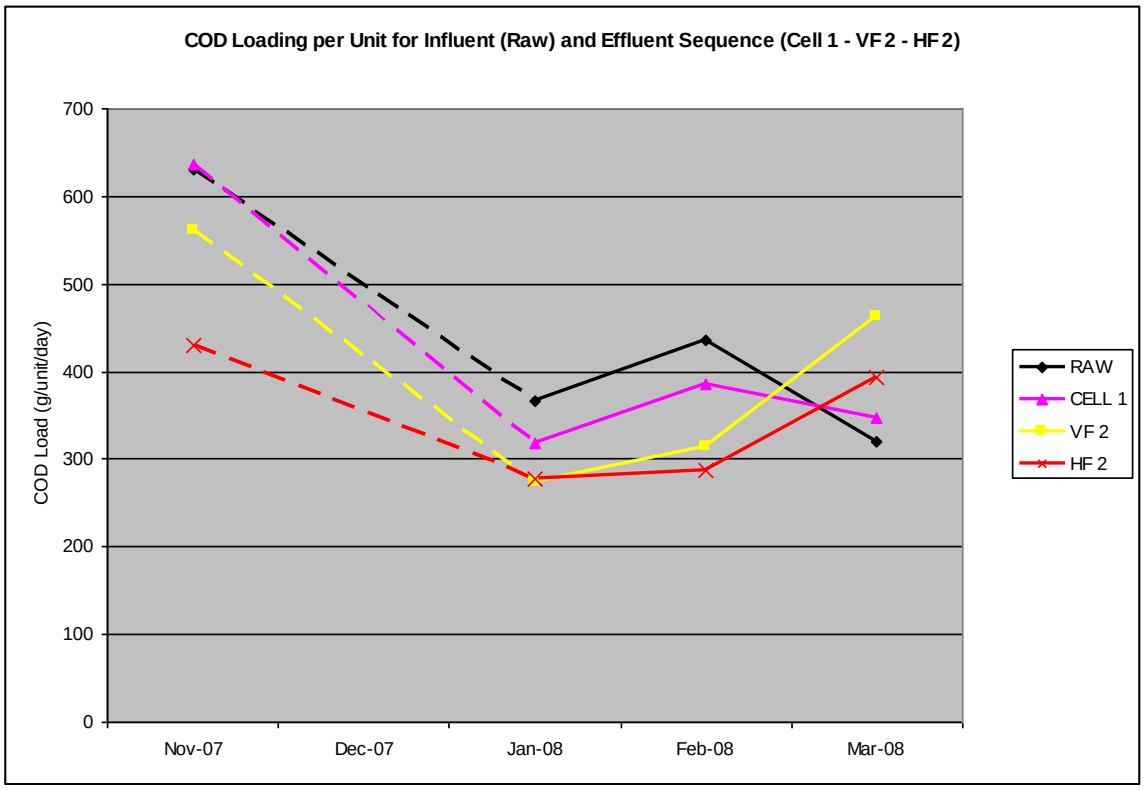


Figure 8.29(c) COD Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day

Area of cells = 2.54m^2

Area of reed beds = 25m^2

Table 8.30(a) Summary of COD Concentrations for sequence Cell 10 – VF 1 – HF 1

COD Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
COD	Influent	4	122 - 240	174 (± 55)
COD	Effluent Cell 10	4	105 - 264	176 (± 75)
COD	Effluent VF 1	4	99 - 309	181 (± 96)
COD	Effluent HF 1	4	75 – 242	158 (± 71)

Table 8.30(b) Summary of COD Load Removal per m^2 for Cell 10 – VF 1 – HF 1

COD	Cell 10	VF 1	HF 1
Influent Load g/m^2/day	164	17	17
Effluent Load g/m^2/day	166	17	15
Load Removal g/m^2/day	-2	-1	2
Cumulative Load Removal g/m^2/day	-2	-3	-1

Table 8.30(c) Summary of COD Load Removal per unit for Cell 10 – VF 1 – HF 1

COD	Cell 10	VF 1	HF 1
Influent Load g/unit/day	416	422	435
Effluent Load g/unit/day	422	435	379
Load Removal g/unit/day	-6	-13	56
Cumulative Load Removal g/unit/day	-6	-19	37
Cumulative Load Removal as % per unit	-1	-5	9

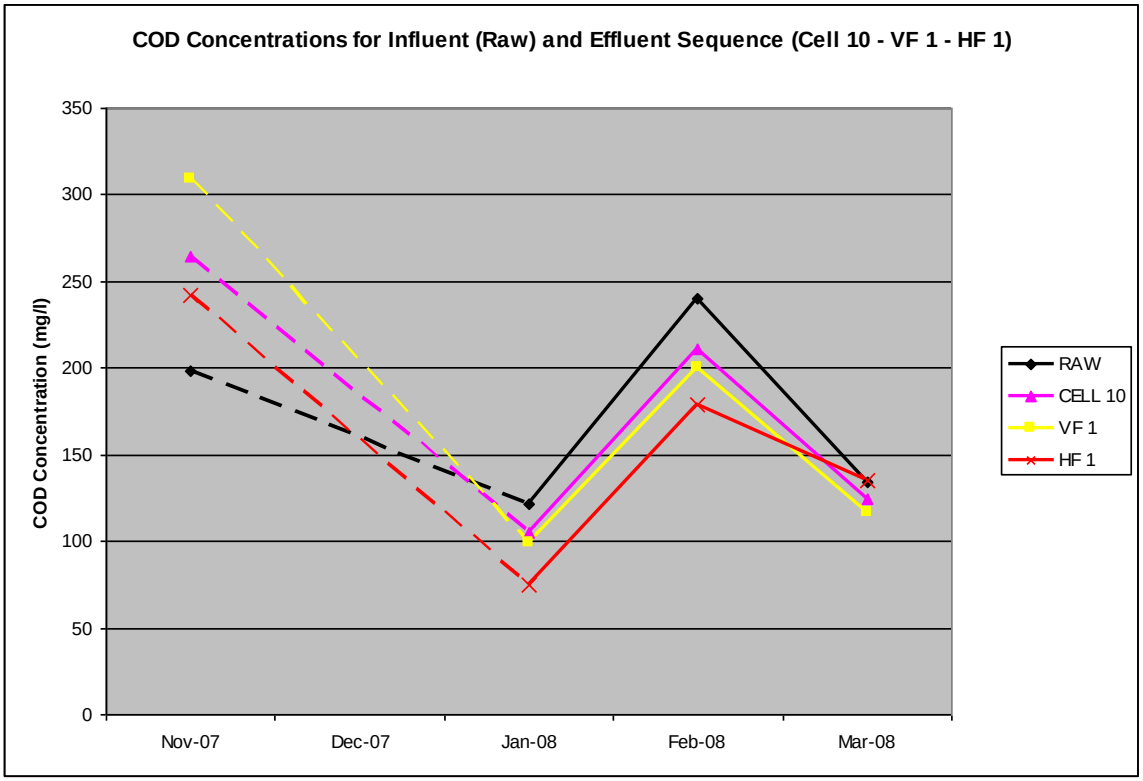


Figure 8.30(a) COD Concentrations in Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

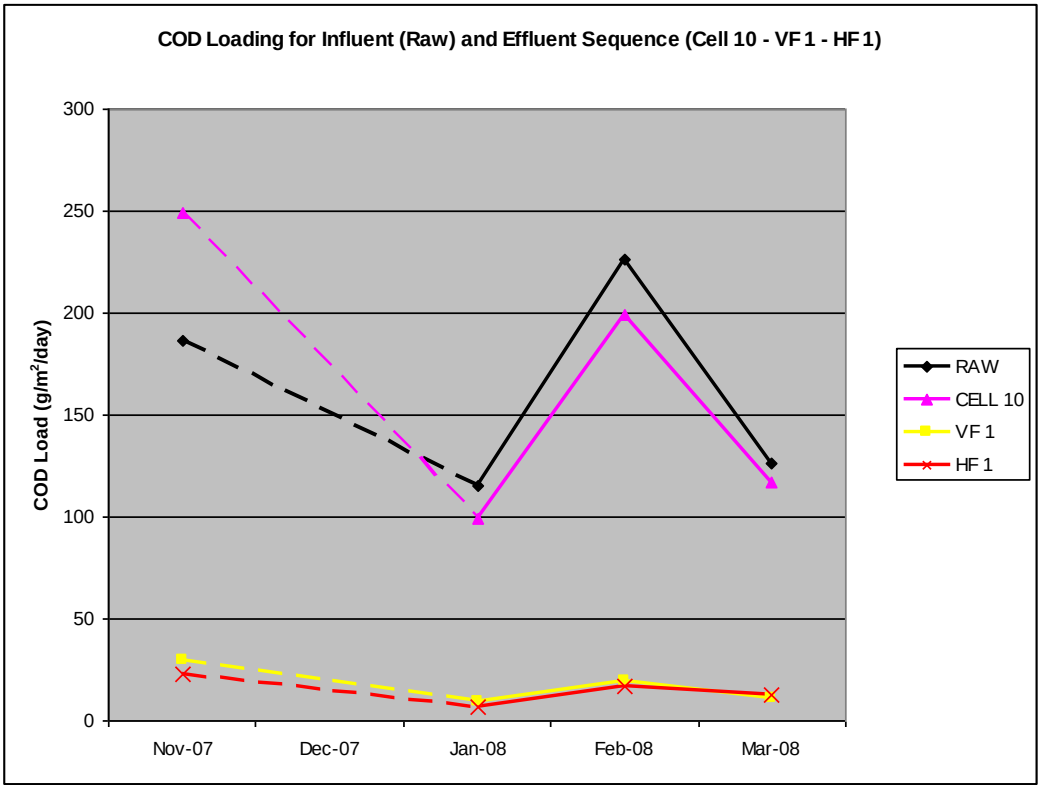


Figure 8.30(b) COD Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

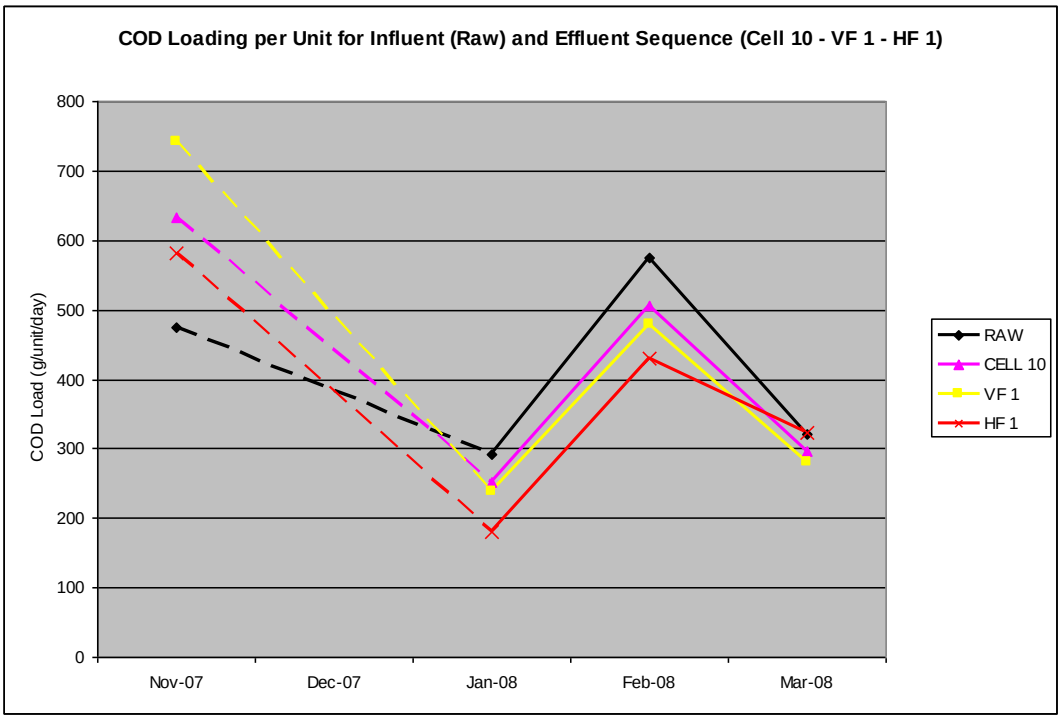


Figure 8.30(c) COD Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.3.6 Interpretation of Organics Removal in Treatment Units Operating in Sequence

Analysis of BOD_5 and COD results for concentrations and load removal rates for treatment units operating in sequence; Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1; reveals a high degree of flux in terms of treatment efficiency. The overall pattern for BOD_5 load removal for Cell 1 – VF 2 – HF 2 was positive with a cumulative load removal of 23g/unit/day (42% removal) at the end point (HF 2) whereas load removal for sequence Cell 10 – VF 1 – HF 1 was negative across the system with a final cumulative load removal of -44g/unit/day (-86% removal) at HF 1.

Charts detailing the range of BOD_5 concentrations and loadings to sequence Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.27(a) to 8.28(c).

BOD unit loading to sequence Cell 1 – VF 2 – HF 2 (Figure 8.27(c)) reveals both positive and negative load removal for Cell 1 and VF 2, whereas, the final unit in the sequence; HF 2; with the exception of a negative result for at the start of trial operations displays positive load removal ranging from 16 to 50g/unit/day.

The results for BOD unit loading to sequence Cell 10 – VF 1 – HF 1 (Figure 8.28(c)) reveals mainly negative load removal for the units throughout the sequence.

The effluent from the final unit in the sequence; HF 1; displayed negative load removal ranging from -8 to -70g/unit/day when compared to the initial influent load to the sequence

In terms of COD, each of the sequences displays positive load removal at system end point with an average cumulative load removal of 91g/unit/day (21% removal) for sequence Cell 1 – VF 2 – HF 2 and 37g/unit/day (9% removal) for sequence Cell 10 – VF 1 – HF 1.

The charts depicting the range of load removal per unit for each of the sequences (Figures 8.29(c) and 8.30(c)) display a relatively consistent pattern of reduction in effluent load. The exception to this being the results for March 2008 for sequence Cell 1 – VF 2 – HF 2, where effluent loads from all units was in excess of the initial influent load. The same pattern of negative load removal in sequence Cell 10 – VF 1 – HF 1 for all units was experienced in November 2007.

A broad interpretation of organics removal from each of the sequences is positive in terms of load removal and lower effluent concentrations (the exception being BOD results for Cell 10 – VF 1 – HF 1); however caution is warranted in reading too much in to the results due to the low sampling number (n = 4) and short period of operation (November 2007 – March 2008).

8.2.4 Suspended Solids Removal

The removal of suspended particulate matter from the system measured as suspended solids (SS) filtered through very fine glass microfiber paper (1.2 microns) is detailed in this section. A series of tables outlining suspended solids removal in individual treatment units is presented below in sections 8.2.4.1 with interpretation in 8.2.4.2.

Similar tables for suspended solids removal within treatment units operating in sequence are presented in section 8.2.4.3 followed by interpretation.

8.2.4.1 Suspended Solids Removal in Individual Treatment Units

Suspended solids concentrations and removal efficiencies for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.31(a) to 8.38(b).

Charts detailing the range of suspended solids concentrations and loadings for cells 1 to 8 are presented in Figures 8.31(a) to 8.38(b).

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.31(a) Summary of SS Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
SS	Influent	7	37 - 62	48 (± 8)	46
SS	Effluent	3	12 - 54	33 (± 21)	31

Table 8.31(b) Summary of SS Load Removal for Cell 1

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
SS	15	33

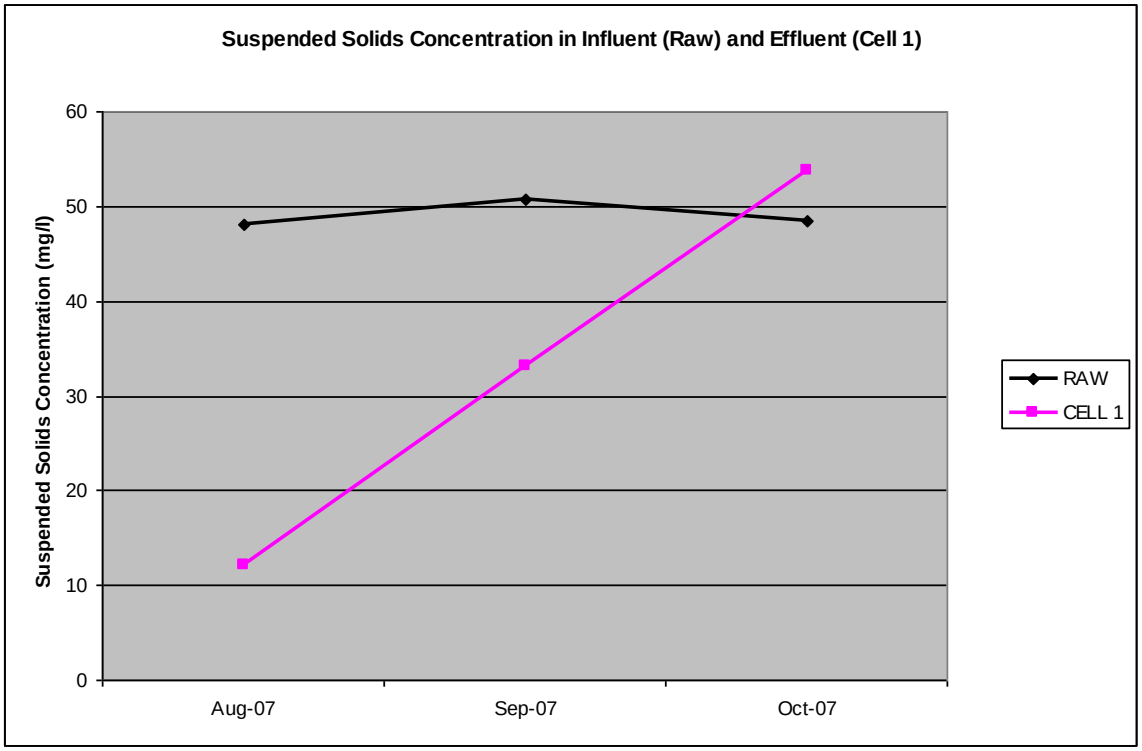


Figure 8.31(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 1)

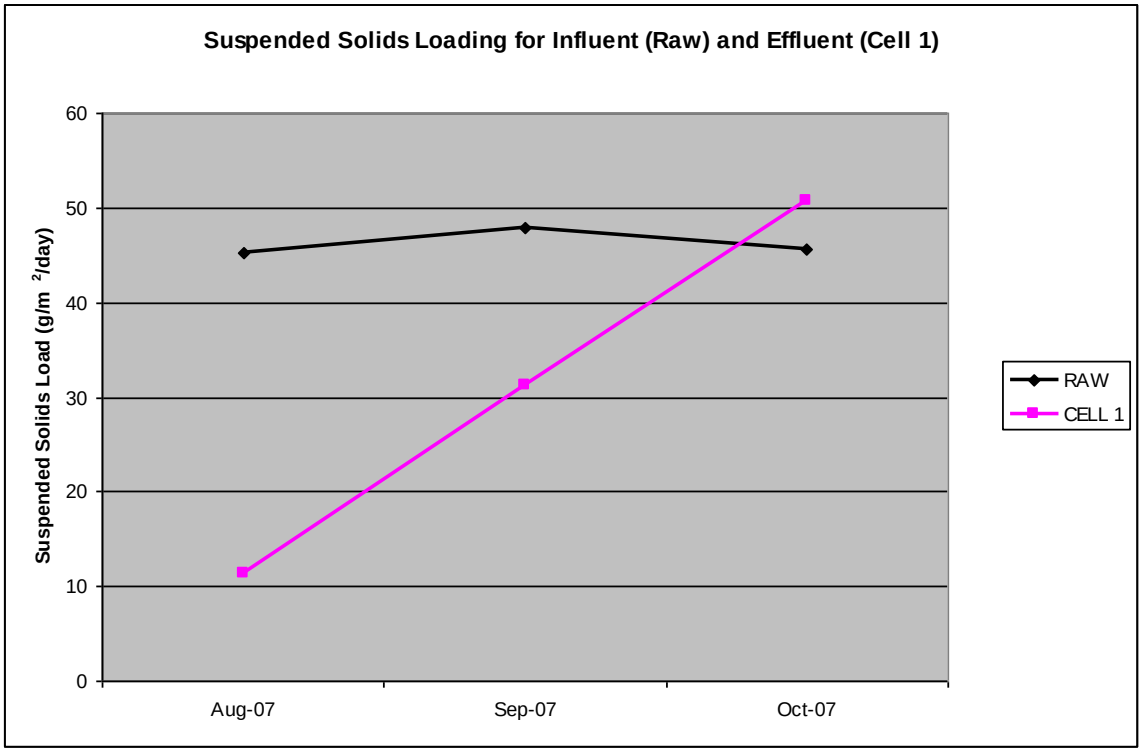


Figure 8.31(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 1)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.32(a) Summary of SS Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	17	14 - 62	40 (± 14)	46
SS	Effluent	7	6 - 49	17 (± 16)	16

Table 8.32(b) Summary of SS Load Removal for Cell 2

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
SS	30	65

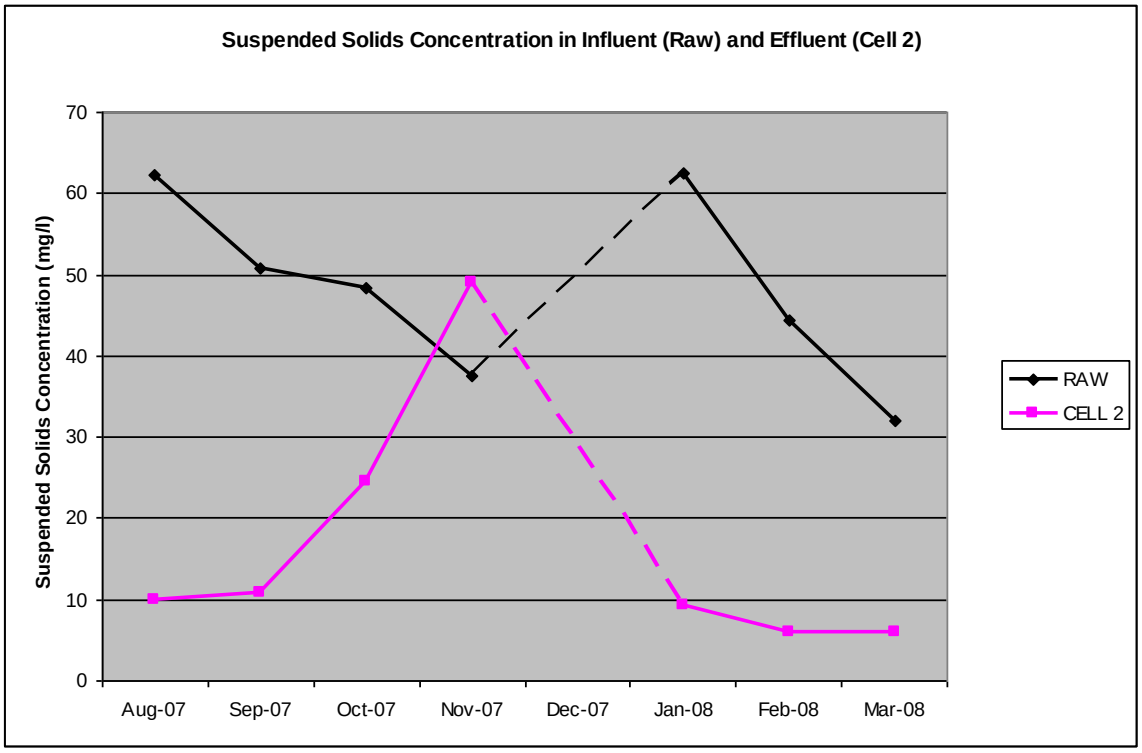


Figure 8.32(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 2)

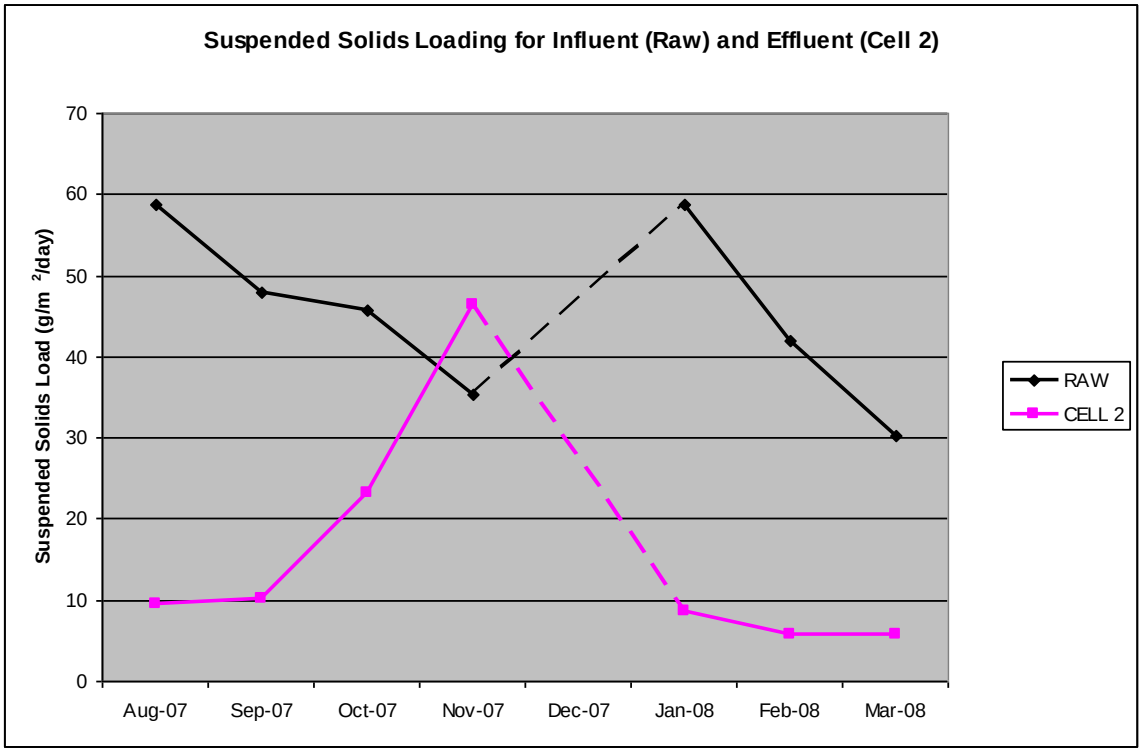


Figure 8.32(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.33(a) Summary of SS Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	10	28 - 62	40 (± 10)	44
SS	Effluent	4	3 - 55	23 (± 22)	22

Table 8.33(b) Summary of SS Load Removal for Cell 3

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
SS	22	50

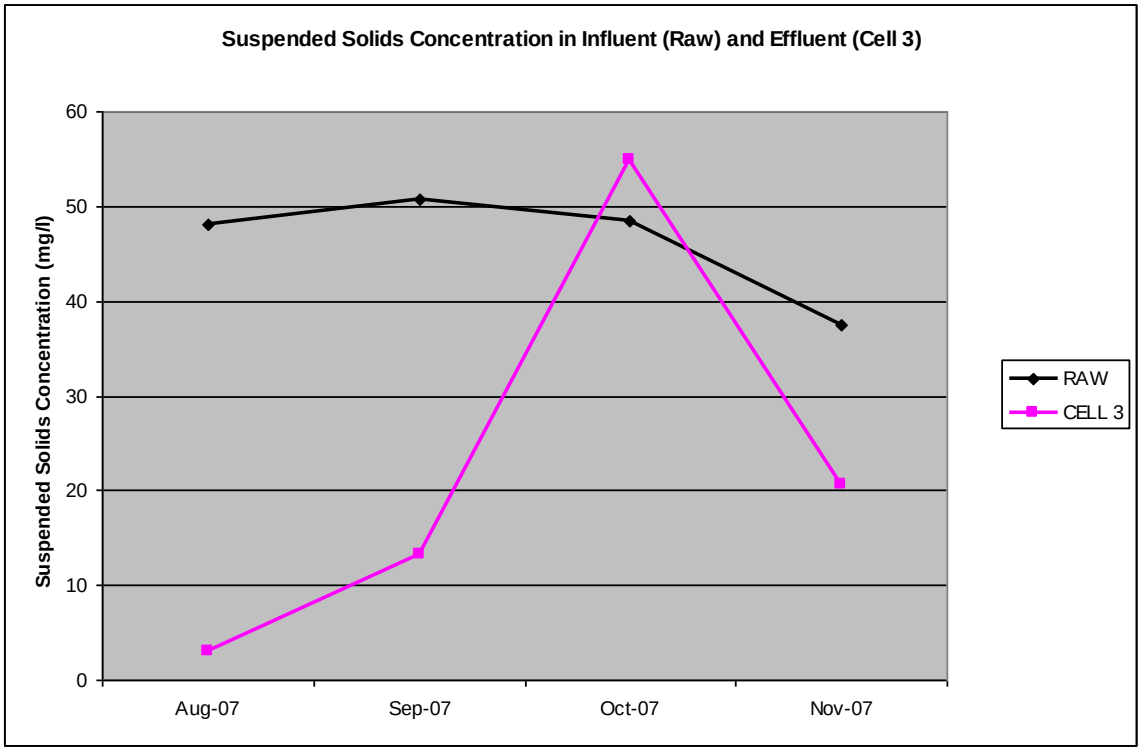


Figure 8.33(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 3)

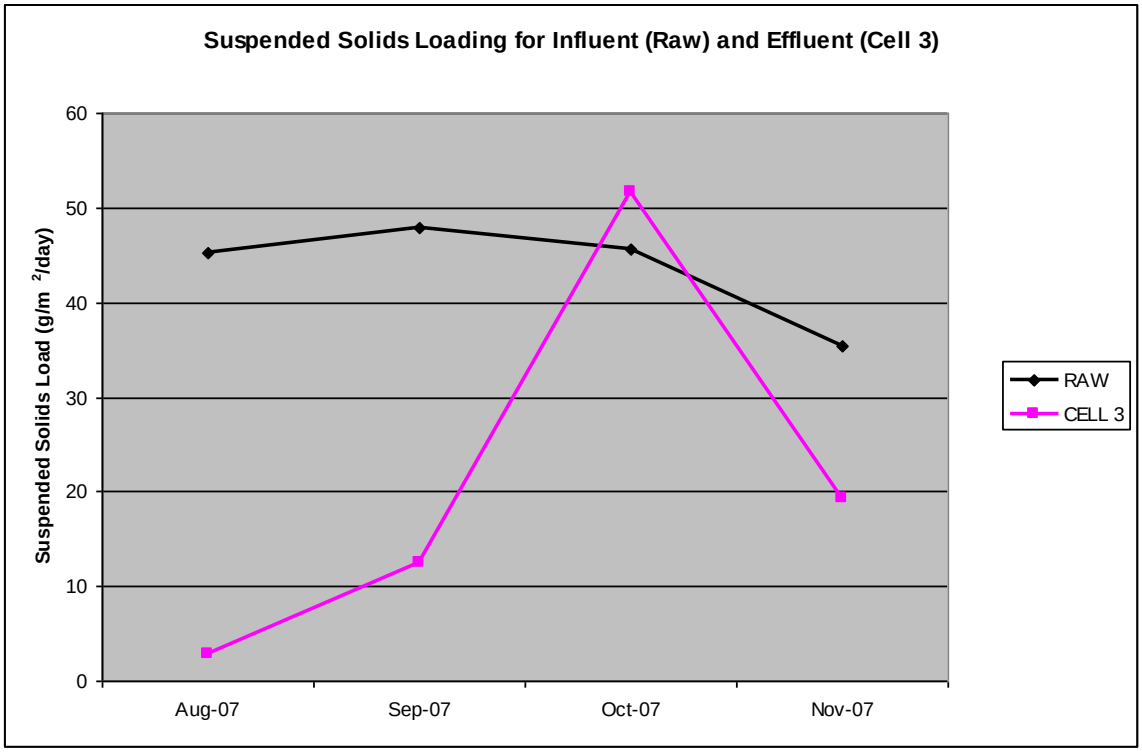


Figure 8.33(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.34(a) Summary of SS Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	19	14 - 62	40 (± 13)	43
SS	Effluent	8	5 - 46	19 (± 15)	18

Table 8.34(b) Summary of SS Load Removal for Cell 4

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
SS	25	58

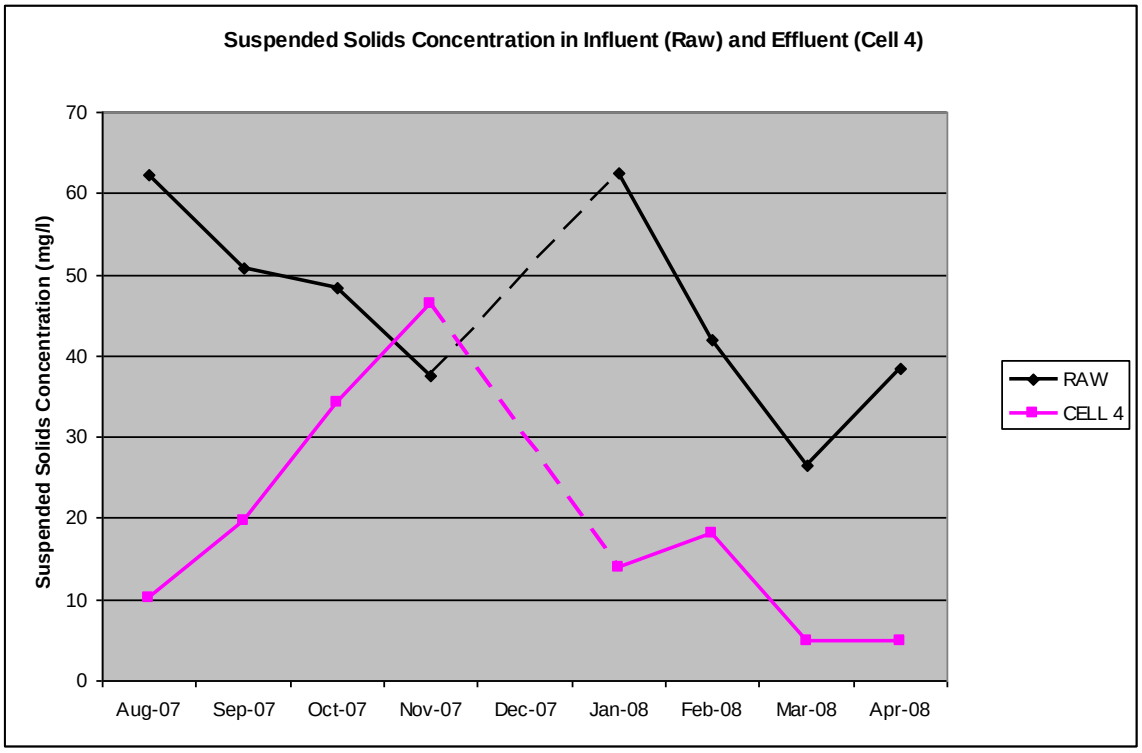


Figure 8.34(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 4)

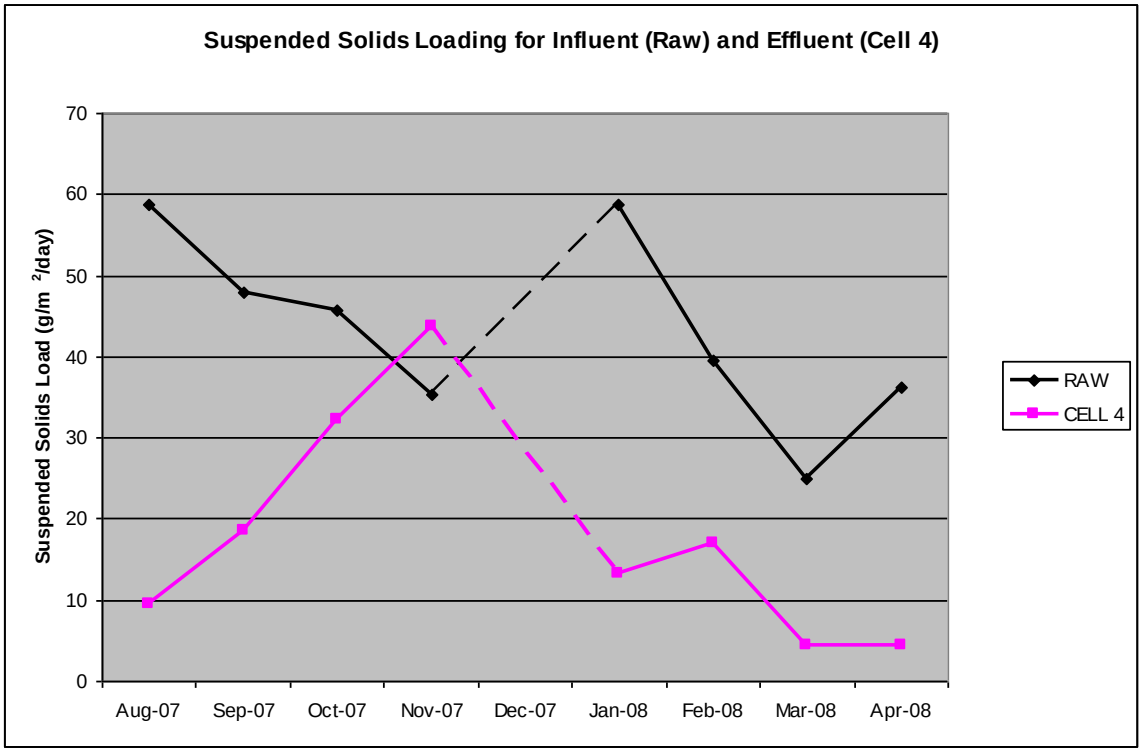


Figure 8.34(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.35(a) Summary of SS Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	24	14 - 62	38 (± 12)	5
SS	Effluent	8	3 - 40	10 (± 12)	2

Table 8.35(b) Summary of SS Load Removal for Cell 5

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
SS	3	60

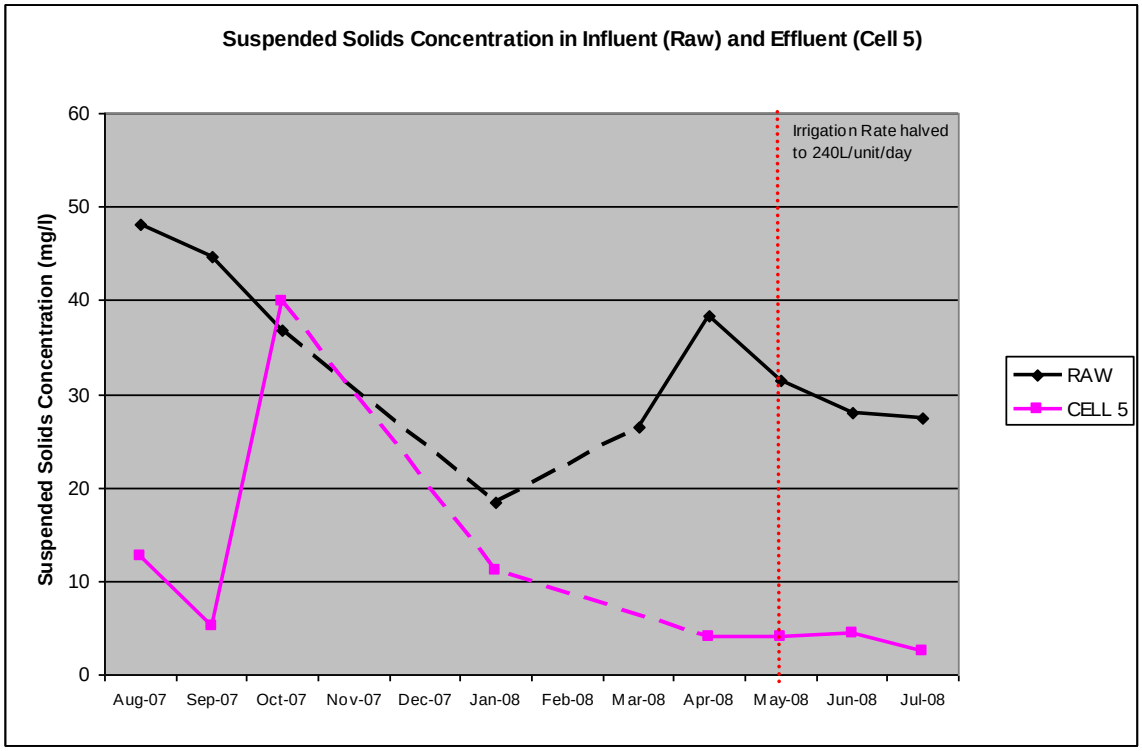


Figure 8.35(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 5)

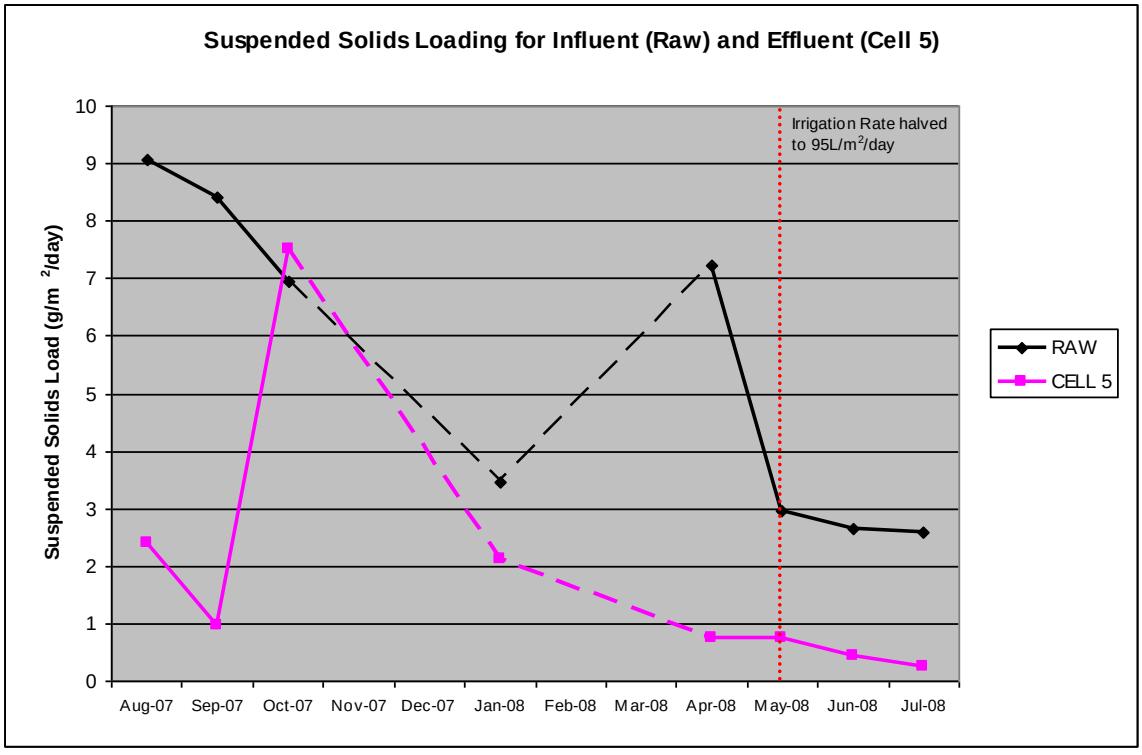


Figure 8.35(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.36(a) Summary of SS Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	23	14 - 62	39 (± 12)	19
SS	Effluent	9	4 - 76	37 (± 23)	17

Table 8.36(b) Summary of SS Load Removal for Cell 6

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
SS	2	11

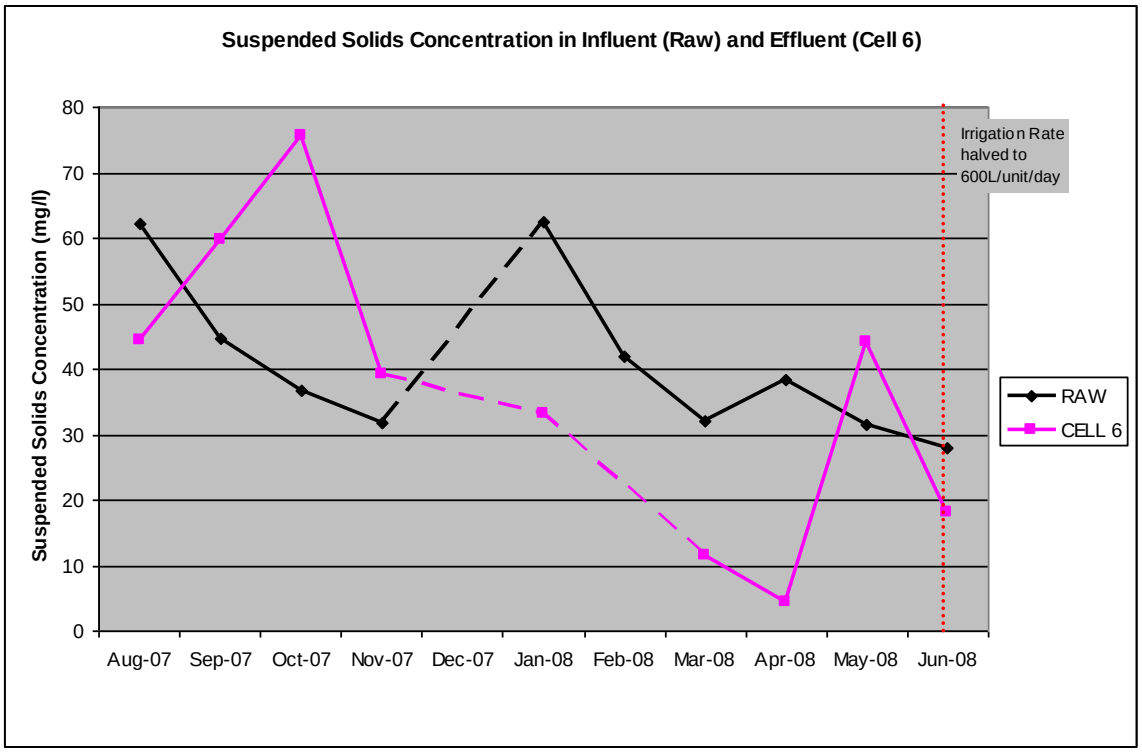


Figure 8.36(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 6)

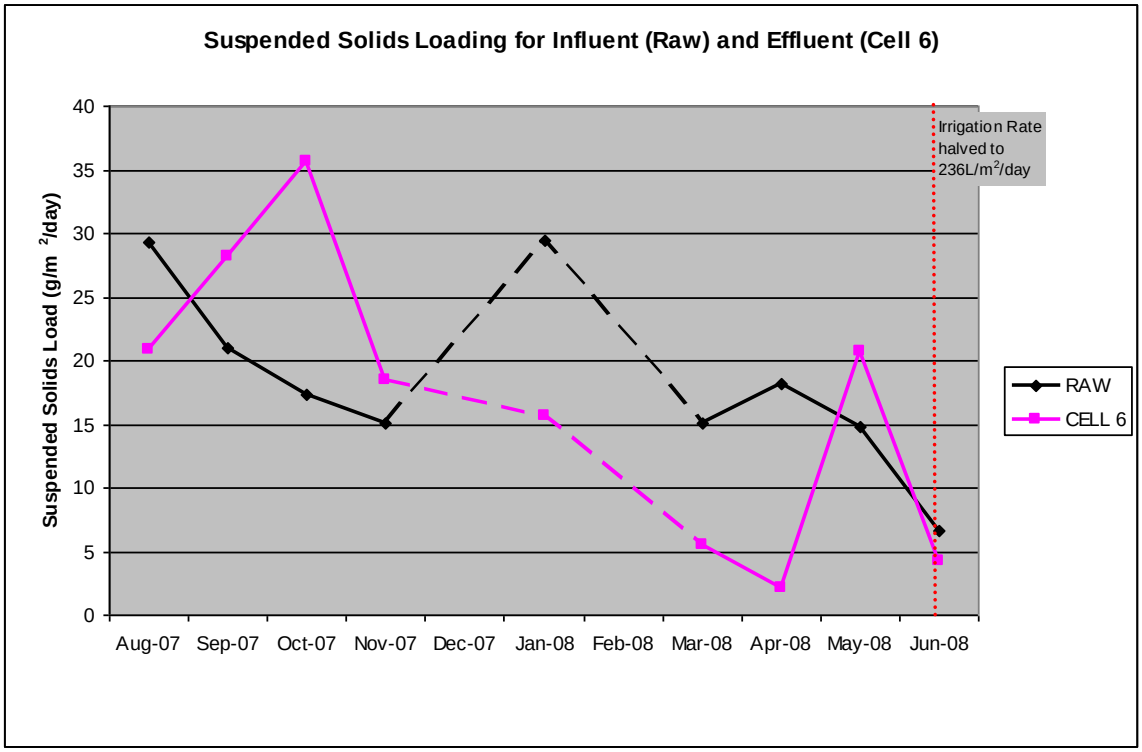


Figure 8.36(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.37(a) Summary of SS Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	26	14 - 62	38 (± 12)	27
SS	Effluent	12	10 - 65	34 (± 20)	25

Table 8.37(b) Summary of SS Load Removal for Cell 7

Parameter	Average Load Removal (g/m^2)	Average % Load Removal
SS	2	7

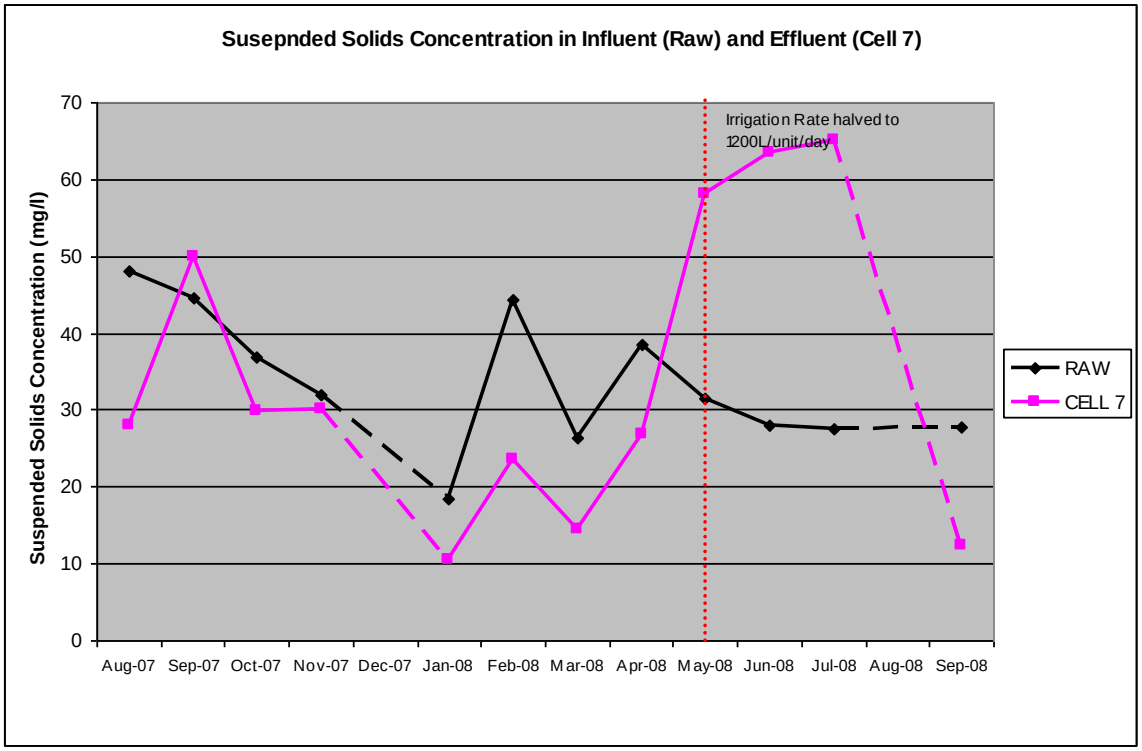


Figure 8.37(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 7)

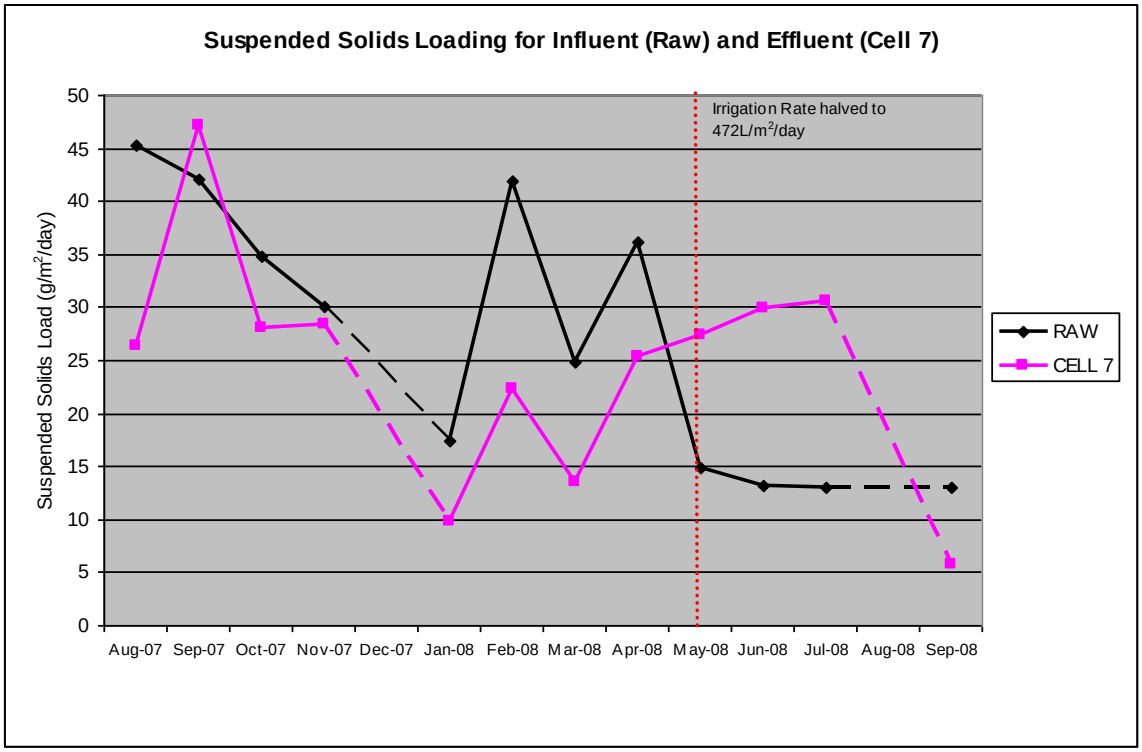


Figure 8.37(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.38(a) Summary of SS Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
SS	Influent	29	14 - 62	38 (± 12)	15
SS	Effluent	9	6 - 52	30 (± 19)	12

Table 8.38(b) Summary of SS Load Removal for Cell 8

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
SS	3	20

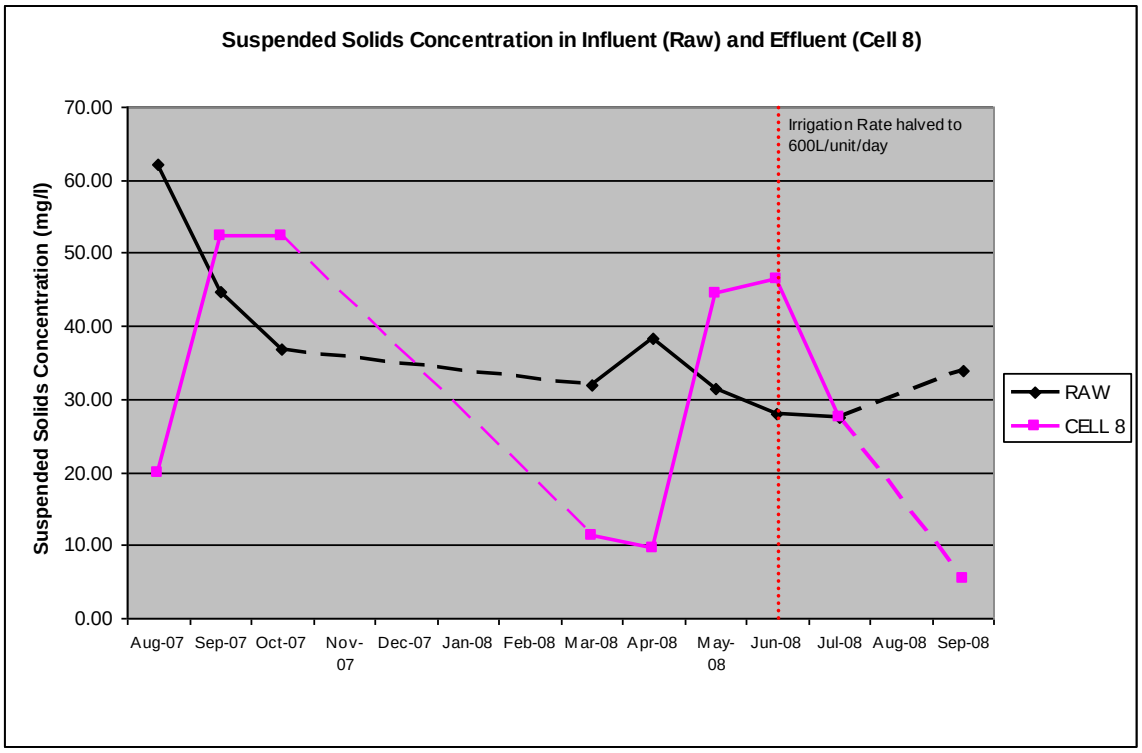


Figure 8.38(a) Suspended Solids Concentration in Influent (Raw) and Effluent (Cell 8)

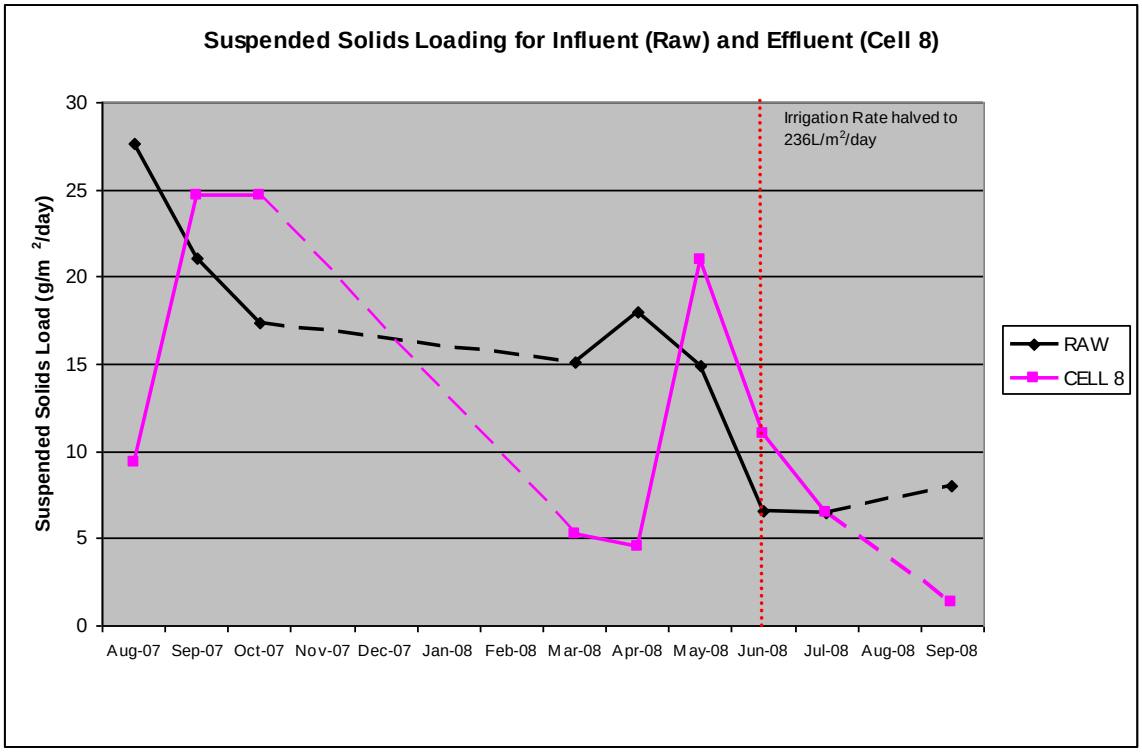


Figure 8.38(b) Suspended Solids Loading for Influent (Raw) and Effluent (Cell 8)

8.2.4.2 Interpretation of Suspended Solids Removal in Individual Treatment Units

Inspection of the results obtained for load removal rates for suspended solids within cells 1 to 8 reveals a positive average load removal for all units.

Cells 1, 2, 3 and 4 recorded high average load removal rates of 15g/m^2/day (33% removal), 30g/m^2/day (65% removal), 22g/m^2/day (50% removal) and 25g/m^2/day (58% removal) respectively (Figures 8.31(b) – 8.34(b)).

Cell 5 recorded an average load removal of 3g/m^2/day (60% removal), albeit at a low influent load (Figure 8.35(b)).

Cells 6, 7 and 8 revealed comparatively poor average load removal rates of 2g/m^2/day (11% removal), 2g/m^2/day (7% removal) and 3g/m^2/day (20% removal) respectively (Figures 8.36(b) – 8.38(b)). These units displayed high fluctuations in removal rates across the sampling period; cell 6 varied from a high load removal rate of 16g/m^2/day (April 2008) to a negative load removal of -18g/m^2/day (October 2007), cell 7 varied between 20g/m^2/day (February 2008) and -18g/m^2/day (July 2008) and cell 8 ranged from 18g/m^2/day (August 2007) and -7g/m^2/day (October 2007).

The explanation for the poor results may lie in the fact that all three units contained subsoil or a component of subsoil as the basis for the treatment media (cells 6 and 7 contained 100% subsoil and cell 8 comprised 33% subsoil). It is likely that the finer particles were washed out of the media matrix during dosing of the units.

The author did consider the effects of high pulse rainfall events as a possible cause of the increase in effluent loadings. However, on examination of the total rainfall data from Cork Airport's meteorological station, the dates where increased effluent loadings were recorded and the timing of high total (daily) rainfall events did not correlate well. In addition to the poor correlation of high effluent loads with high total rainfall; when the maximum total daily rainfall for the sampling period is added to the system, (i.e. maximum daily rainfall for 2008 was 47.7mm, which fell on 21st June) it represented a 5% - 11% increase in terms of volume dosed to the system. Again, this did not correlate well with results obtained as rainfall volumetric increase could not account for the increase in suspended solids in the effluent load.

With the exception of cell 5, it was difficult to discern whether a 50% reduction in the loading rate applied in the latter stages of operation for cells 5, 6, 7 and 8 had any impact in terms of increased treatment efficiency due to the erratic nature of the results.

8.2.4.3 Suspended Solids Removal in Treatment Units Operating in Sequence

Suspended Solids concentrations and removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.39(a) to 8.40(c).

Charts detailing the range of suspended solids concentrations and loadings for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.39(a) to 8.40(c).

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.39(a) Summary of SS Concentrations for sequence Cell 1 – VF 2 – HF 2

SS Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
SS	Influent	4	18 − 44	32 (± 12)
SS	Effluent Cell 1	4	8 − 38	17 (± 14)
SS	Effluent VF 2	4	2 − 13	6 (± 5)
SS	Effluent HF 2	4	2 − 7	4 (± 3)

Table 8.39(b) Summary of SS Load Removal per m^2 for Cell 1 – VF 2 – HF 2

SS	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/m^2/day	29.9	1.6	0.6
Effluent Load g/m^2/day	16.0	0.6	0.4
Load Removal g/m^2/day	14.0	1.1	0.1
Cumulative Load Removal g/m^2/day	14.0	15.0	15.2

Table 8.39(c) Summary of SS Load Removal per unit for Cell 1 – VF 2 – HF 2

SS	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/unit/day	76	41	14
Effluent Load g/unit/day	41	14	11
Load Removal g/unit/day	35	27	3
Cumulative Load Removal g/unit/day	35	62	65
Cumulative Load Removal as % per unit	47	82	86

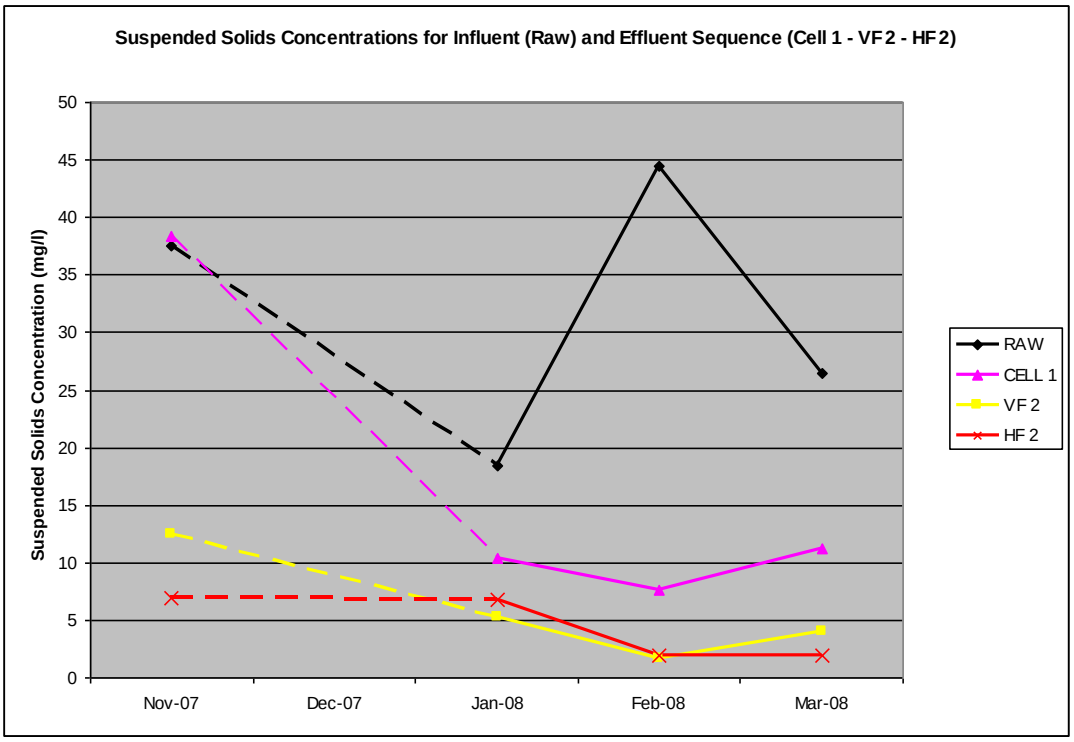


Figure 8.39(a) Suspended Solids Concentrations in Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

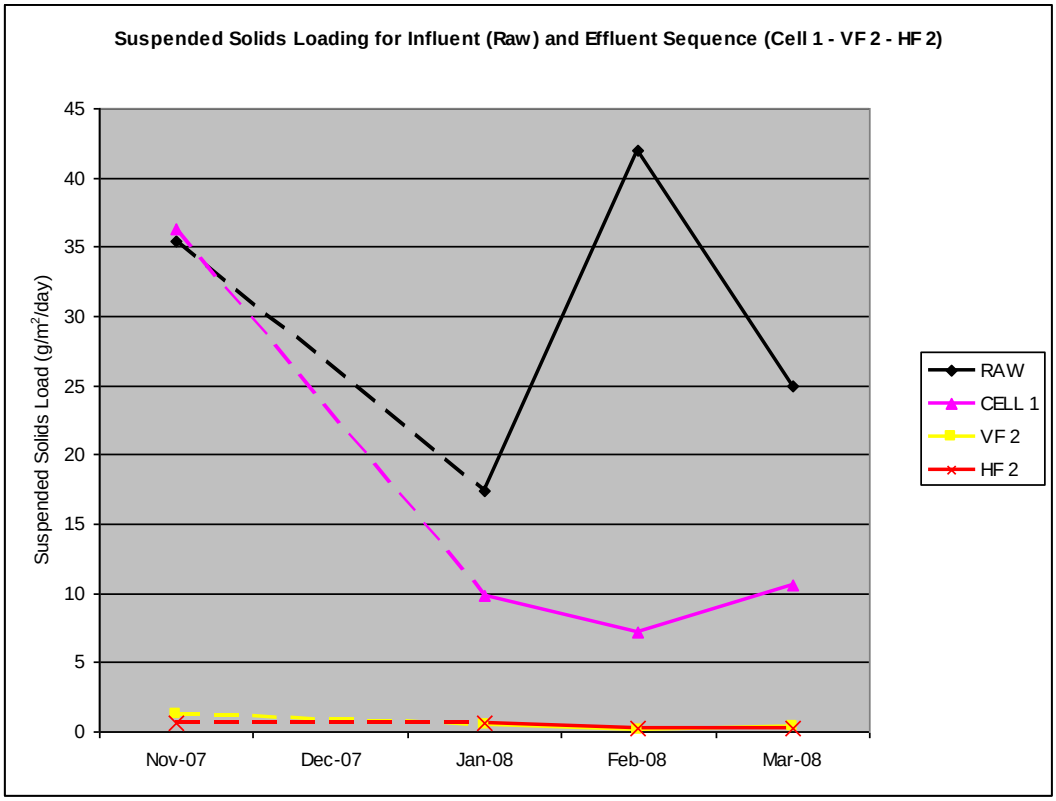


Figure 8.39(b) Suspended Solids Loading for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

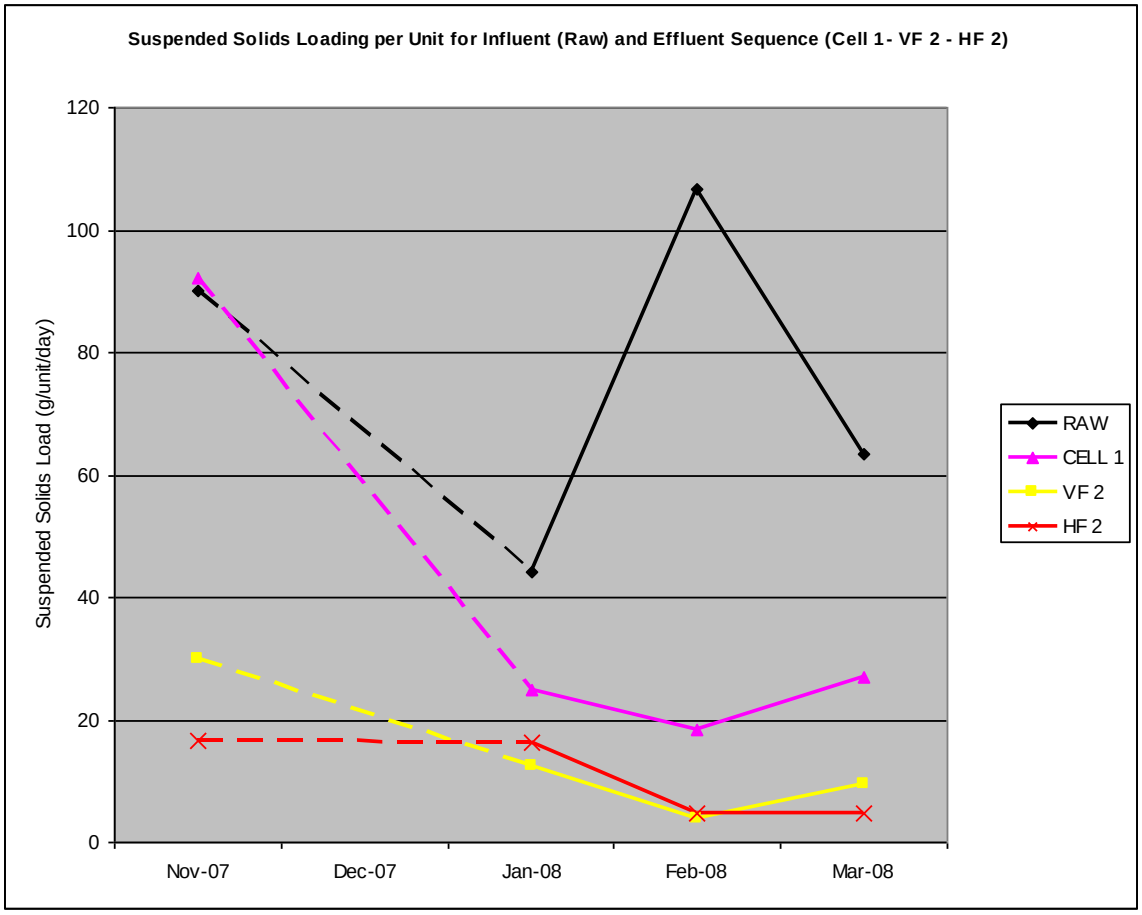


Figure 8.39(c) Suspended Solids Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.40(a) Summary of SS Concentrations for sequence Cell 10 – VF 1 – HF 1

SS Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
SS	Influent	4	26 − 62	41 (± 16)
SS	Effluent Cell 10	4	8 − 9	15 (± 10)
SS	Effluent VF 1	4	3 − 17	7 (± 7)
SS	Effluent HF 1	4	4 − 34	16 (± 13)

Table 8.40(b) Summary of SS Load Removal per m^2 for Cell 10 – VF 1 – HF 1

SS	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/m^2/day	38.4	1.5	0.7
Effluent Load g/m^2/day	14.5	0.7	1.6
Load Removal g/m^2/day	23.9	0.8	-0.9
Cumulative Load Removal g/m^2/day	23.9	24.7	23.8

Table 8.40(c) Summary of SS Load Removal per unit for Cell 10 – VF 1 – HF 1

SS	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/unit/day	98	37	17
Effluent Load g/unit/day	37	17	39
Load Removal g/unit/day	61	20	-23
Cumulative Load Removal g/unit/day	61	81	58
Cumulative Load Removal as % per unit	62	83	60

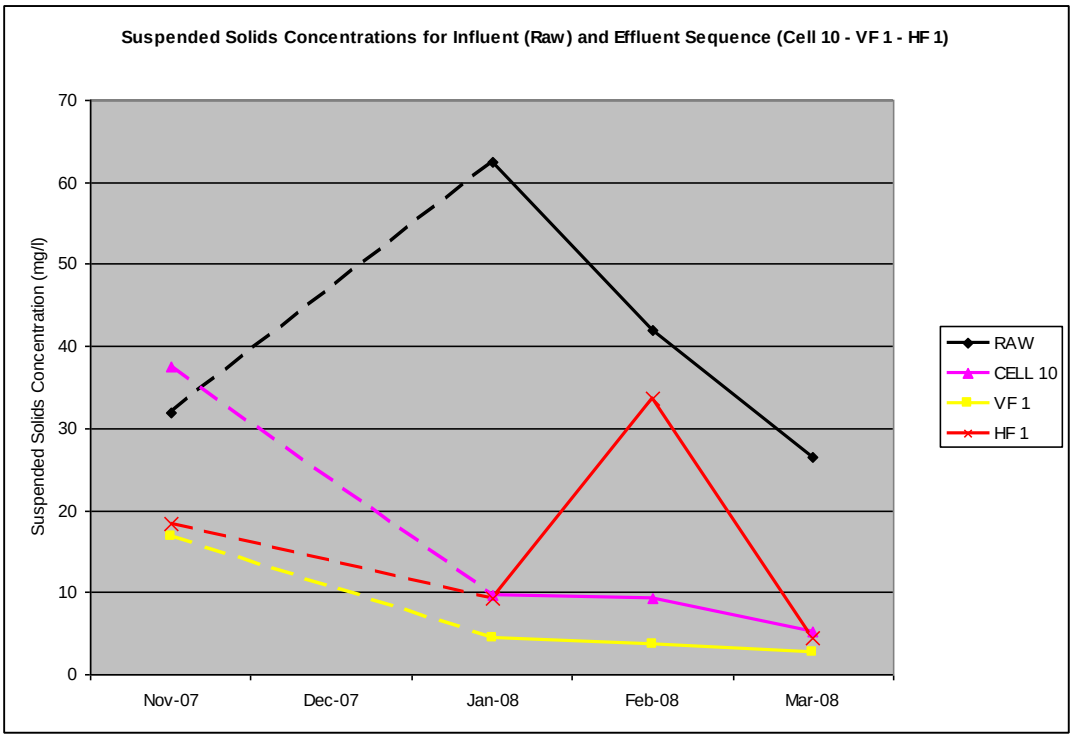


Figure 8.40(a) Suspended Solids Concentrations in Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

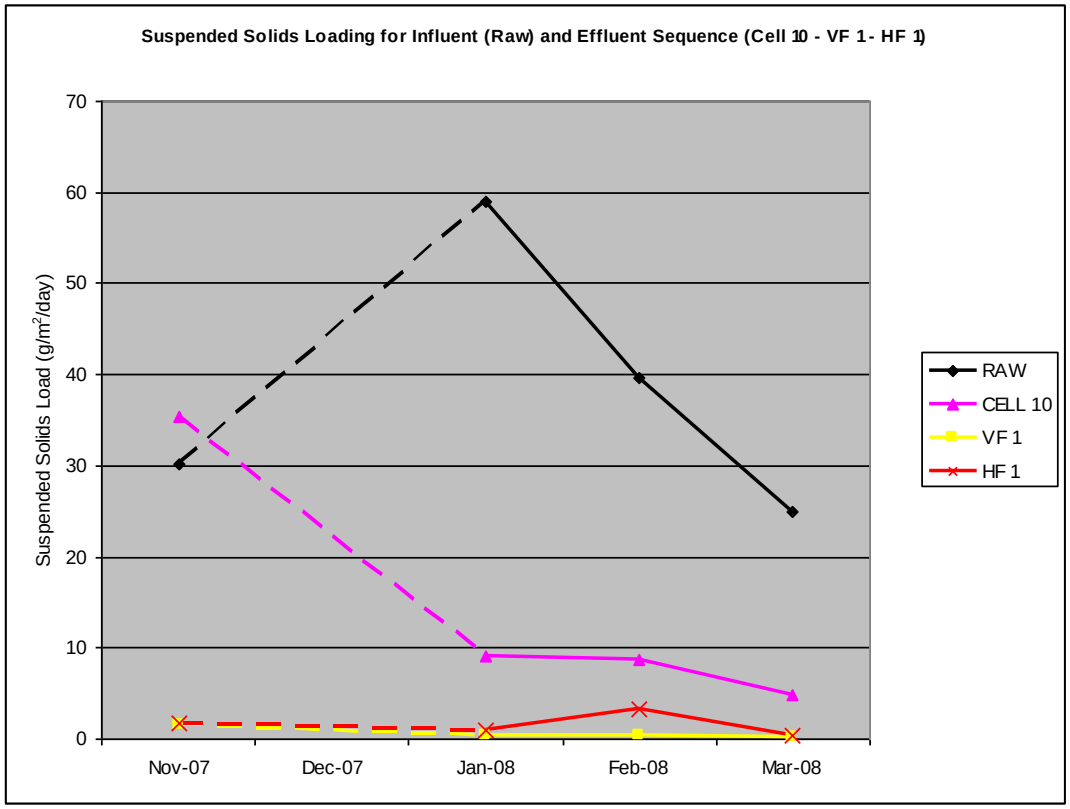


Figure 8.40(b) Suspended Solids Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

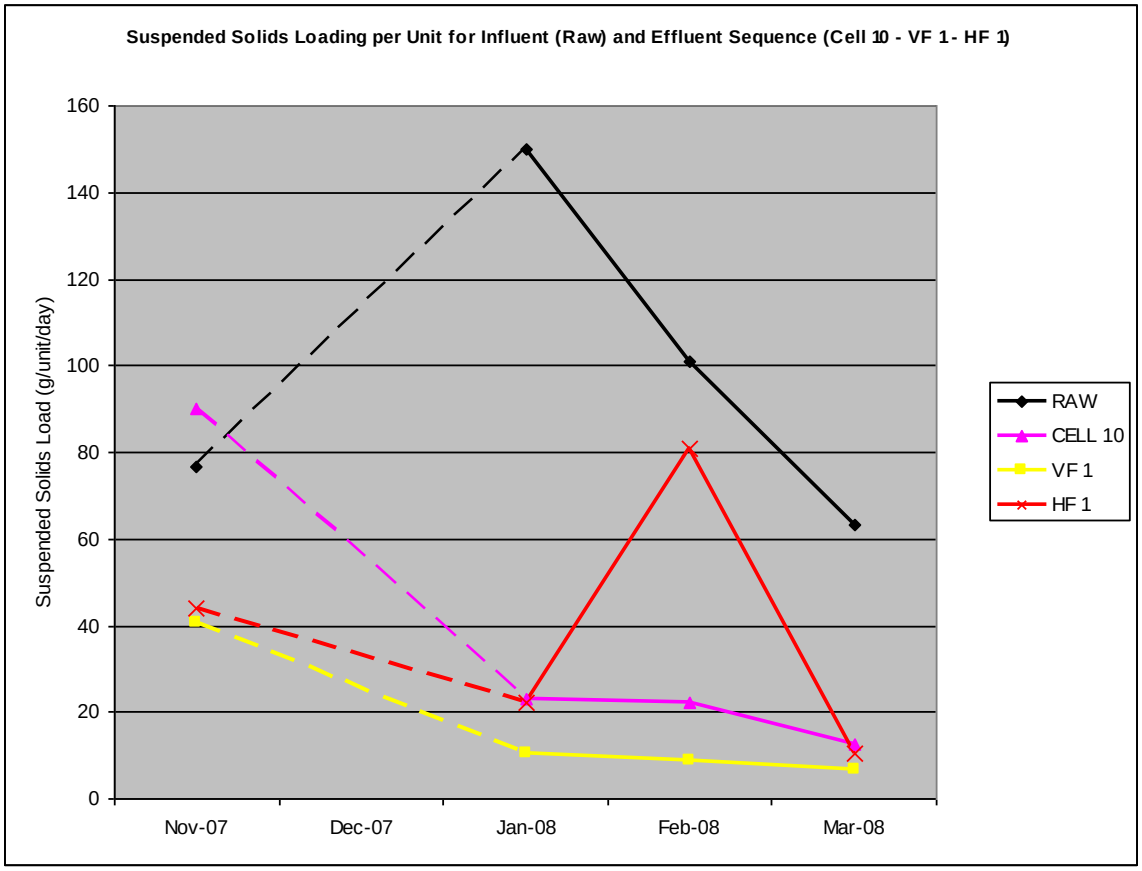


Figure 8.40(c) Suspended Solids Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.4.4 Interpretation of Suspended Solids Removal in Treatment Units Operating in Sequence

Analysis of suspended solids results for concentrations and load removal rates for treatment units operating in sequence; Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1; reveals a positive average load removal and lower effluent concentrations for both sequences. Each of the primary treatment (cells 1 and 10) and secondary treatment units (VF 1 and VF 2) display high load removal rates; 35g/unit/day and 27g/unit/day load removal for Cell 1 and VF 2 and 61g/unit/day and 20g/unit/day load removal for Cell 10 and VF 1.

HF 2 displayed a small average load removal from the system of 3g/unit/day, while HF 1 revealed a negative average load removal from the system of -23g/unit/day.

It is likely that sedimentation and filtration were the primary mechanisms for suspended solids removal. The spaces within the gravel medium of HF 2 were possibly too large to

contribute significantly to suspended solids removal and since subsoil was the growth medium for HF 1, the finer particles would have washed out of the medium as wastewater flowed across the reed bed.

The charts detailing the influent and effluent loads per unit for each of the sequences reveals a lower effluent load for all units with the exception of one result for cell 1 and cell 10 in November 2007 (trial commencement) where negative load removals of -2g/unit/day and -14g/unit/day were recorded respectively (Figures 8.39(c) and 8.40(c)).

8.2.5 Analysis of Chloride and Electrical Conductivity

The results from analysis of chloride and electrical conductivity (EC) of the system's influent and effluents are detailed in this section. A series of tables outlining chloride and EC results for individual treatment units is presented below in section 8.2.5.1. The full suite of concentrations for influent and effluent for Raw – Cell 2 (also including sequence Raw – Cell 1 – Cell 2) and for Raw – Cell 6 is provided in Tables 8.42(a) and 8.46(a) respectively. The reasons for presenting these tables will be explained in the section on interpretation in 8.2.5.2.

Similar tables for chloride and EC results for treatment units operating in sequence are presented in section 8.2.5.3 followed by interpretation.

8.2.5.1 Chloride and Electrical Conductivity Results for Individual Treatment Units

Chloride and Electrical Conductivity results for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.41(a) to 8.48(c).

Charts detailing the range of chloride concentrations and loadings as well as electrical conductance for cells 1 to 8 are presented in Figures 8.41(a) to 8.48(c).

<u>Cell 1 - Medium: Coarse Grade Compost</u>

Operational Period: August – October 2007

Table 8.41(a) Summary of Chloride Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	7	349 - 513	443 (± 62)	419
Chloride	Effluent	3	414 - 465	436 (± 26)	411

Table 8.41(b) Summary of Chloride Load Removal for Cell 1

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	8	2

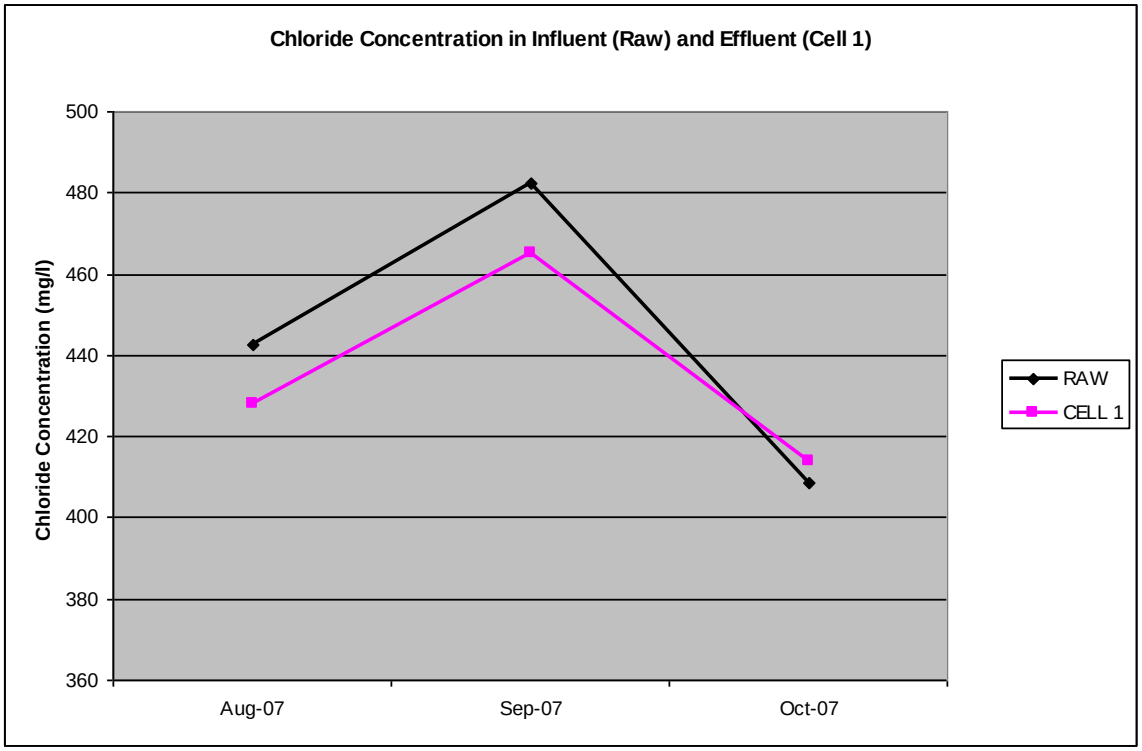


Figure 8.41(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 1)

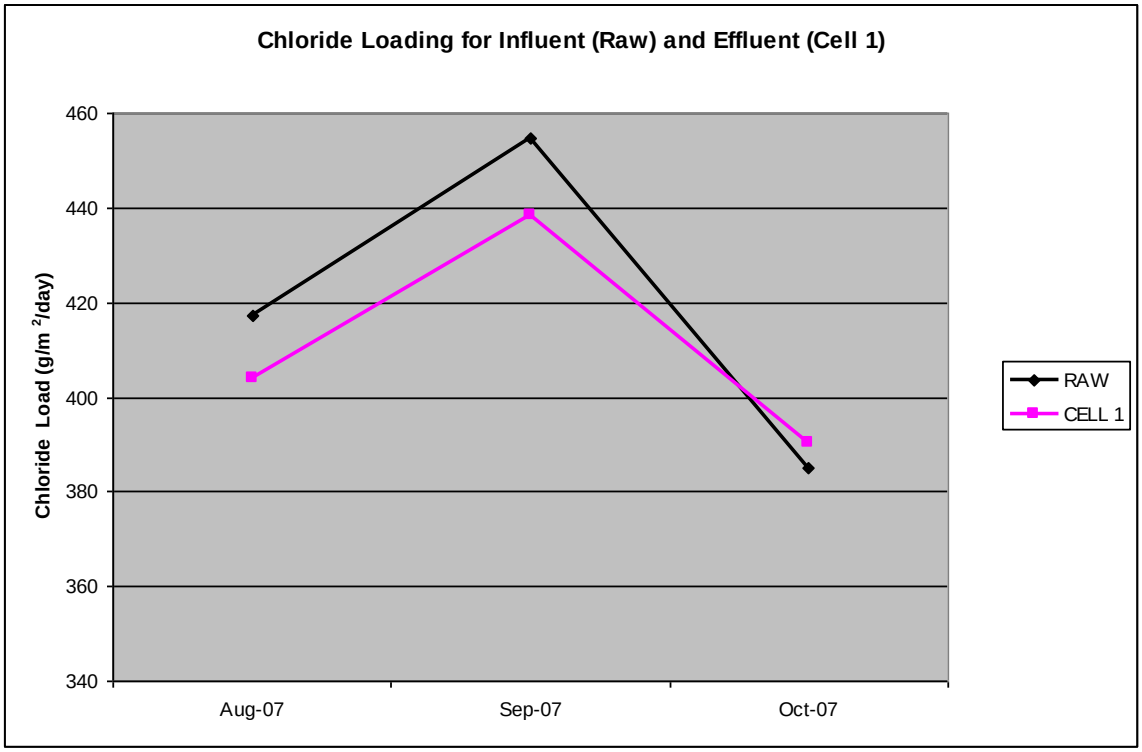


Figure 8.41(b) Chloride Loading for Influent (Raw) and Effluent (Cell 1)

Table 8.41(c) Summary of EC Results for Cell 1

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	7	4.06 - 5.40	4.74 (± 0.5)
EC	Effluent	3	4.28 - 4.50	4.35 (± 0.13)

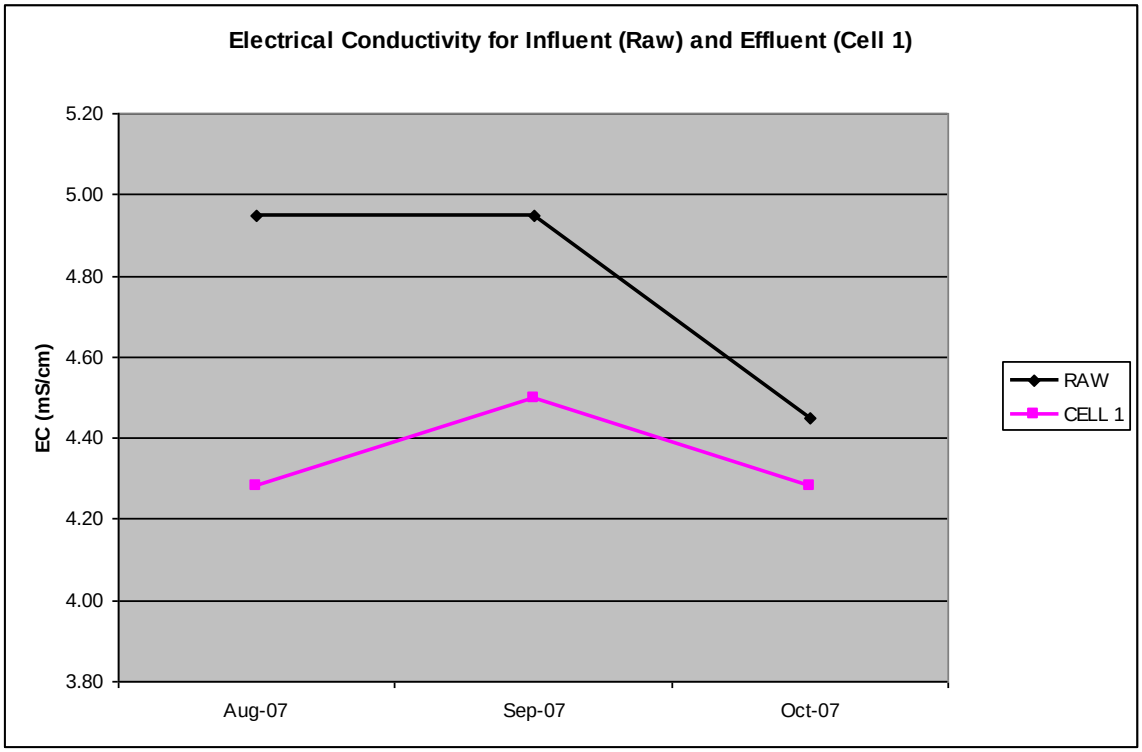


Figure 8.41(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 1)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: Phase 1 - August 2007 – March 2008

(Flow Sequence: Raw – Cell 2)

Phase 2 - April 2008 – July 2008

(Flow Sequence: Raw - Cell 1 – Cell 2)

Table 8.42(a) Chloride Concentrations (mg/l) for Influent (Raw) and Effluent (Cell 2) and Sequence (Cell 1 - Cell 2)

	Influent		**Effluent**
Sequence	**Raw (mg/l)**	→	**Cell 2 (mg/l)**
Aug-07	513	→	479
Sep-07	482	→	440
Oct-07	408	→	428
Nov-07	429	→	423
Dec-07			
Jan-08	186	→	147
Feb-08	275	→	224
Mar-08	448	→	405
	Influent	**Effluent**	**Effluent**
Sequence	**Raw (mg/l)**	**Cell 1 (mg/l)**	**Cell 2 (mg/l)**
Apr-08	411	428	437
May-08	431	423	444
Jun-08	844	546	539
Jul-08	319		

Table 8.42(b) Summary of Chloride Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Chloride	Influent	17	176 - 513	365 (± 110)	369
Chloride	Effluent	7	147 - 479	364 (± 126)	343

Table 8.42(c) Summary of Chloride Load Removal for Cell 2

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Chloride	26	7

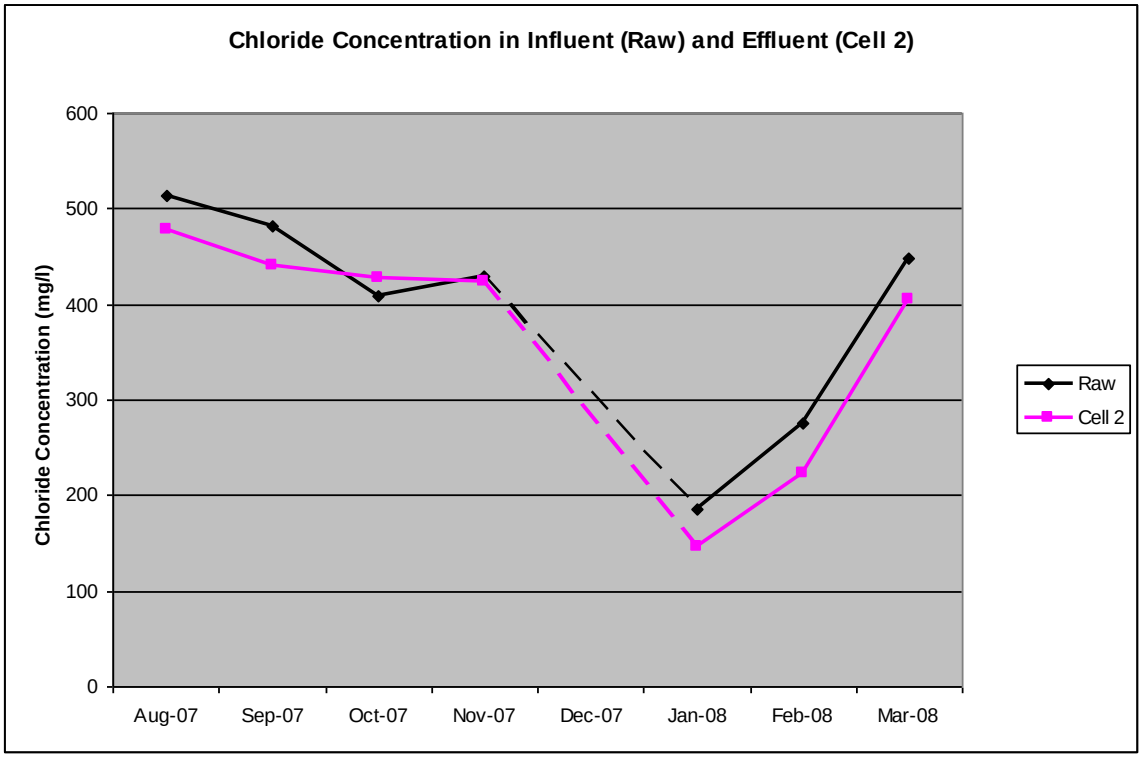


Figure 8.42(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 2)

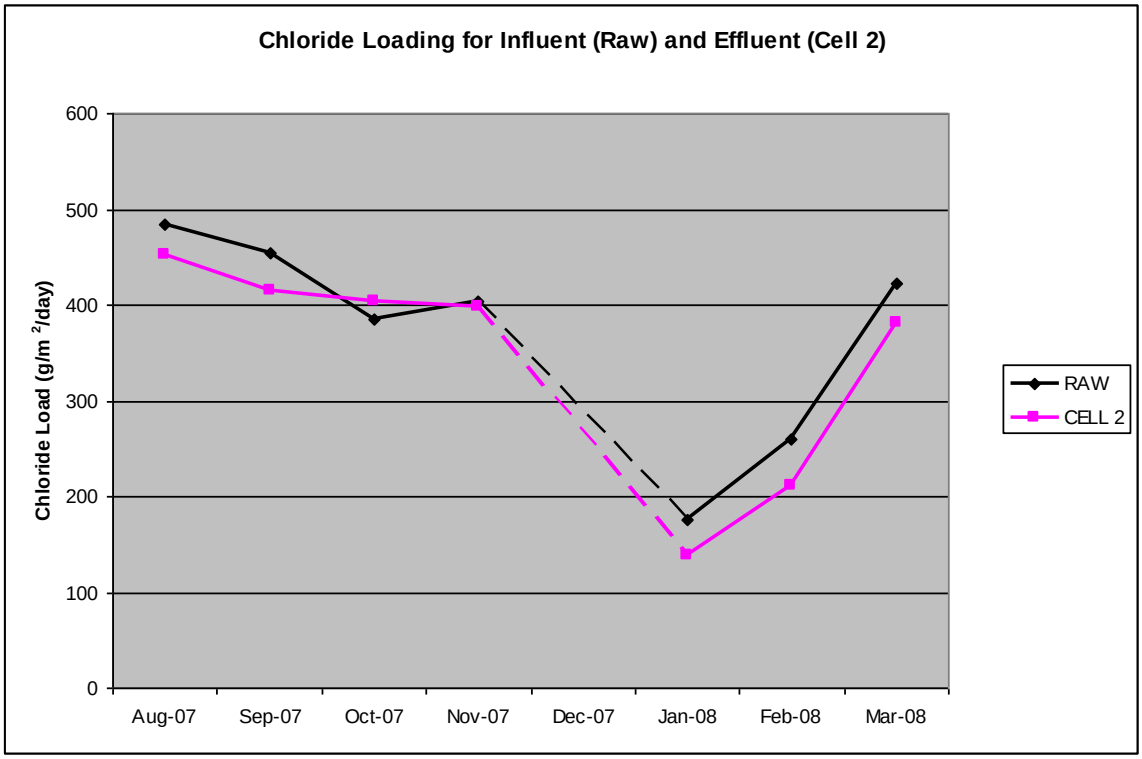


Figure 8.42(b) Chloride Loading for Influent (Raw) and Effluent (Cell 2)

Table 8.42(d) Summary of Chloride Concentrations and Loadings for Sequence (Raw – Cell 1 - Cell 2)

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	3	431 - 844	562 (± 244)	734
Chloride	Effluent (Cell 1)	3	423 - 546	466 (± 70)	619
Chloride	Effluent (Cell 2)	3	444 - 539	473 (± 57)	630

Table 8.42(e) Summary of Chloride Load Removal for Sequence (Raw – Cell 1 - Cell 2)

Parameter		Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	Cell 1	115	16
	Cell 2	-11	-2

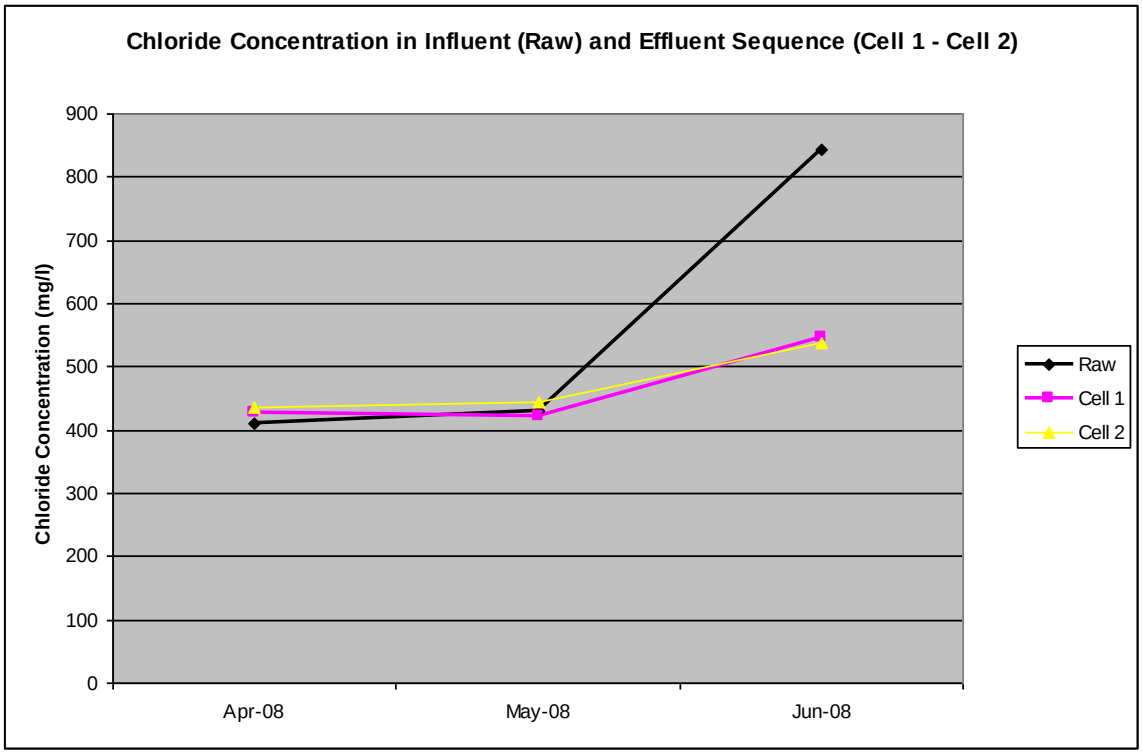


Figure 8.42(c) Chloride Concentration in Influent (Raw) and Effluent Sequence (Cell 1 - Cell 2)

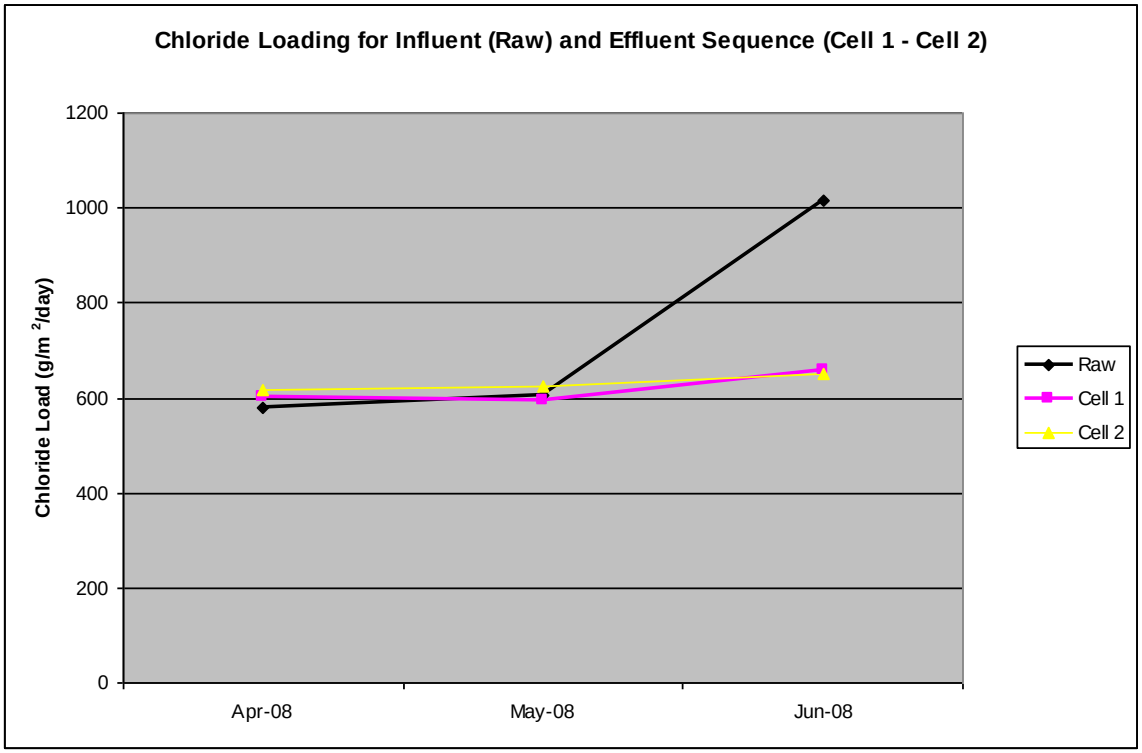


Figure 8.42(d) Chloride Loading for Influent (Raw) and Effluent Sequence (Cell 1 - Cell 2)

Table 8.42(f) Summary of EC Results for Cell 2

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	17	2.22 - 5.40	3.84 (± 1.01)
EC	Effluent	7	2.01 - 4.90	3.76 (± 1.15)

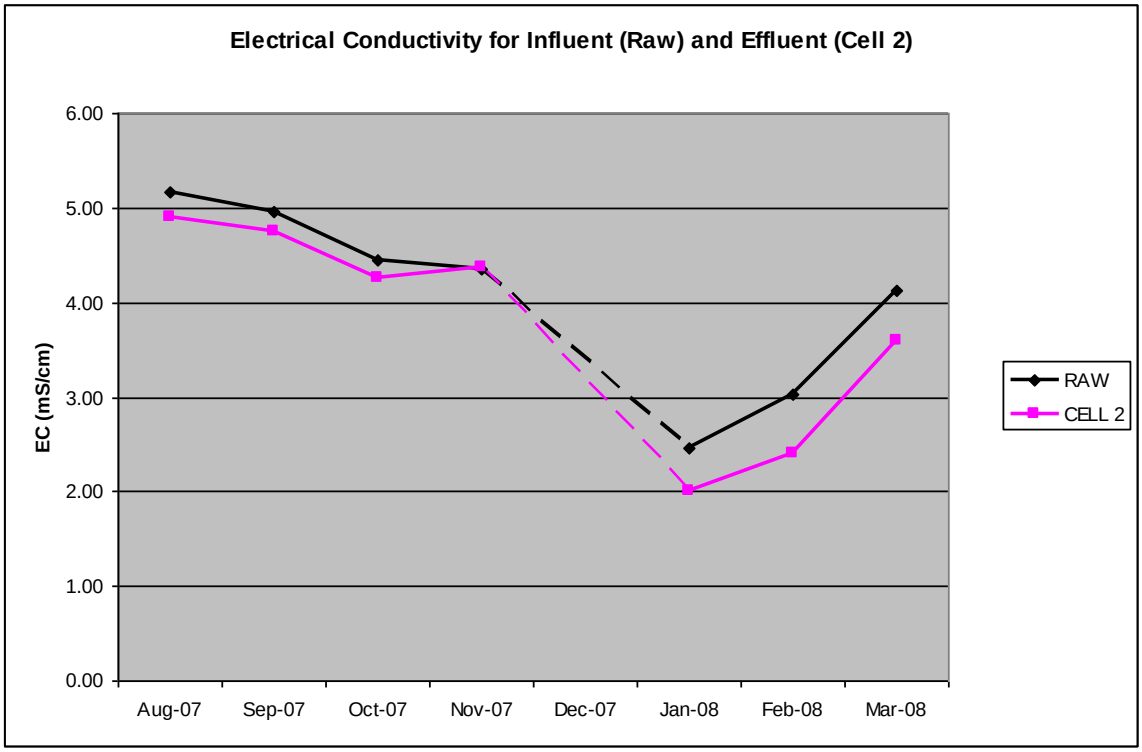


Figure 8.42(e) Electrical Conductivity for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.43(a) Summary of Chloride Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	10	272 - 513	408 (± 86)	415
Chloride	Effluent	4	425 - 513	457 (± 39)	431

Table 8.43(b) Summary of Chloride Load Removal for Cell 3

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	-16	-4

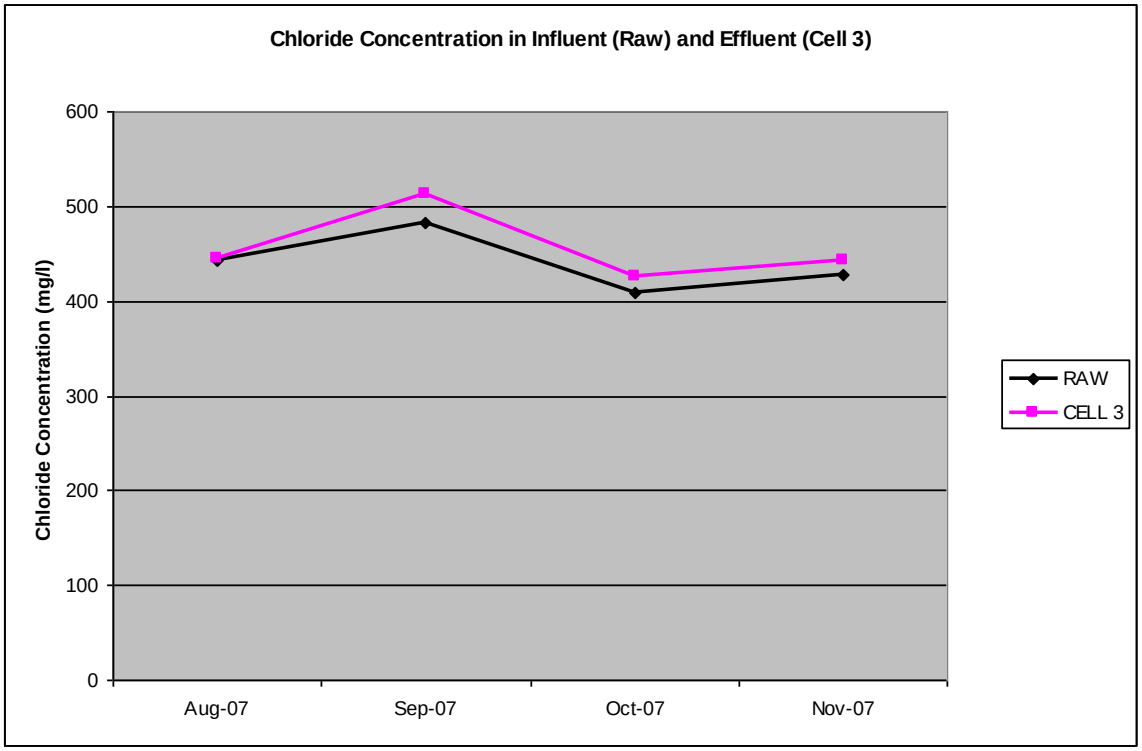


Figure 8.43(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 3)

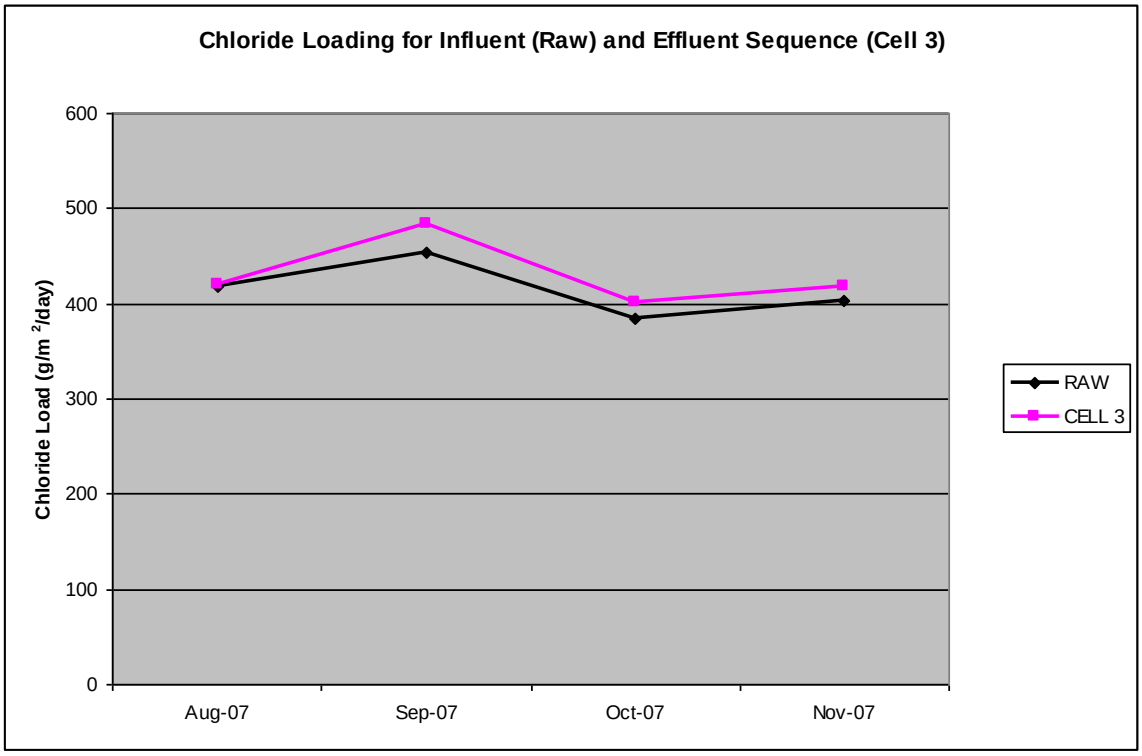


Figure 8.43(b) Chloride Loading for Influent (Raw) and Effluent (Cell 3)

Table 8.43(c) Summary of EC Results for Cell 3

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	10	3.12 - 5.40	4.38 (± 0.79)
EC	Effluent	4	4.43 - 4.94	4.58 (± 0.24)

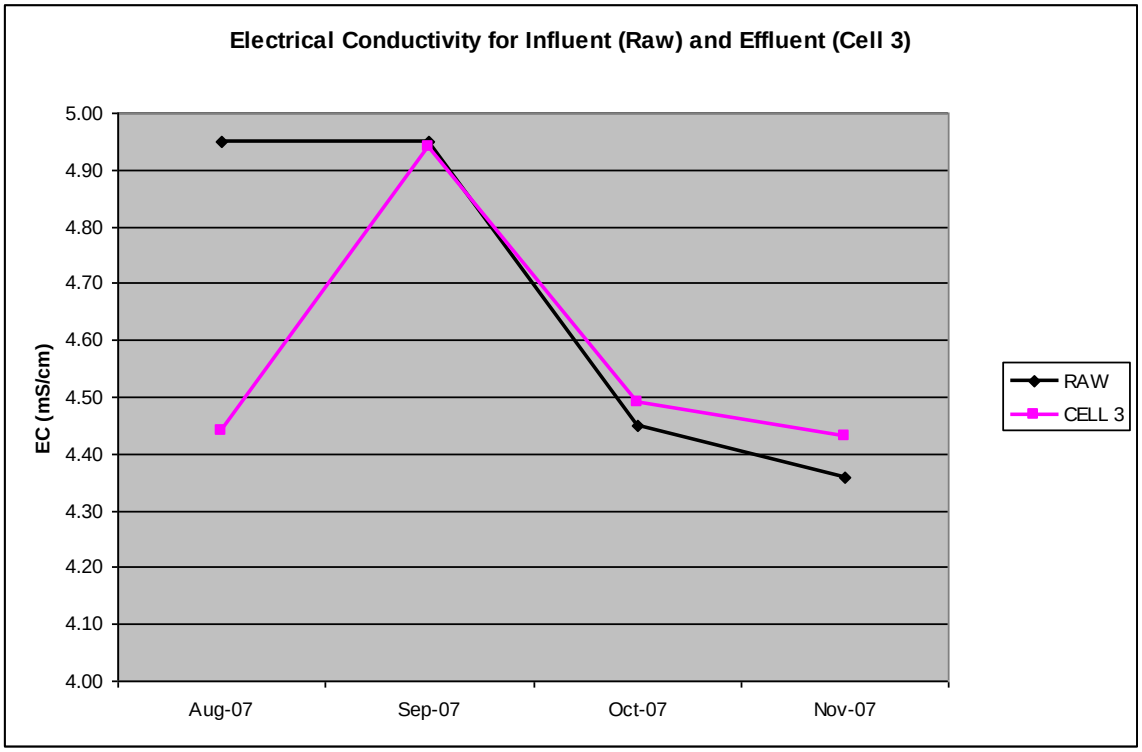


Figure 8.43(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.44(a) Summary of Chloride Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	19	176 - 513	372 (± 106)	386
Chloride	Effluent	8	146 - 593	406 (± 137)	382

Table 8.44(b) Summary of Chloride Load Removal for Cell 4

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	4	1

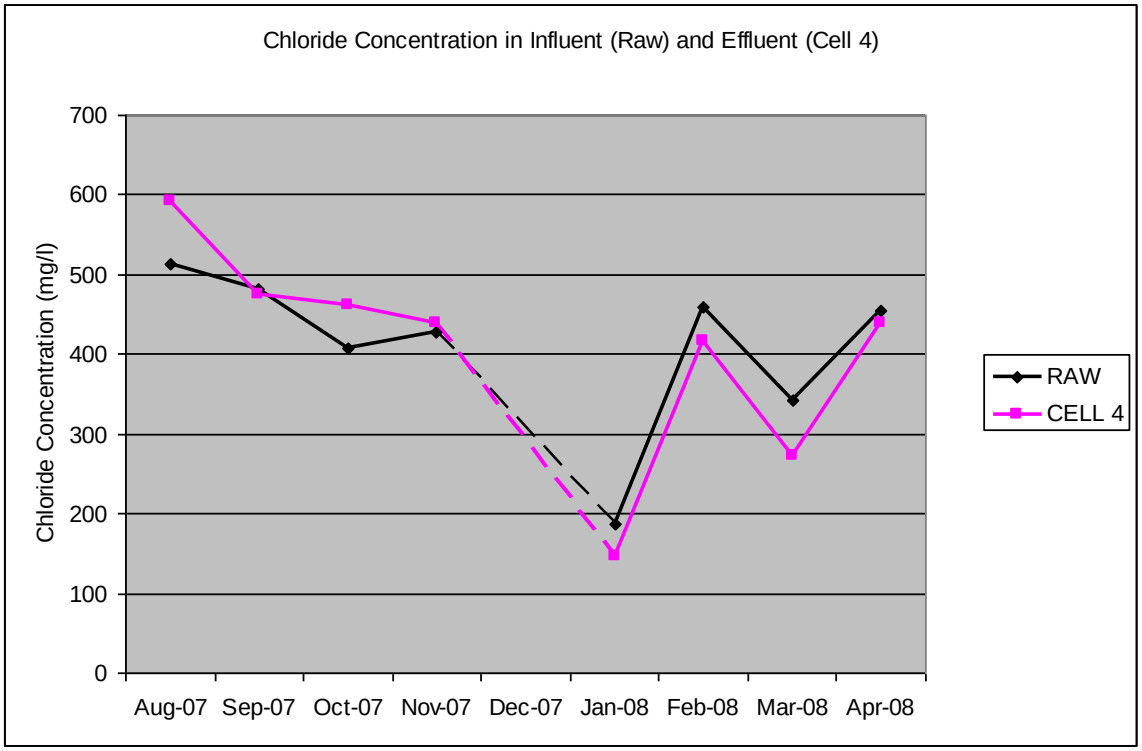


Figure 8.44(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 4)

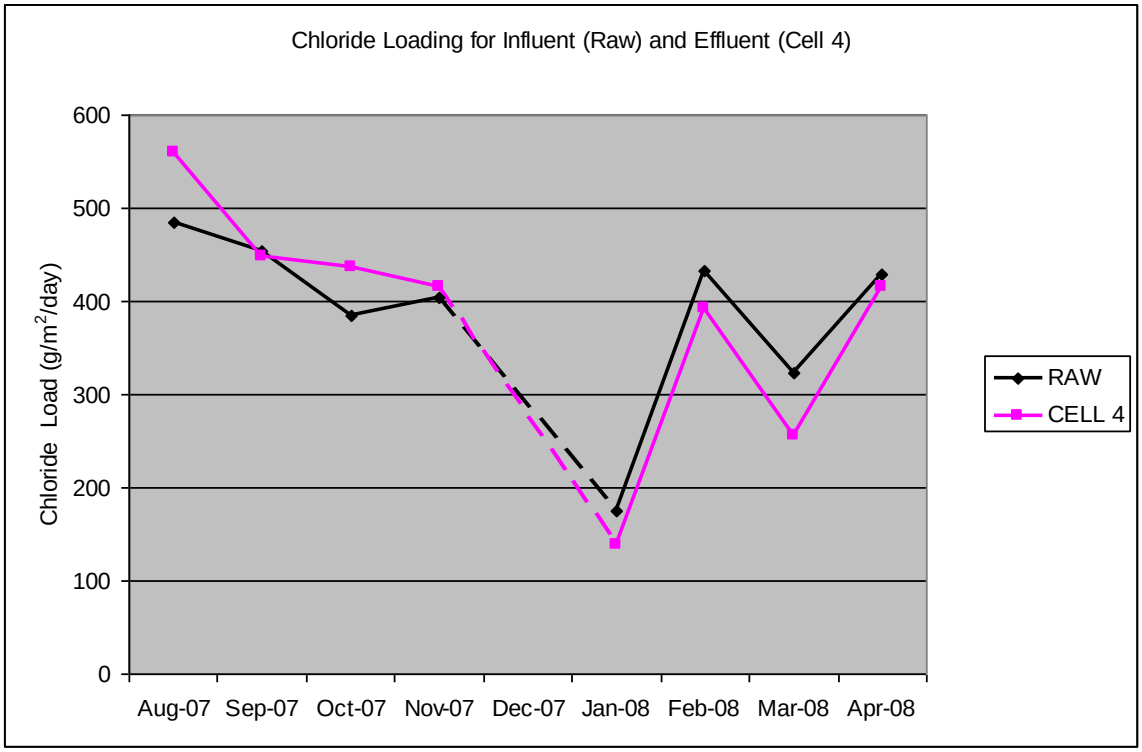


Figure 8.44(b) Chloride Loading for Influent (Raw) and Effluent (Cell 4)

Table 8.44(c) Summary of EC Results for Cell 4

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	19	2.22 - 5.40	3.94 (± 0.99)
EC	Effluent	8	2.20 - 4.97	4.05 (± 1.03)

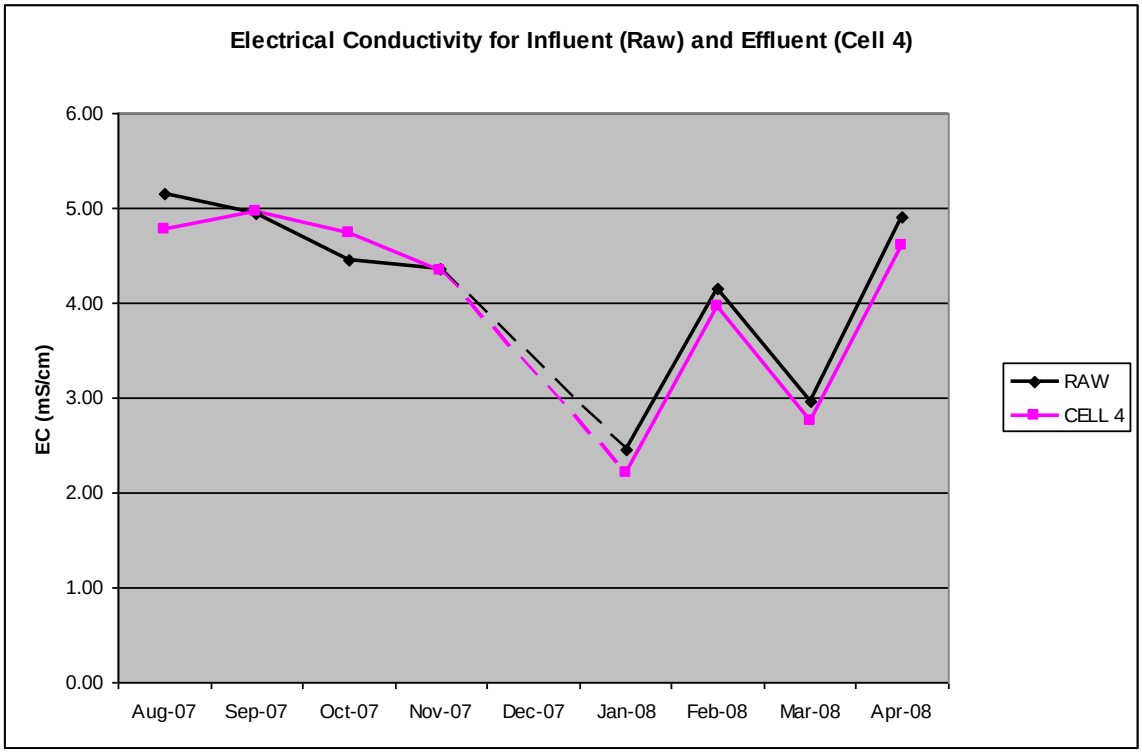


Figure 8.44(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.45(a) Summary of Chloride Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	24	176 - 844	395 (± 136)	60
Chloride	Effluent	8	272 - 496	412 (± 85)	63

Table 8.45(b) Summary of Chloride Load Removal for Cell 5

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	-3	-5

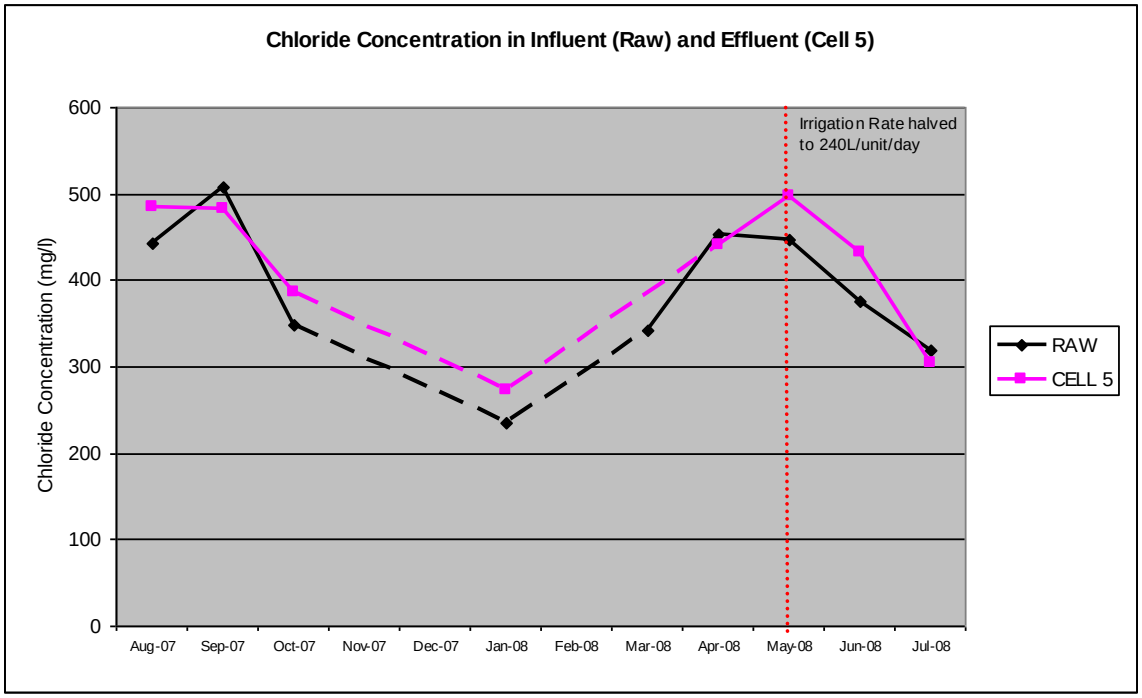


Figure 8.45(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 5)

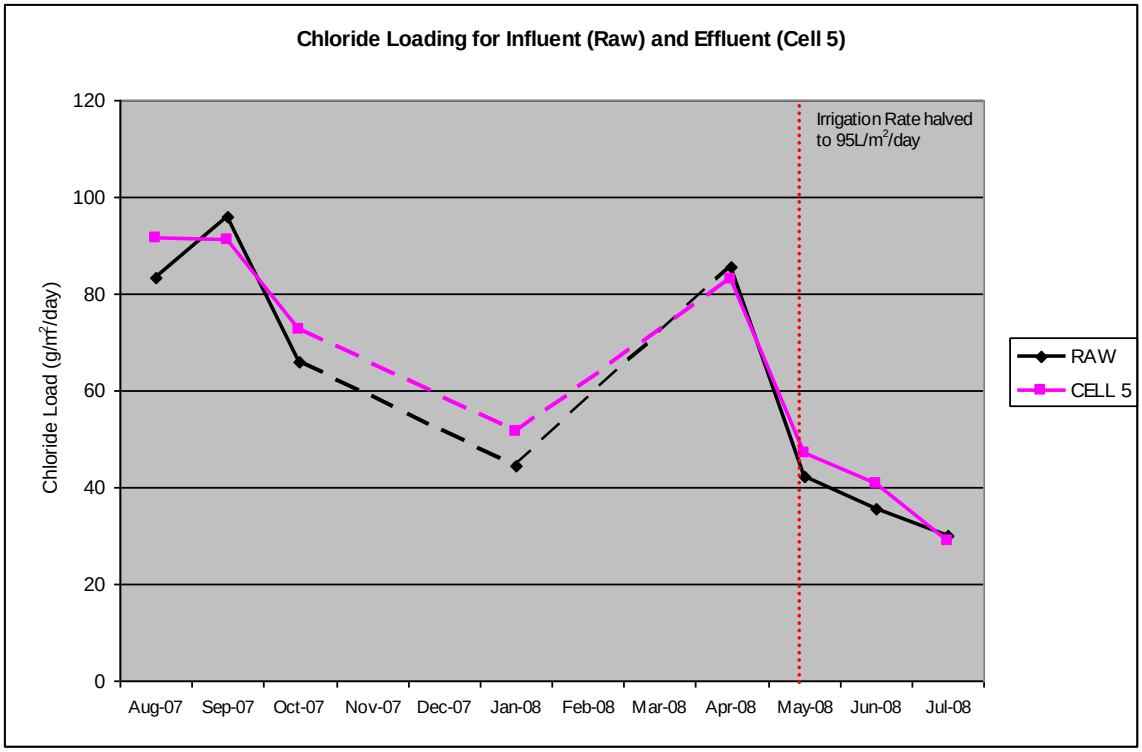


Figure 8.45(b) Chloride Loading for Influent (Raw) and Effluent (Cell 5)

Table 8.45(c) Summary of EC Results for Cell 5

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	24	2.22 - 5.40	4.02 (± 0.95)
EC	Effluent	8	2.70 - 4.70	3.84 (± 0.79)

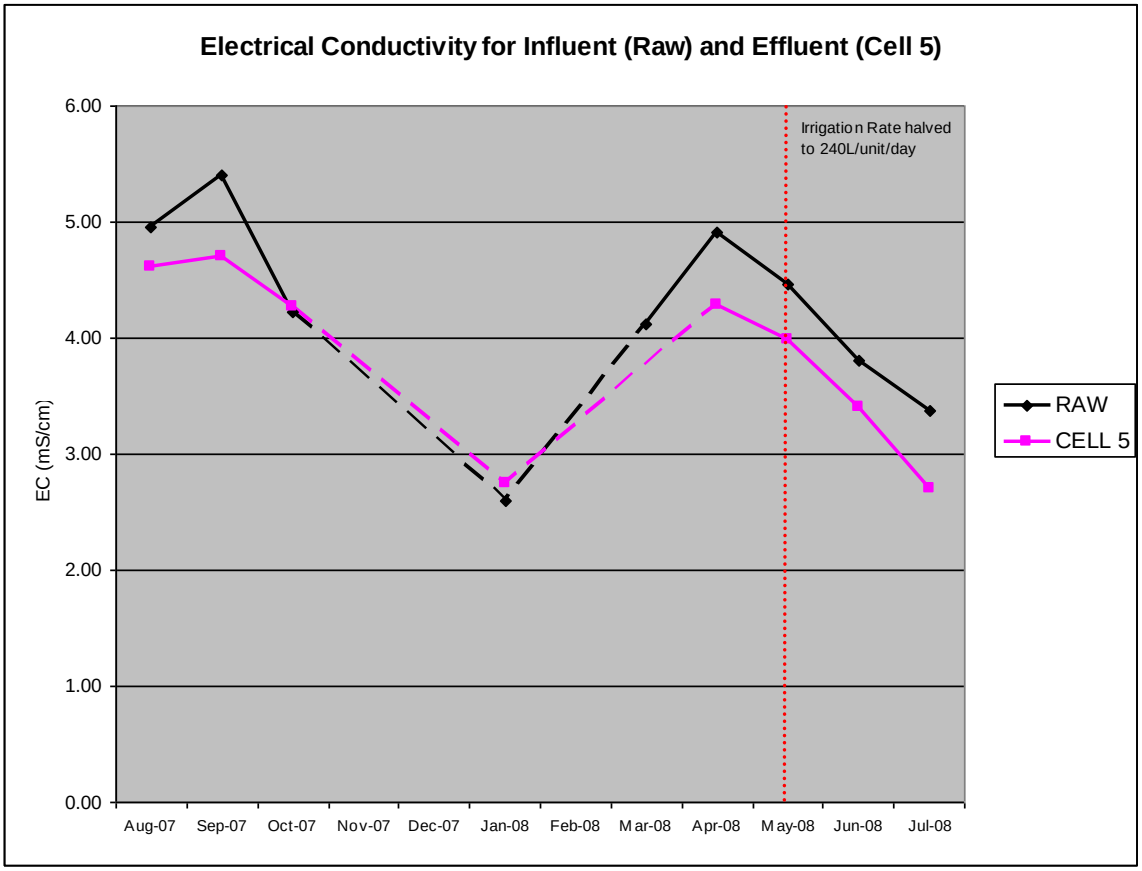


Figure 8.45(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.46(a) Chloride Concentrations (mg/l) for Influent and Effluent (Cell 6)

	Raw	**Cell 6**
Aug-07	513	525
Sep-07	508	474
Oct-07	349	437
Nov-07	272	315
Dec-07		
Jan-08	186	193
Feb-08	459	
Mar-08	448	343
Apr-08	454	329
May-08	447	503
Jun-08	376	461
Jul-08	319	

Table 8.46(b) Summary of Chloride Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Chloride	Influent	23	176 - 844	399 (± 138)	176
Chloride	Effluent	9	193 - 525	398 (± 109)	175

Table 8.46(c) Summary of Chloride Load Removal for Cell 6

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Chloride	1	0.6

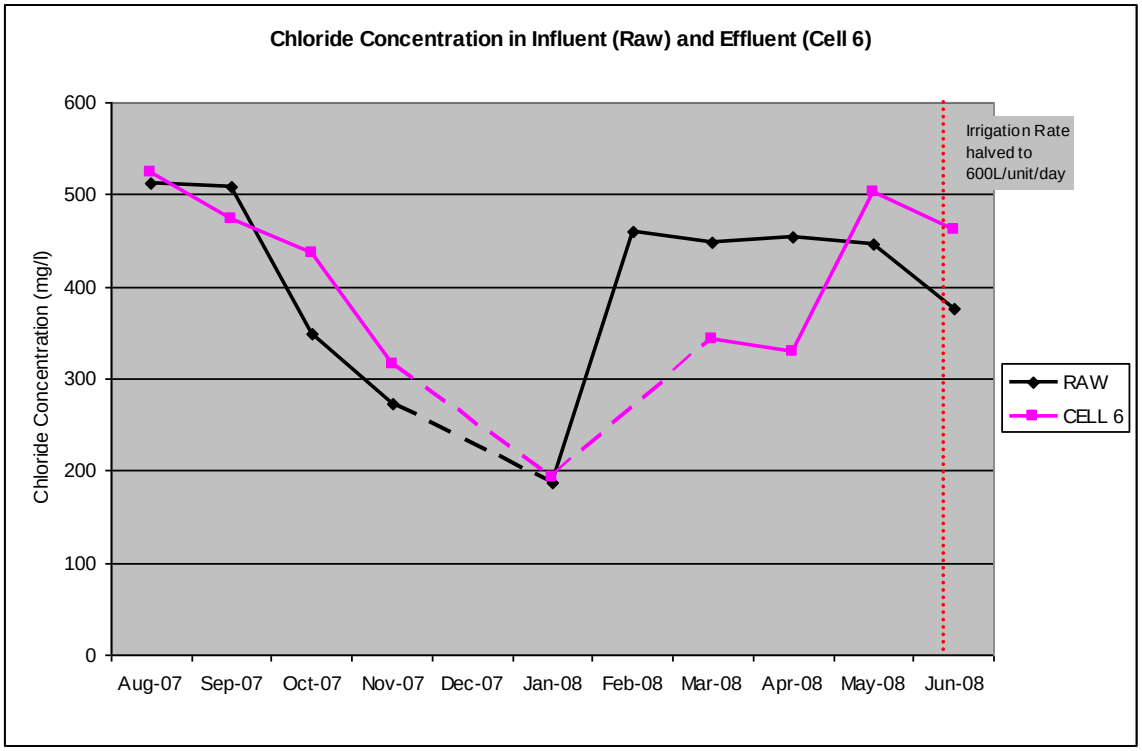


Figure 8.46(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 6)

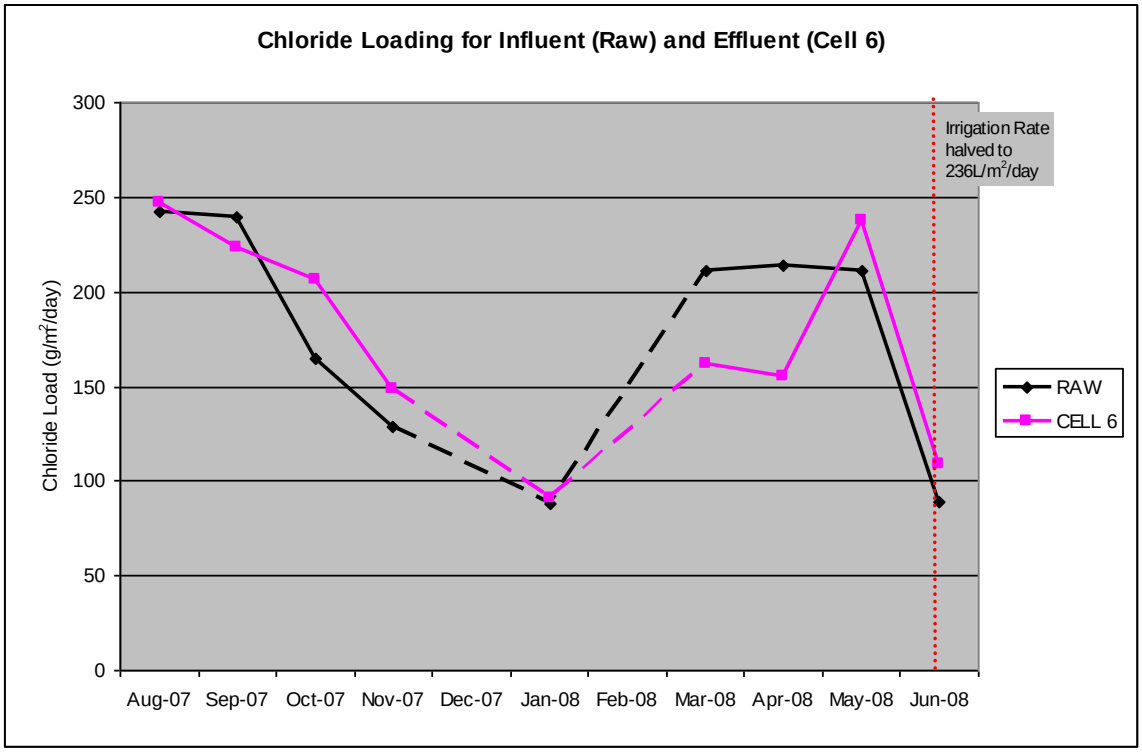


Figure 8.46(b) Chloride Loading for Influent (Raw) and Effluent (Cell 6)

Table 8.46(d) Summary of EC Results for Cell 6

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	23	2.22 - 5.40	4.05 (± 0.96)
EC	Effluent	9	5.13 - 2.65	3.99 (± 0.93)

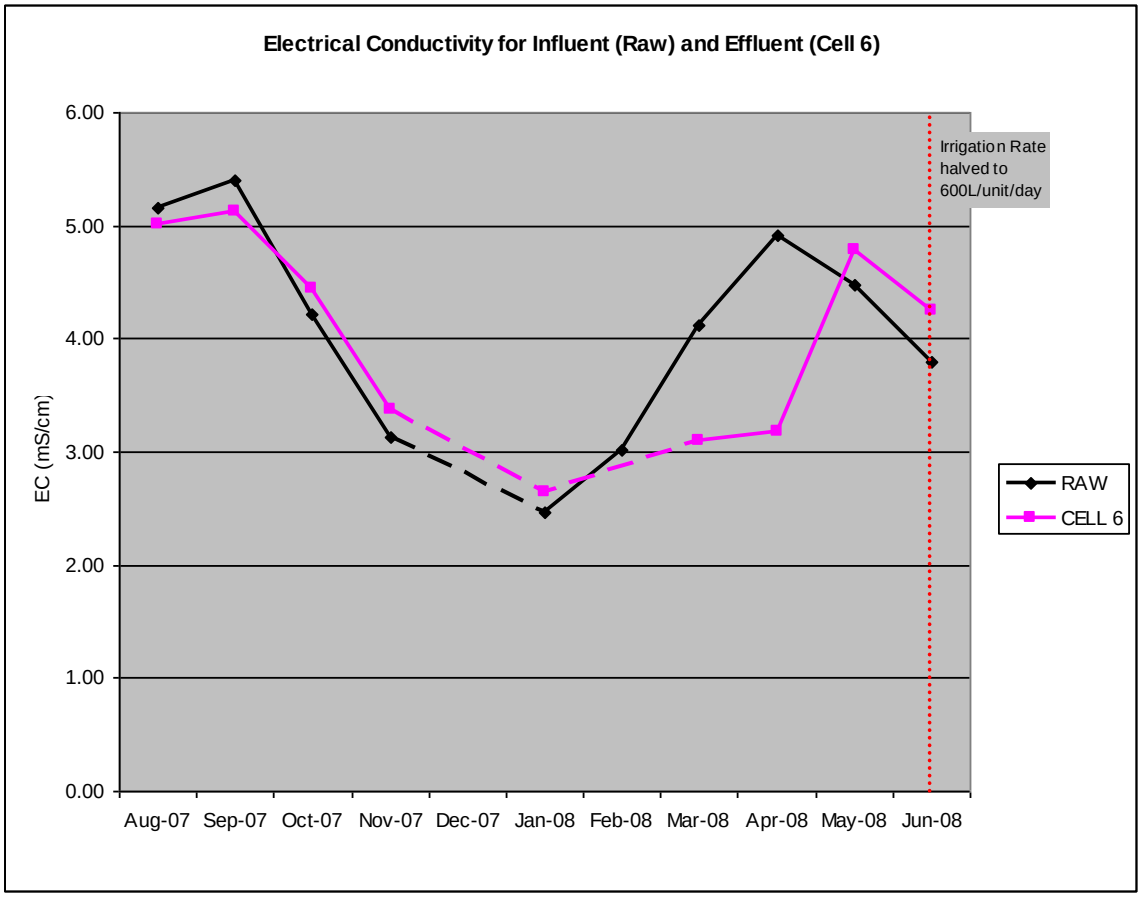


Figure 8.46(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.47(a) Summary of Chloride Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	26	176 - 844	393 (± 133)	282
Chloride	Effluent	12	206 - 508	374 (± 94)	292

Table 8.47(b) Summary of Chloride Load Removal for Cell 7

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	-10	-4

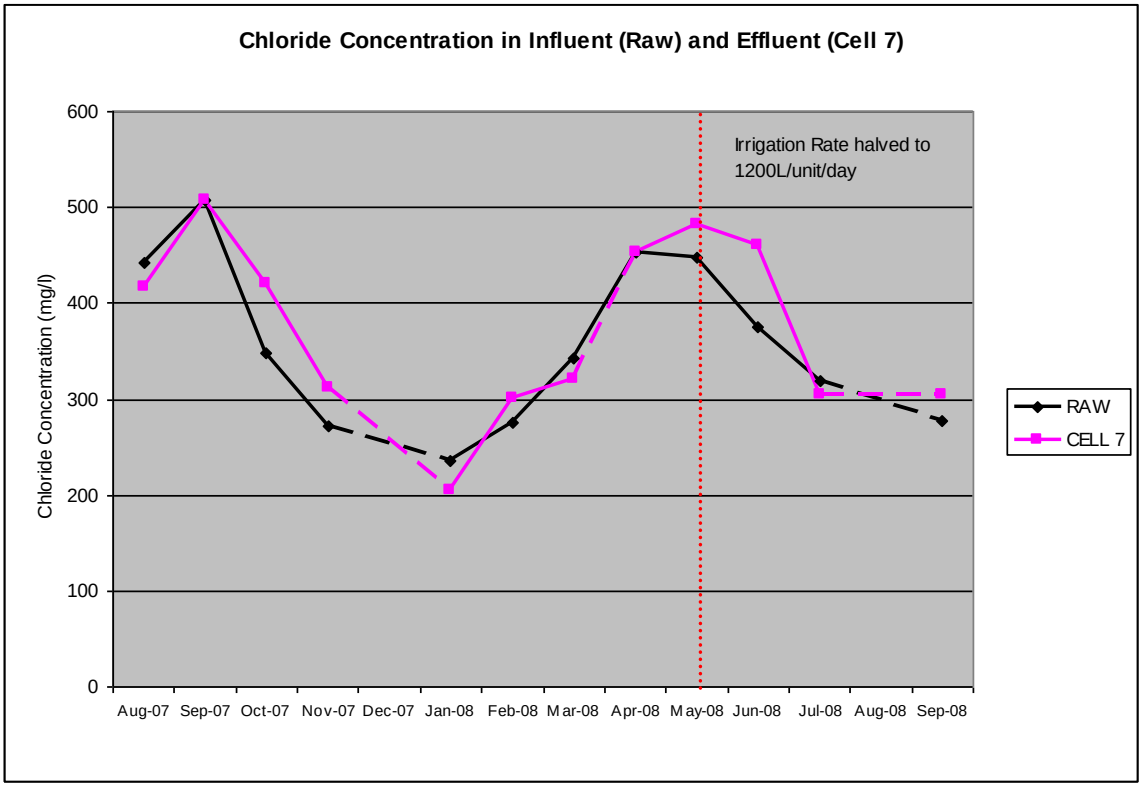


Figure 8.47(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 7)

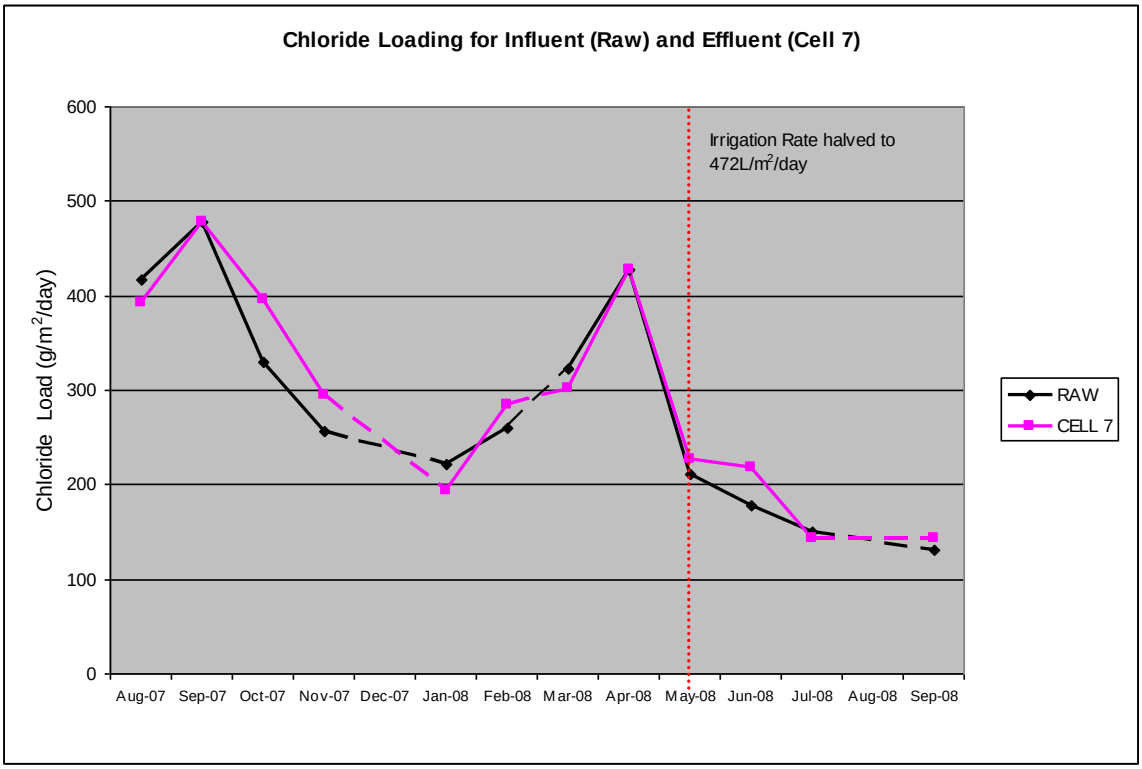


Figure 8.47(b) Chloride Loading for Influent (Raw) and Effluent (Cell 7)

Table 8.47(c) Summary of EC Results for Cell 7

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	26	2.22 - 5.40	3.99 (± 0.93)
EC	Effluent	12	2.55 - 5.17	3.76 (± 0.93)

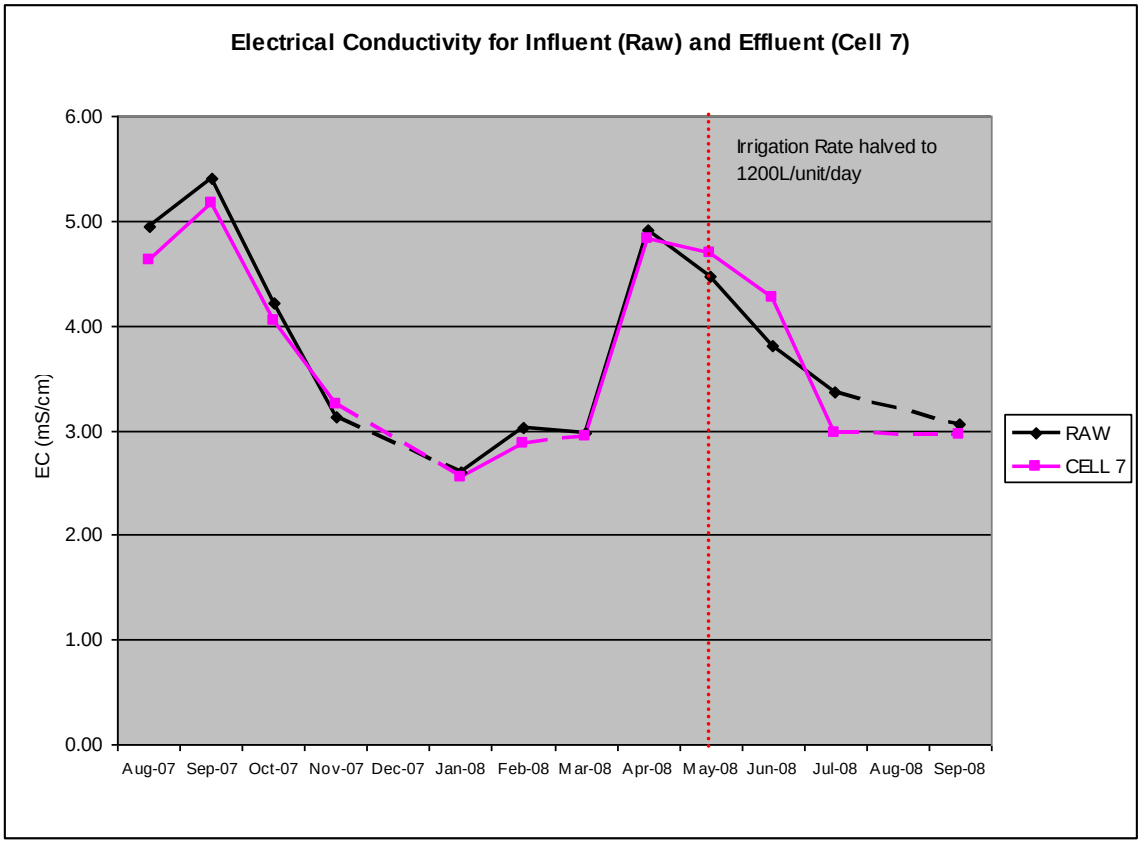


Figure 8.47(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.48(a) Summary of Chloride Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Chloride	Influent	26	176 - 844	393 (± 133)	173
Chloride	Effluent	9	241 - 527	418 (± 102)	171

Table 8.48(b) Summary of Chloride Load Removal for Cell 8

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Chloride	2	1

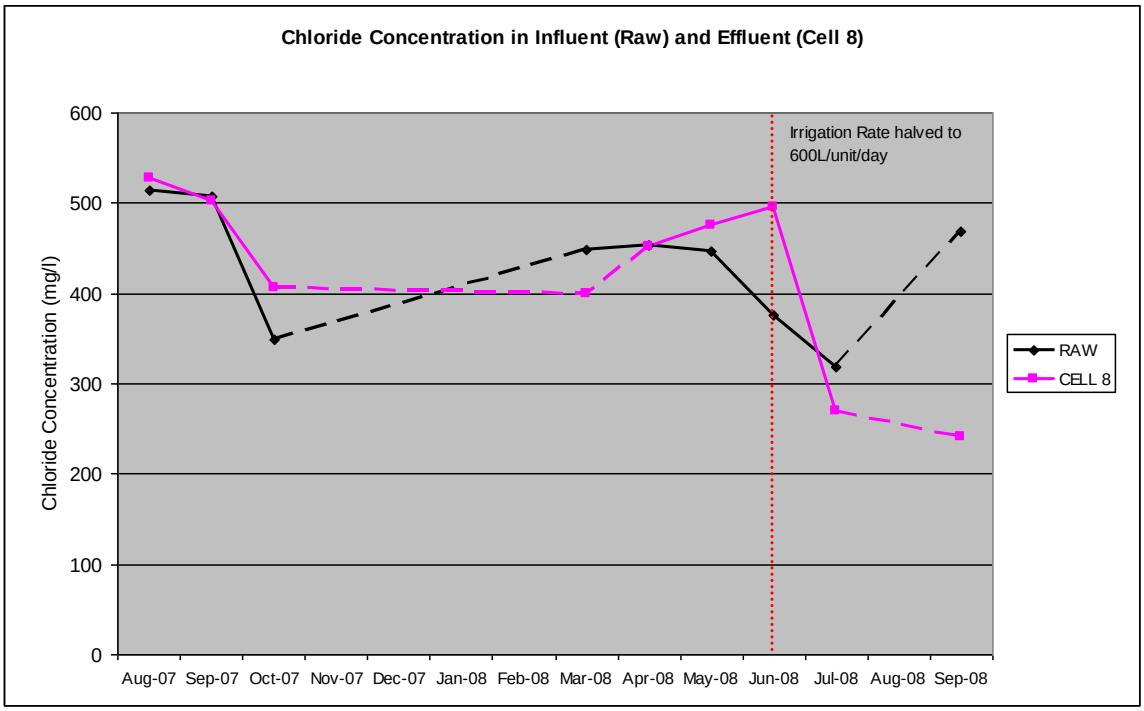


Figure 8.48(a) Chloride Concentration in Influent (Raw) and Effluent (Cell 8)

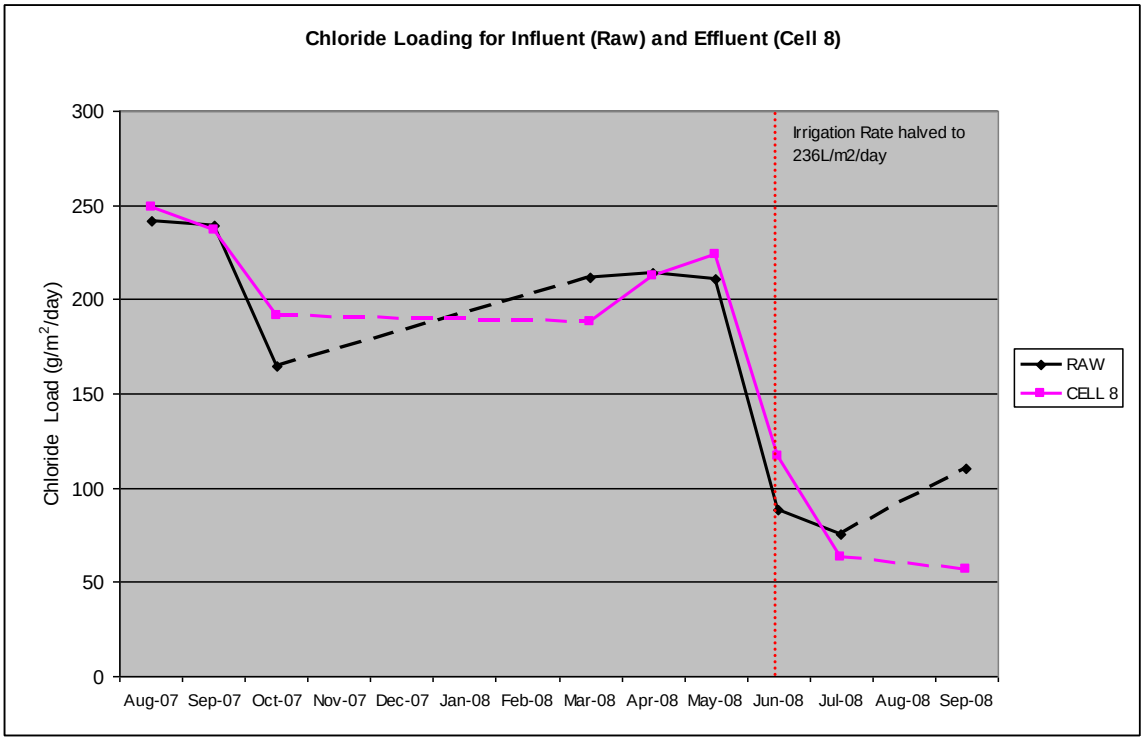


Figure 8.48(b) Chloride Loading for Influent (Raw) and Effluent (Cell 8)

Table 8.48(c) Summary of EC Results for Cell 8

Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	26	2.22 - 5.40	3.99 (± 0.93)
EC	Effluent	9	2.80 - 5.27	4.29 (± 0.92)

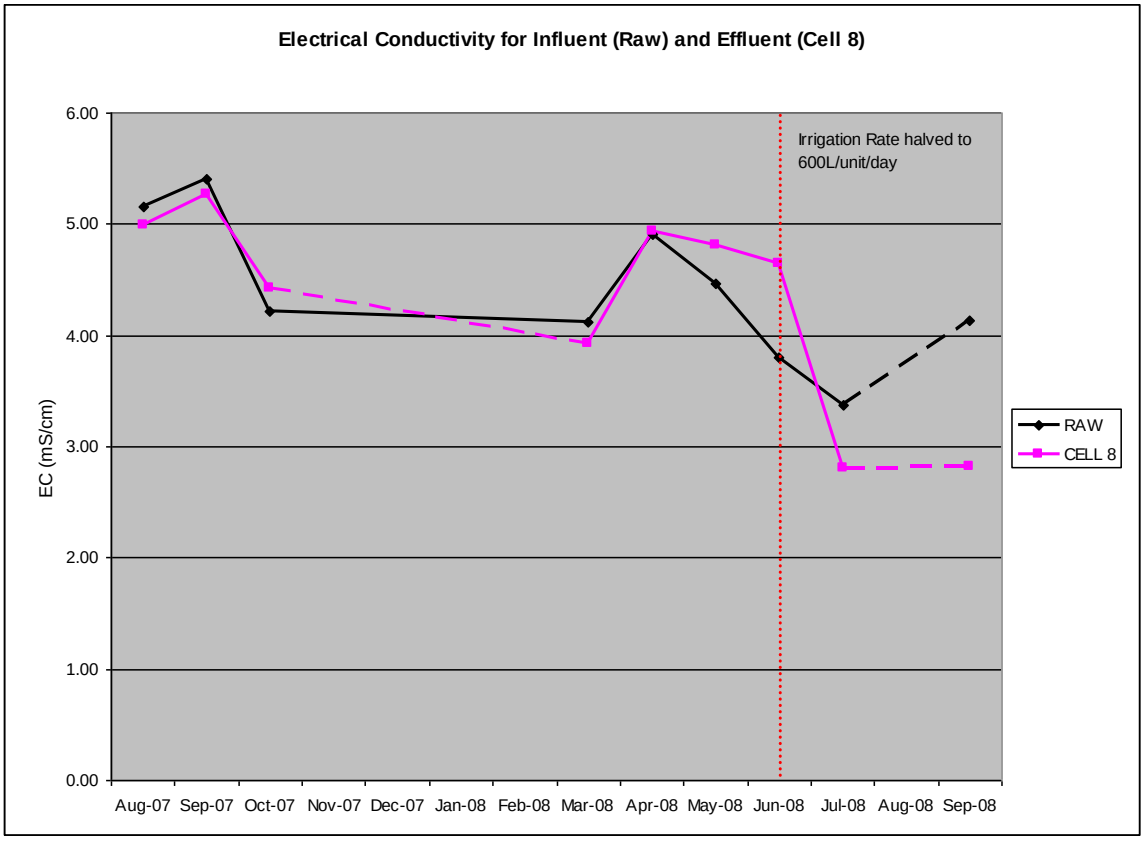


Figure 8.48(c) Electrical Conductivity for Influent (Raw) and Effluent (Cell 8)

8.2.5.2 Interpretation of Chloride and Electrical Conductivity Results for Individual Treatment Units

Since chloride is a conservative pollutant and readily moves through the environment with little or no reaction or degradation, it was not expected that results would record any significant load removal throughout the system. Similarly with electrical conductivity (EC) being a measure of the quantity of dissolved salts in a solution, lower effluent readings were deemed unlikely.

However, inspection of the results obtained for chloride and electrical conductivity for cells 1 to 8 reveals positive load removal for chloride and lower effluent conductance for a number of units. Cells 1, 2, 4, 6 and 8 all record positive average load removal (8, 26, 4,

1 and 2g/m^2/day respectively) for chloride with cells 1, 2, 5, 6 and 7 recording a slightly lower average value for effluent EC.

The range of chloride effluent load for all cells; whether averaged results were positive or negative in terms of chloride load removal; displayed fluctuations above and below the influent load across the sampling period. EC data tended to follow a similar pattern of fluctuations.

It is interesting to note that the units where positive chloride (average) load removal occurred tended to contain a compost medium (cell 6 containing subsoil was an exception and cell 8 contained a partial compost mix). It is possible that the compost provided surface area for the agglomeration and immobilisation of chloride and chloride compounds within colloidal flocs. It also possible, given the right conditions that the chloride precipitated out of the wastewater stream on to the media surface as a ferric salt (ferric chloride ($FeCl_3$).

Another mechanism for chloride removal is via plant uptake, specifically in this case uptake by the willow trees in cells 2 and 6. The level of chloride uptake by the trees has not been quantified, however; irrespective of the efficiency of chloride removal by the trees; the uptake of chloride resulted in osmotic shock and ultimate die back of each of the willows. The author believes the tree die back was the result of a doubling of the chloride concentration within the leachate for a brief period during June 2008 (Cl of 844mg/l recorded in raw leachate on 18th June 2008). The exact cause of the high chloride concentration within the leachate is not fully understood, but it may have been linked to ongoing restoration capping works at this time. During the course of ground preparation and grading works, the soil covering 3.6 hectares of an old waste cell was removed and over 7,000 tonnes of previously landfilled waste was deposited in the then active waste area. It is possible that the combination of exposing and denuding such a large area of previously deposited waste, and agitation and re-deposition of excavated waste; coupled with high pulse rainfall events all culminated in the release and re-entrainment of precipitated chloride in to the waste body for later collection via the leachate management network.

The chloride levels recorded during the period of operation for cell 2 (and the later sequence of cell 1 – cell 2) and cell 6 are detailed in Tables 8.42(a) and 8.46(a) and are displayed in Figures 8.42(a) – 8.42(d) and 8.46(a) – 8.46(b).

With the exception of cell 5 results for EC, it was difficult to discern whether a 50% reduction in the loading rate applied in the latter stages of operation for cells 5, 6, 7 and 8 had any impact in terms of increased treatment efficiency due to the erratic nature of the results.

8.2.5.3 Chloride and Electrical Conductivity Results for Treatment Units Operating in Sequence

Chloride and Electrical Conductivity concentrations and chloride removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.49(a) to 8.50(d).

Charts detailing the range of chloride concentrations and loadings as well as electrical conductance for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.49(a) to 8.50(d).

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.49(a) Summary of Chloride Concentrations for sequence Cell 1 – VF 2 – HF 2

Chloride Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Chloride	Influent	4	235 − 428	320 (± 85)
Chloride	Effluent Cell 1	4	224 - 431	300 (± 91)
Chloride	Effluent VF 2	4	156 − 357	269 (± 92)
Chloride	Effluent HF 2	4	145 − 323	254 (± 77)

Table 8.49(b) Summary of Chloride Load Removal per m^2 for Cell 1 – VF 2 – HF 2

Chloride	CELL 1	VF 2	HF 2
Influent Load g/m^2/day	303	29	25.8
Effluent Load g/m^2/day	284	26	24.3
Load Removal g/m^2/day	19	3	1.5
Cumulative Load Removal g/m^2/day	19	22	23.3

Table 8.49(c) Summary of Chloride Load Removal per unit for Cell 1 – VF 2 – HF 2

Chloride	CELL 1	VF 2	HF 2
Influent Load g/unit/day	769	721	646
Effluent Load g/unit/day	721	646	609
Load Removal g/unit/day	48	75	37
Cumulative Load Removal g/unit/day	48	123	160
Cumulative Load Removal as % per unit	6	16	21

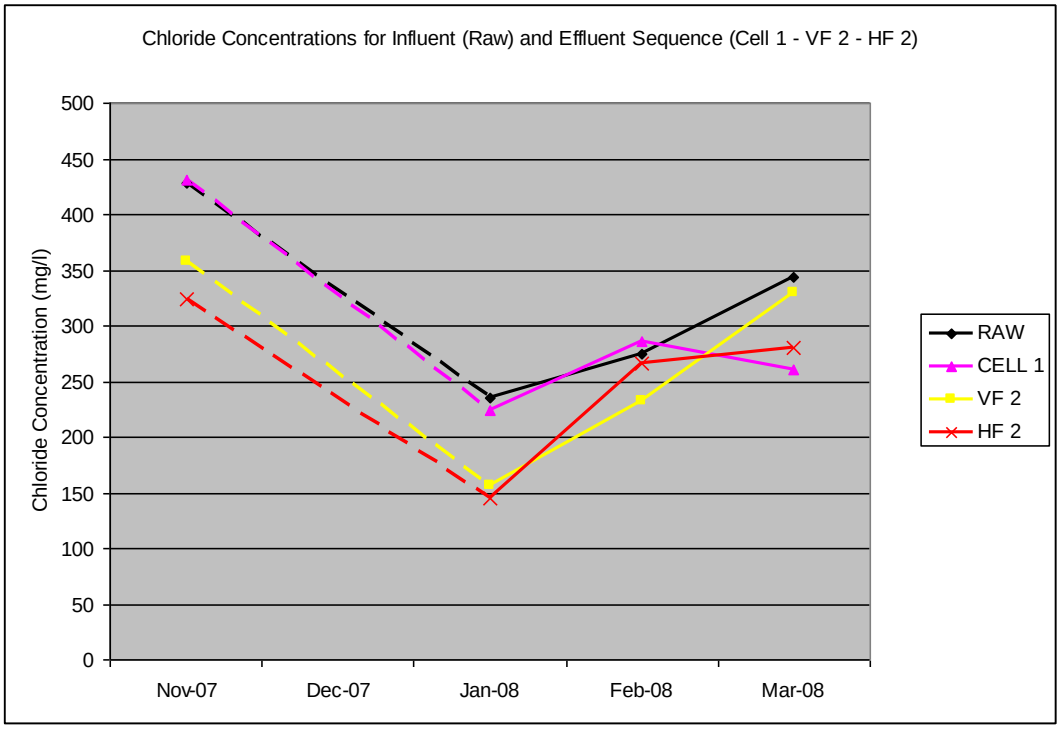


Figure 8.49(a) Chloride Concentrations in Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

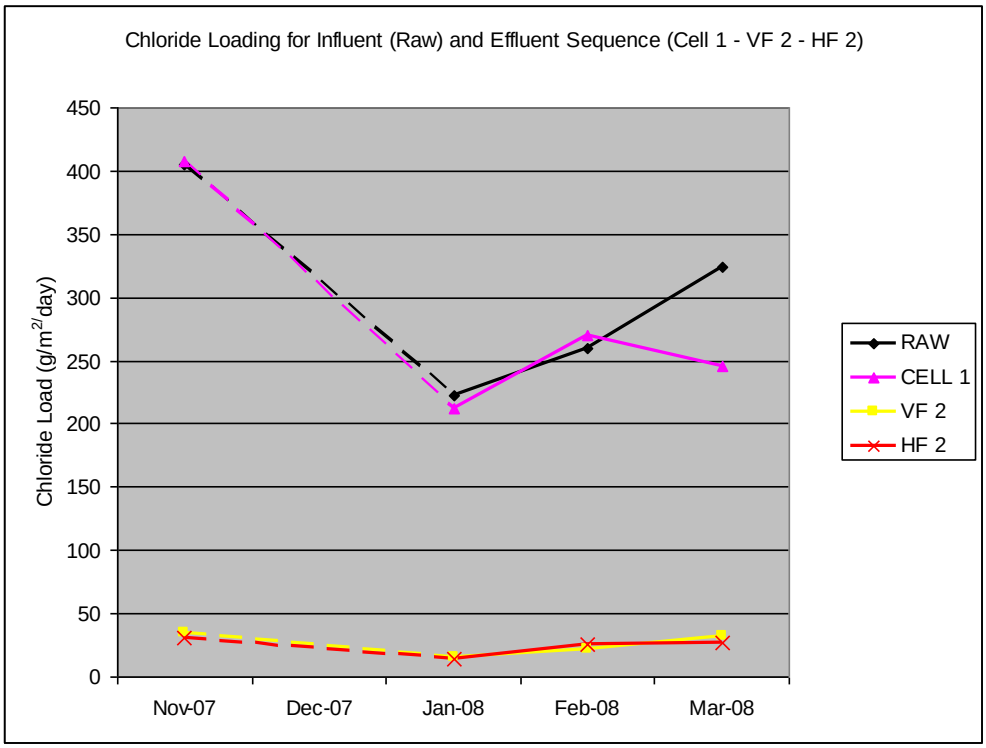


Figure 8.49(b) Chloride Loading for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

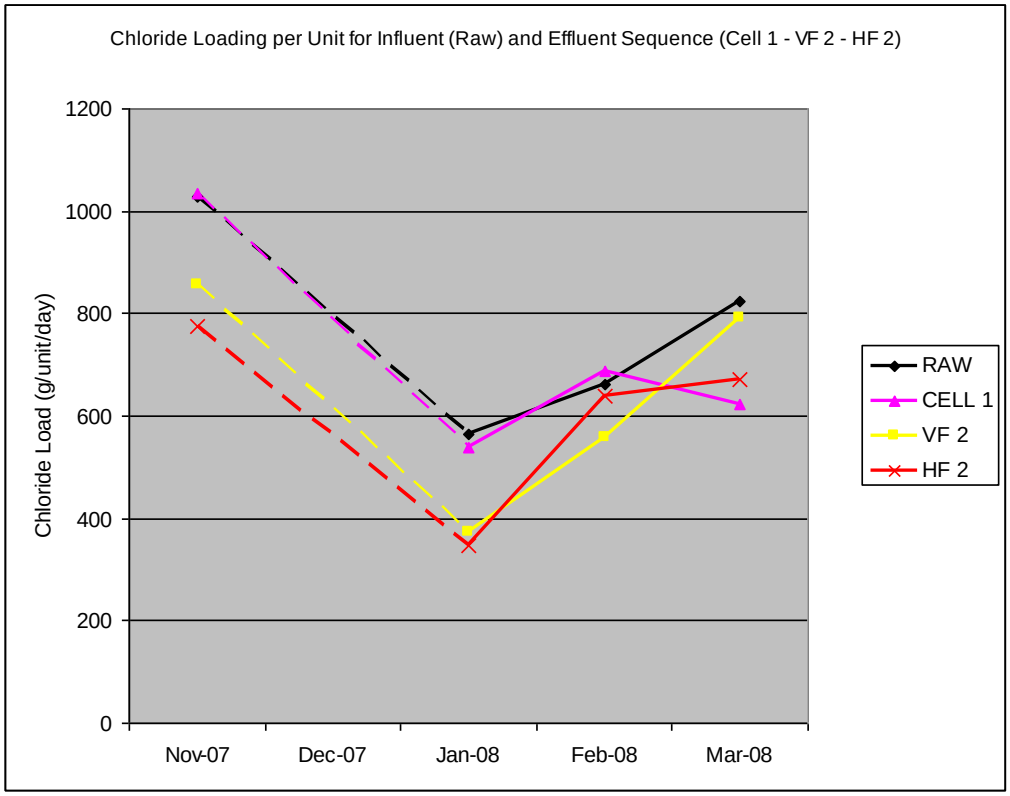


Figure 8.49(c) Chloride Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Table 8.49(d) Summary of EC Results for sequence Cell 1 – VF 2 – HF 2

Conductivity (Raw - Cell 1 - VF 2 - HF 2) Nov 07 - March 08				
Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	4	2.60 − 4.36	3.24 (± 0.77)
EC	Effluent Cell 1	4	2.59 - 4.29	3.11 (± 0.80)
EC	Effluent VF 2	4	1.60 − 2.95	2.35 (± 0.64)
EC	Effluent HF 2	4	1.52 − 2.63	2.15 (± 0.49)

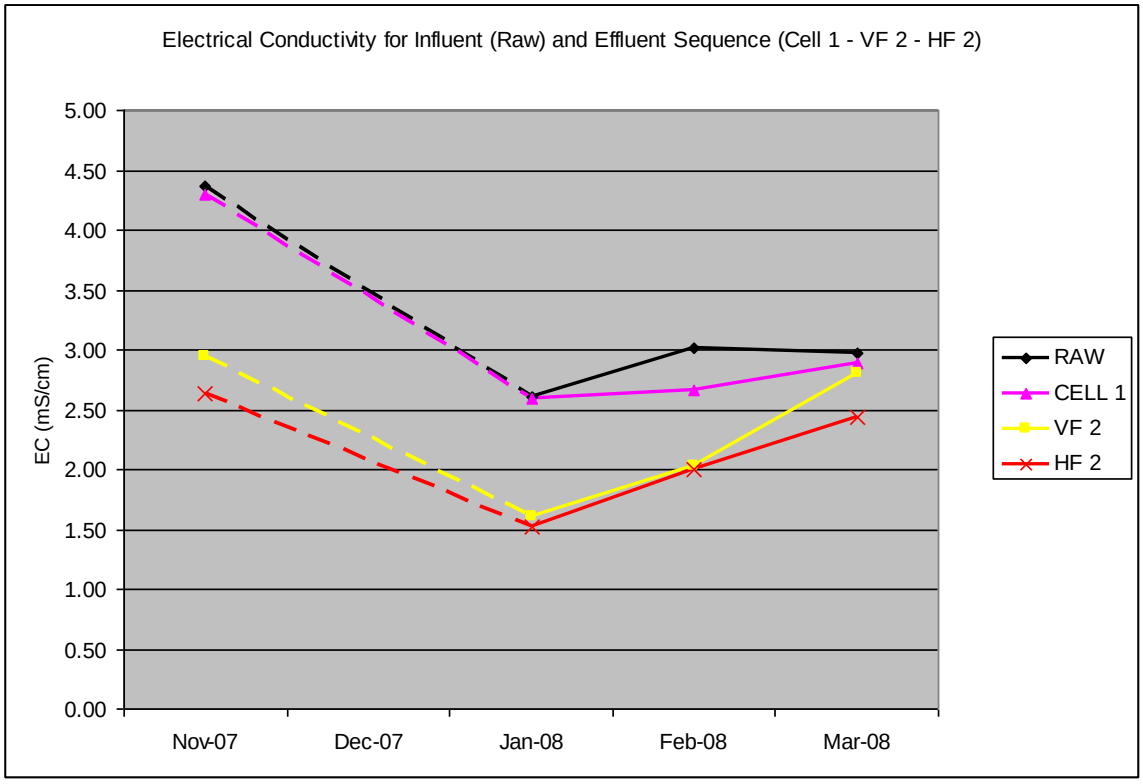


Figure 8.49(d) Electrical Conductivity for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.50(a) Summary of Chloride Concentrations for sequence Cell 10 – VF 1 – HF 1

Chloride Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Chloride	Influent	4	186 − 459	315 (± 115)
Chloride	Effluent Cell 10	4	152 − 340	279 (± 87)
Chloride	Effluent VF 1	4	146 − 387	281 (± 105)
Chloride	Effluent HF 1	4	126 − 366	299 (± 116)

Table 8.50(b) Summary of Chloride Load Removal per m^2 for Cell 10 – VF 1 – HF 1

Chloride	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/m^2/day	297.7	26.8	27.0
Effluent Load g/m^2/day	263.4	27.0	28.7
Load Removal g/m^2/day	34.3	-0.2	-1.7
Cumulative Load Removal g/m^2/day	34.3	34.1	32.3

Table 8.50(c) Summary of Chloride Load Removal per unit for Cell 10 – VF 1 – HF 1

Chloride	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/unit/day	756	669	675
Effluent Load g/unit/day	669	675	718
Load Removal g/unit/day	87	-6	-43
Cumulative Load Removal g/unit/day	87	81	38
Cumulative Load Removal as % per unit	12	11	5

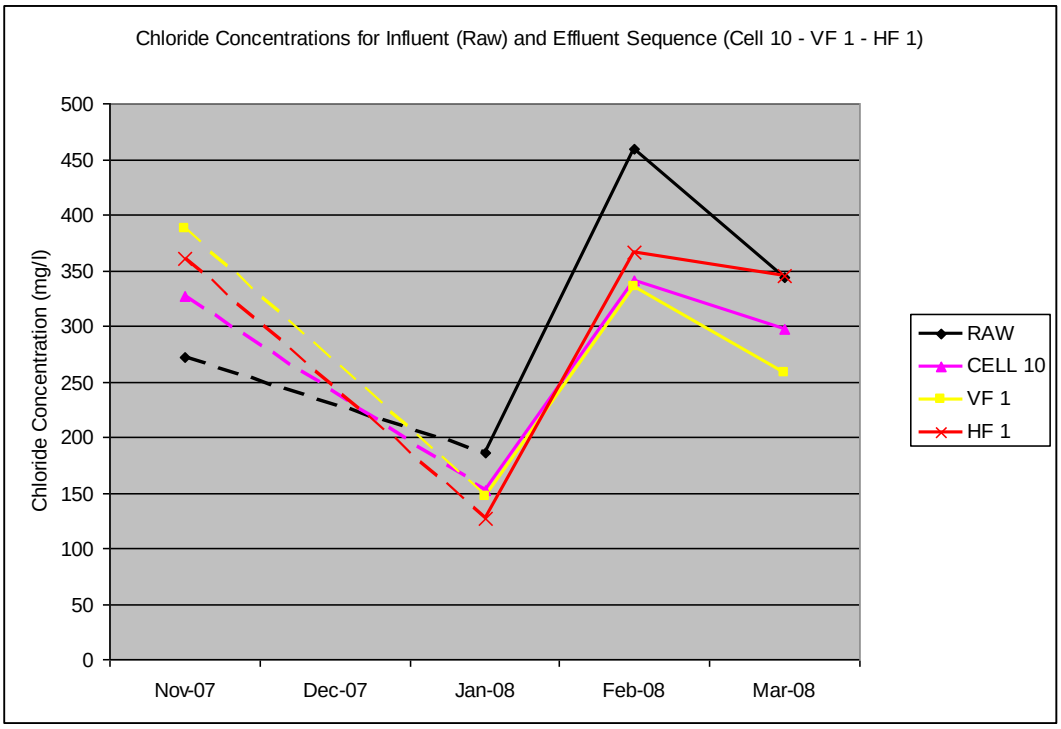


Figure 8.50(a) Chloride Concentrations in Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

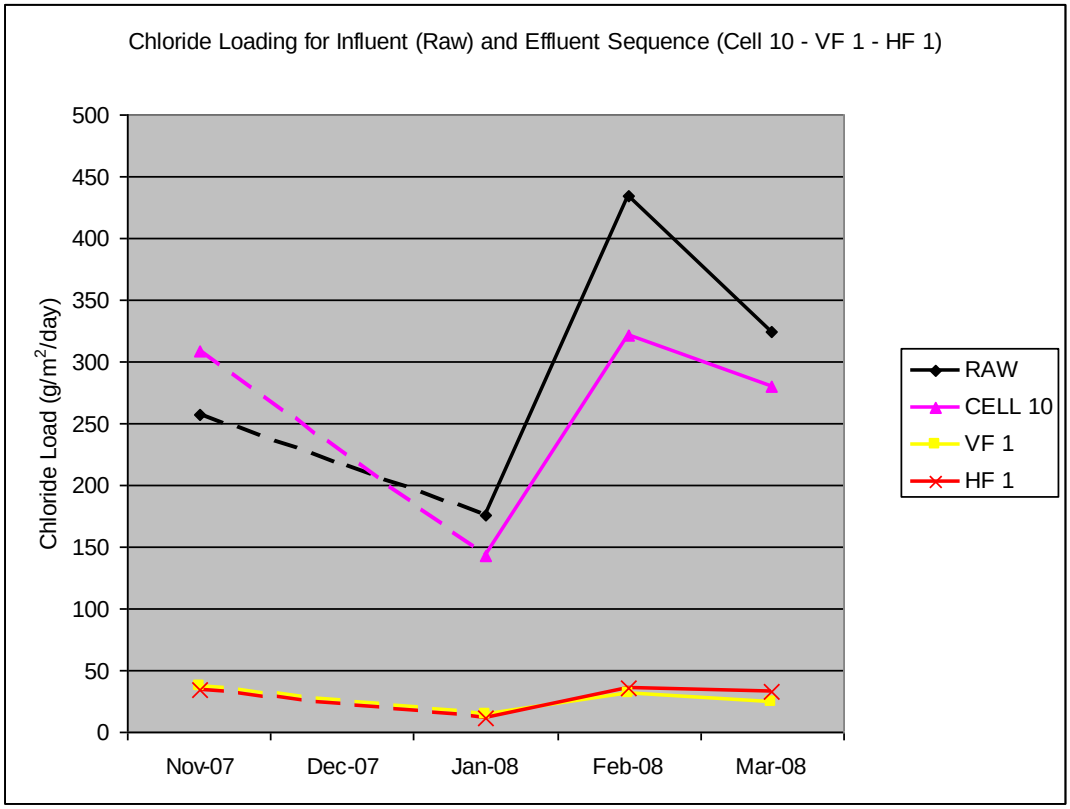


Figure 8.50(b) Chloride Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

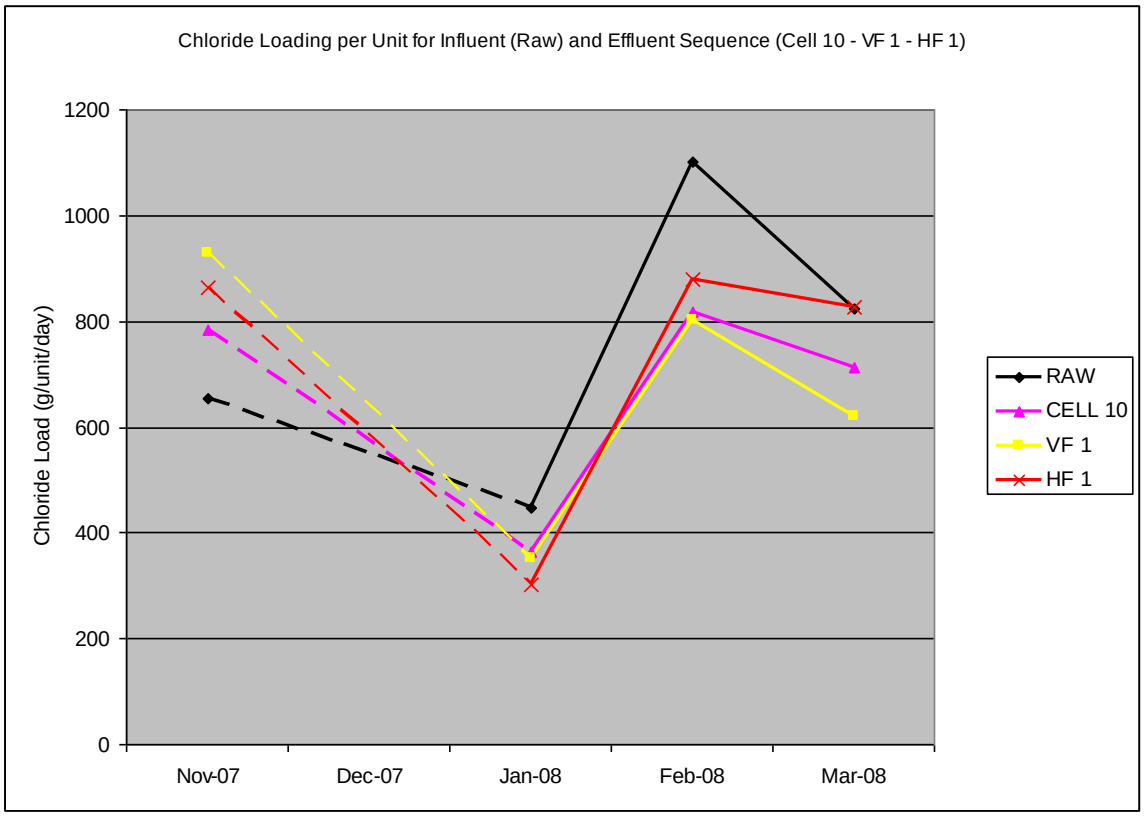


Figure 8.50(c) Chloride Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

Table 8.50(d) Summary of EC Results for sequence Cell 10 – VF 1 – HF 1

Conductivity (Raw - Cell 10 - VF 1 - HF 1) Nov 07 - March 08				
Parameter		n	Range (mS/cm)	Mean (± sd)
EC	Influent	4	2.46 − 4.15	3.18 (± 0.71)
EC	Effluent Cell 10	4	2.16 − 3.96	3.04 (± 0.76)
EC	Effluent VF 1	4	1.65 − 3.39	2.64 (± 0.83)
EC	Effluent HF 1	4	1.60 − 3.05	2.51 (± 0.64)

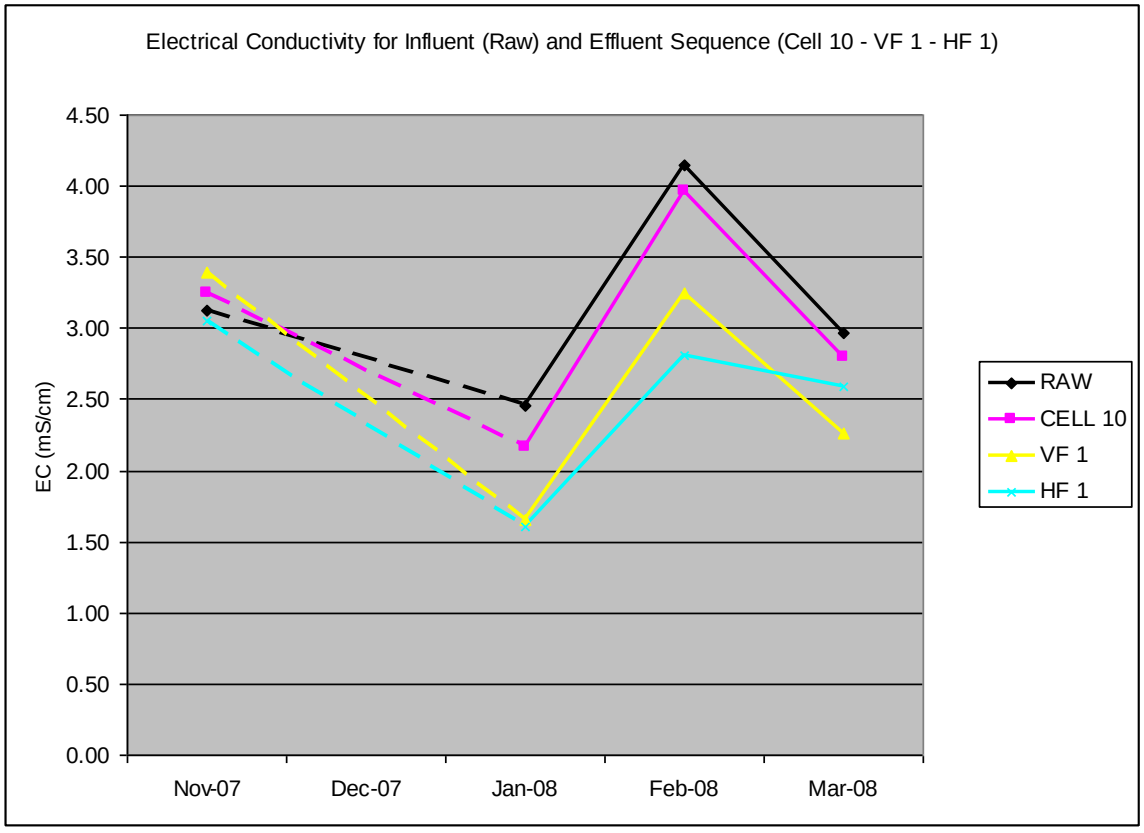


Figure 8.50(d) Electrical Conductivity for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.5.4 Interpretation of Chloride and Electrical Conductivity Results for Treatment Units Operating in Sequence

Analysis of results for chloride and electrical conductivity for treatment units operating in sequence; Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1; reveals a positive load removal for chloride and lower effluent conductivity for both sequences; with average cumulative load removal in the final effluent for chloride of 160g/unit/day (21% removal) and 38g/unit/day (5% removal) respectively (Figures 8.49(c) and 8.50(c)) and EC down from 3.24mS/cm to 2.15mS/cm (Cell 1 – VF 2 – HF 2) and 3.18mS/cm to 2.51mS/cm (Cell 10 – VF 1 – HF 1).

Each of the primary treatment units (cells 1 and 10) display positive load removal for chloride; 48g/unit/day and 87g/unit/day respectively; whereas averaged results for secondary effluent load removal in VF 1 and VF 2 reveal -6g/unit/day and 75g/unit/day respectively. The average load removal result for VF 1 is skewed slightly by a negative load removal of -145g/unit/day in November 2007.

Tertiary treatment in the HF reed beds was mixed with both positive and negative load removal recorded for Cl.

There was a small but steady decline in electrical conductivity from influent to effluent for each of the sequences (Figures 8.49(d) and 8.50(d)).

Mechanisms for chloride removal most likely mirror those mentioned above with reeds instead of trees for chloride biomass uptake.

8.2.6 Iron and Manganese Removal

The removal of iron and manganese from the system is detailed in this section. A series of tables outlining iron and manganese removal in individual treatment units is presented below in sections 8.2.6.1 and 8.2.6.2 respectively with interpretation in 8.2.6.3.

Similar tables for iron and manganese removal within treatment units operating in sequence are presented in sections 8.2.6.4 and 8.2.6.5 followed by interpretation.

8.2.6.1 Iron Removal in Individual Treatment Units

Iron concentrations and removal efficiencies for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.51(a) to 8.58(b).

Charts detailing the range of iron concentrations and loadings for cells 1 to 8 are presented in Figures 8.51(a) to 8.58(b).

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.51(a) Summary of Iron Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Iron	Influent	7	4.96 - 10.60	7.98 (± 2.33)	7.78
Iron	Effluent	3	1.12 - 5.23	3.78 (± 2.31)	3.57

Table 8.51(b) Summary of Iron Load Removal for Cell 1

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Iron	4.21	54

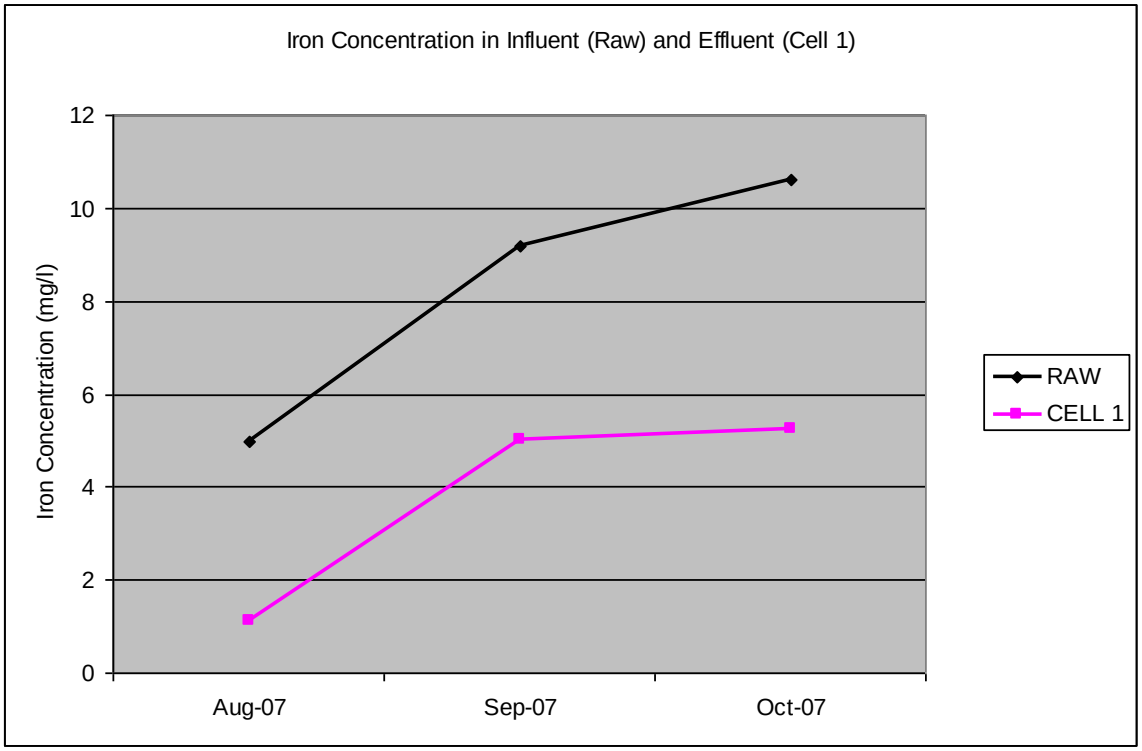


Figure 8.51(a) Iron Concentration in Influent (Raw) and Effluent (Cell 1)

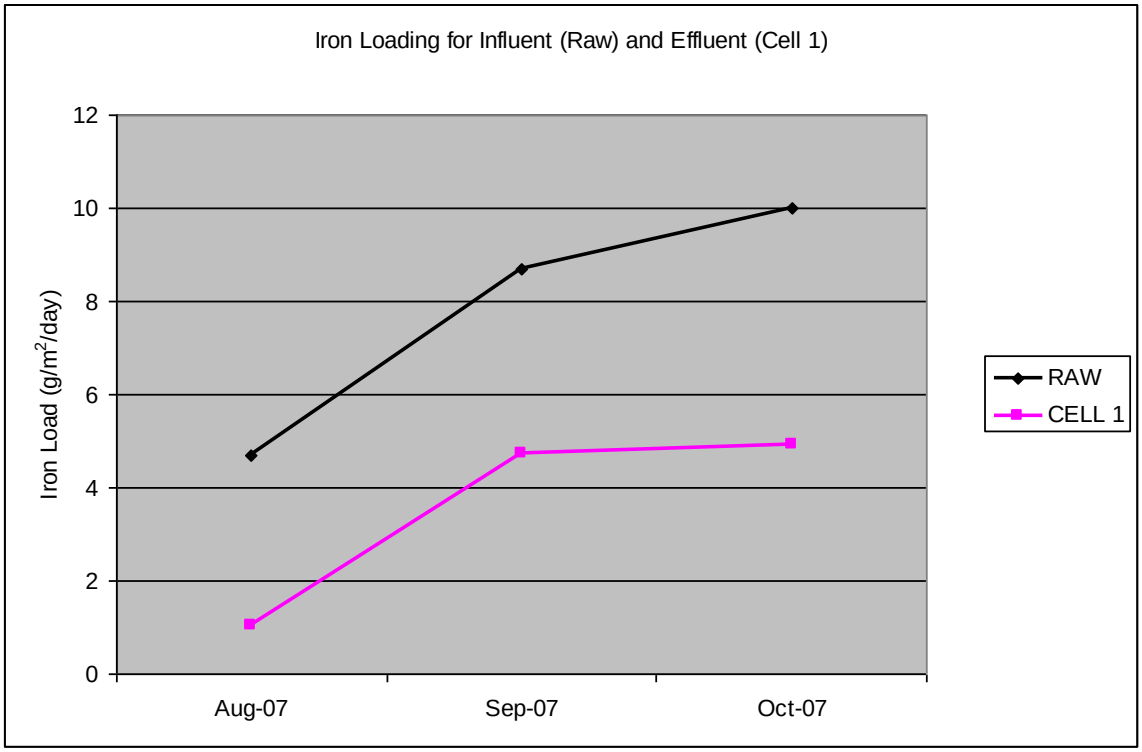


Figure 8.51(b) Iron Loading for Influent (Raw) and Effluent (Cell 1)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.52(a) Summary of Iron Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Iron	Influent	16	1.81 - 10.6	5.71 (± 2.92)	6.73
Iron	Effluent	6	0.30 - 3.11	1.54 (± 1.19)	1.45

Table 8.52(b) Summary of Iron Load Removal for Cell 2

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Iron	5.28	78

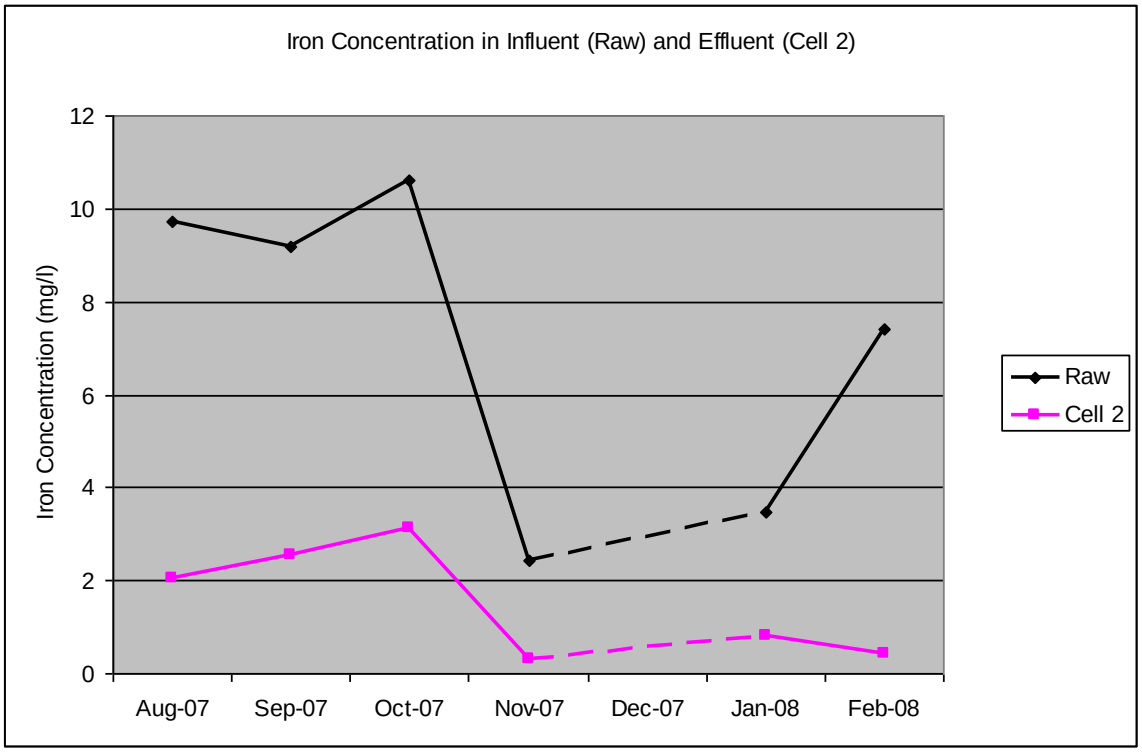


Figure 8.52(a) Iron Concentration in Influent (Raw) and Effluent (Cell 2)

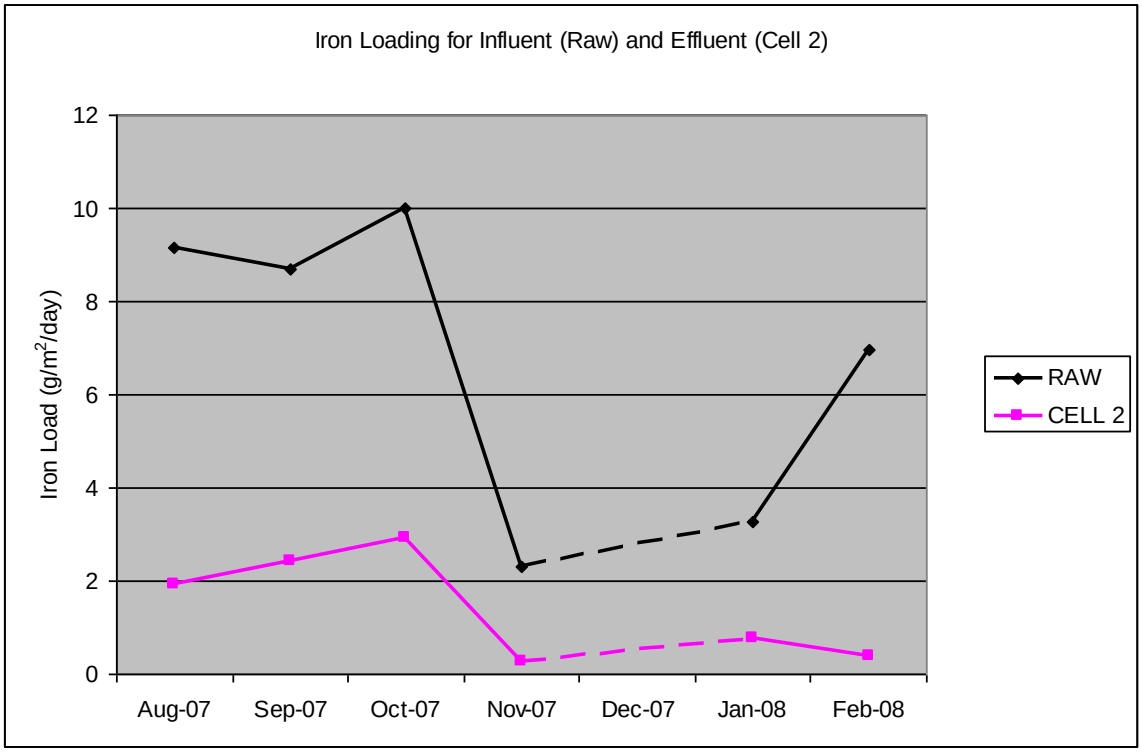


Figure 8.52(b) Iron Loading for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.53(a) Summary of Iron Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Iron	Influent	10	1.81 - 10.60	6.25 (± 3.38)	6.41
Iron	Effluent	4	0.40 - 9.30	3.34 (± 4.20)	3.15

Table 8.53(b) Summary of Iron Load Removal for Cell 3

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Iron	3.26	51

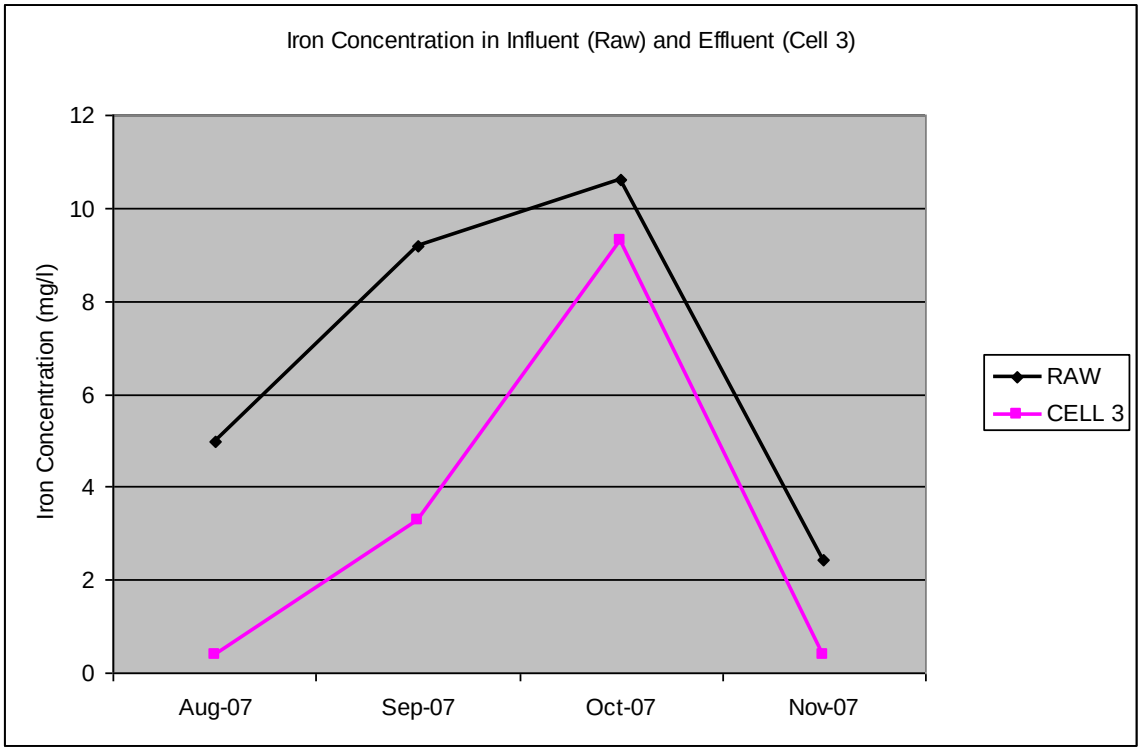


Figure 8.53(a) Iron Concentration in Influent (Raw) and Effluent (Cell 3)

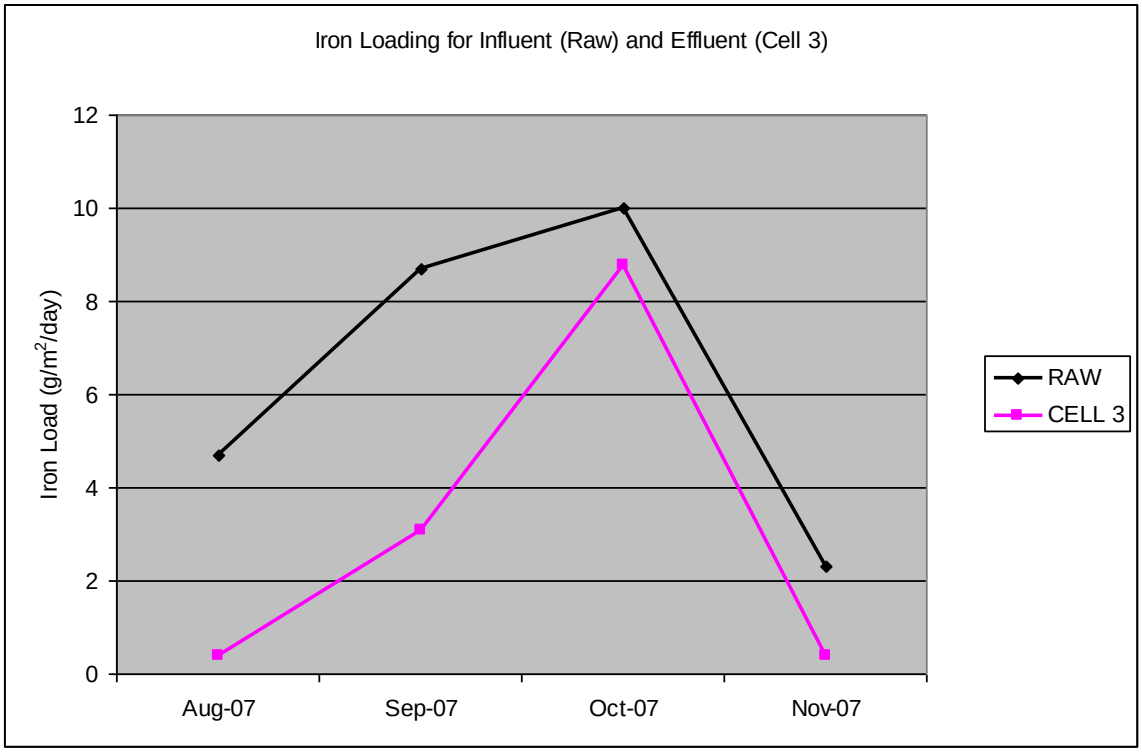


Figure 8.53(b) Iron Loading for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.54(a) Summary of Iron Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Iron	Influent	19	1.81 - 16.70	7.13 (± 4.34)	7.67
Iron	Effluent	6	0.43 - 3.76	1.96 (± 1.14)	1.85

Table 8.54(b) Summary of Iron Load Removal for Cell 4

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Iron	5.82	76

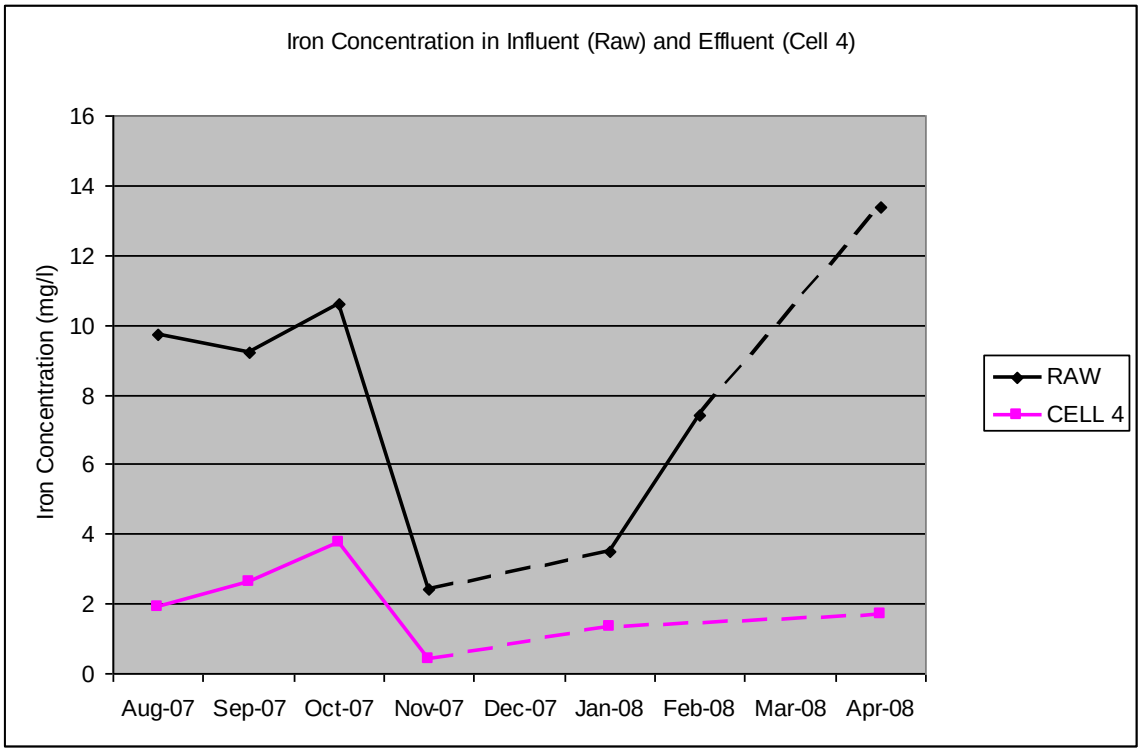


Figure 8.54(a) Iron Concentration in Influent (Raw) and Effluent (Cell 4)

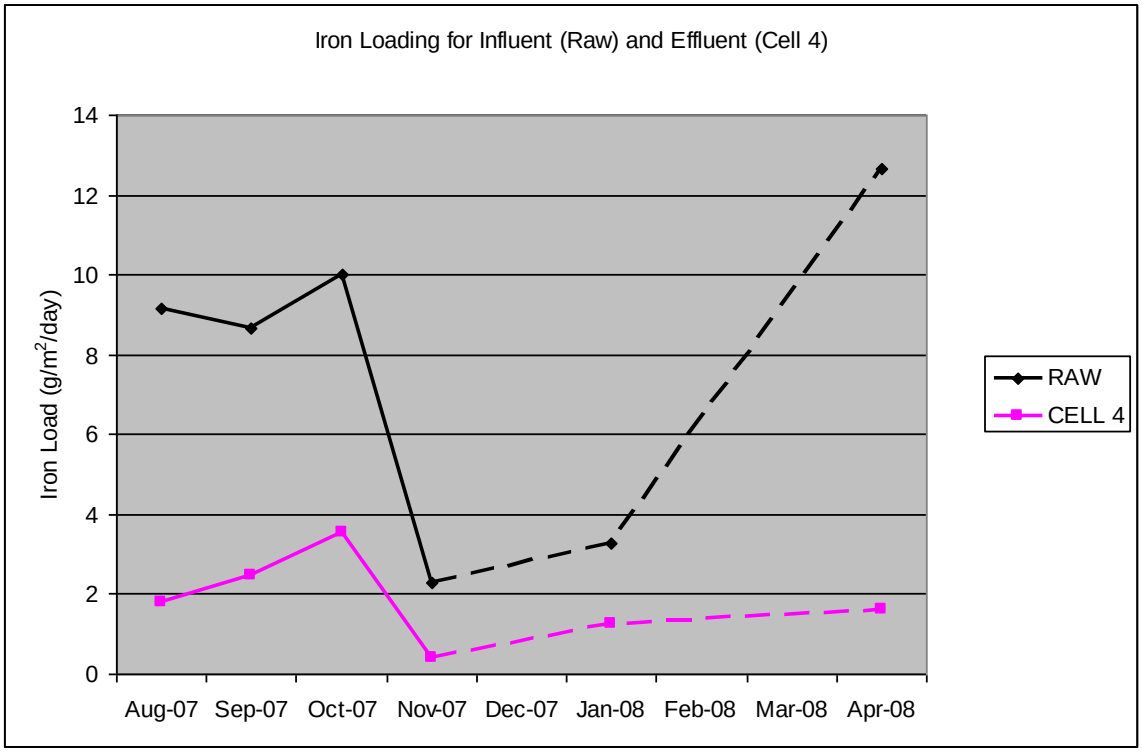


Figure 8.54(b) Iron Loading for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.55(a) Summary of Iron Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Iron	Influent	24	1.81 - 16.85	7.83 (± 4.61)	1.24
Iron	Effluent	8	0.29 - 6.10	1.55 (± 1.87)	0.26

Table 8.55(b) Summary of Iron Load Removal for Cell 5

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Iron	0.98	79

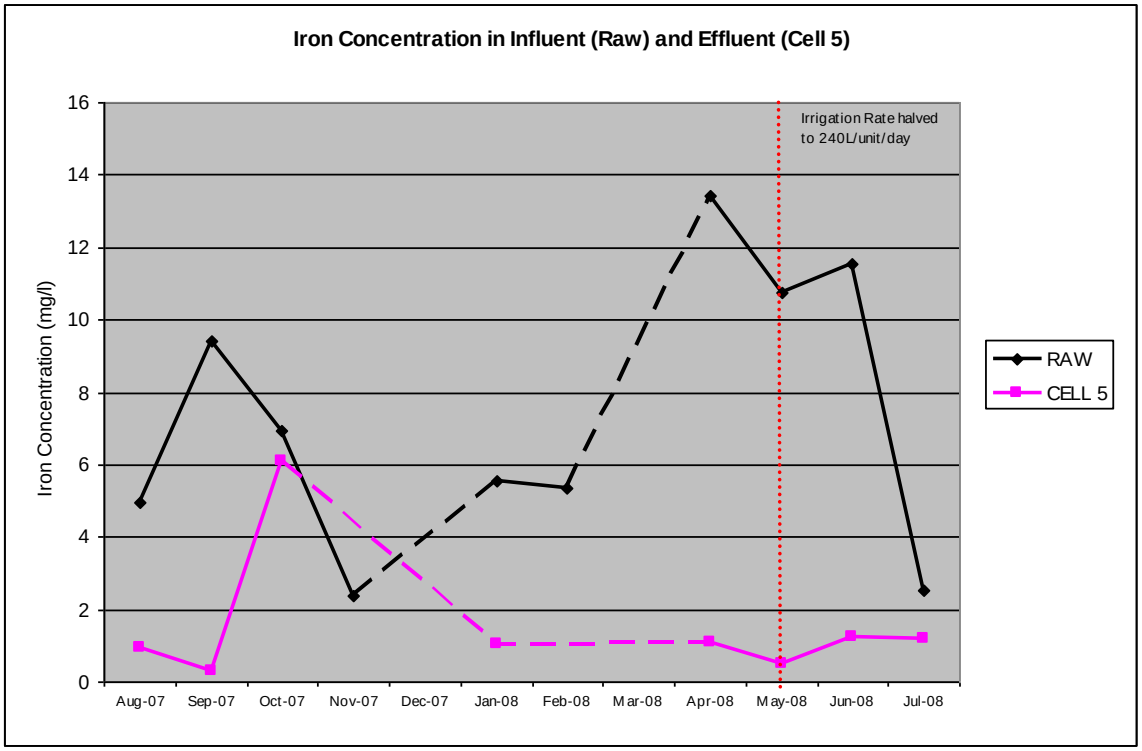


Figure 8.55(a) Iron Concentration in Influent (Raw) and Effluent (Cell 5)

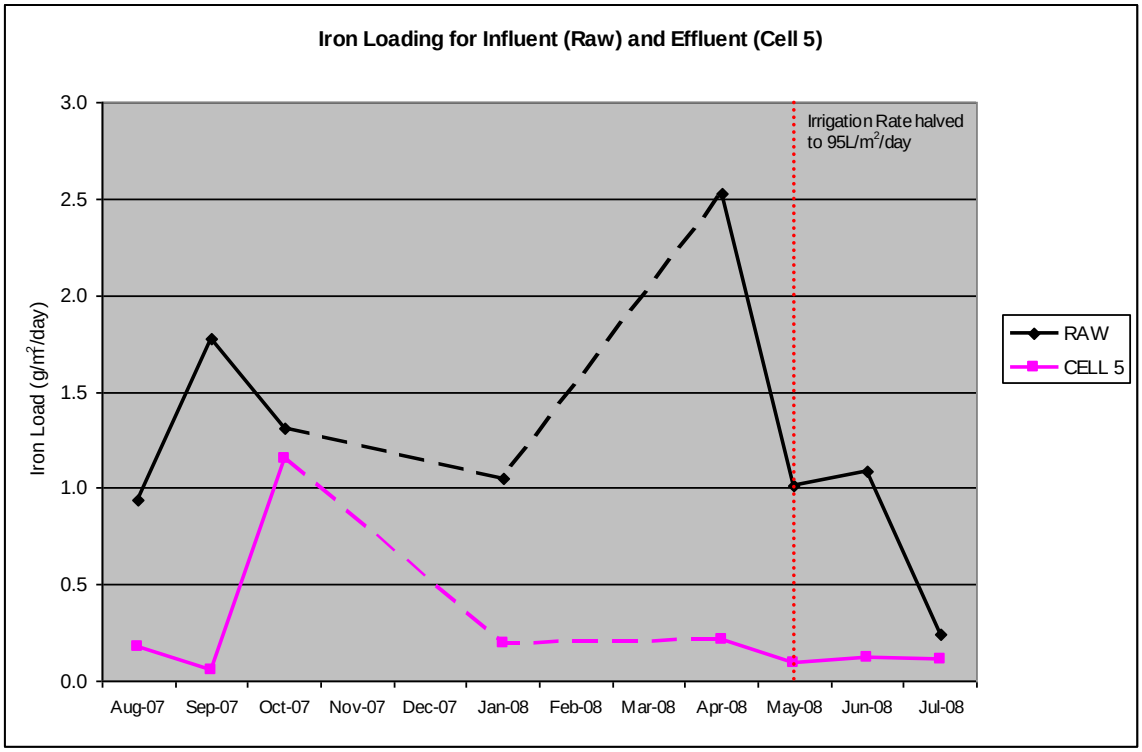


Figure 8.55(b) Iron Loading for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.56(a) Summary of Iron Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Iron	Influent	23	1.81 - 16.85	8.06 (± 4.57)	3.65
Iron	Effluent	8	0.24 - 13.40	5.50 (± 4.62)	2.48

Table 8.56(b) Summary of Iron Load Removal for Cell 6

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Iron	1.17	32

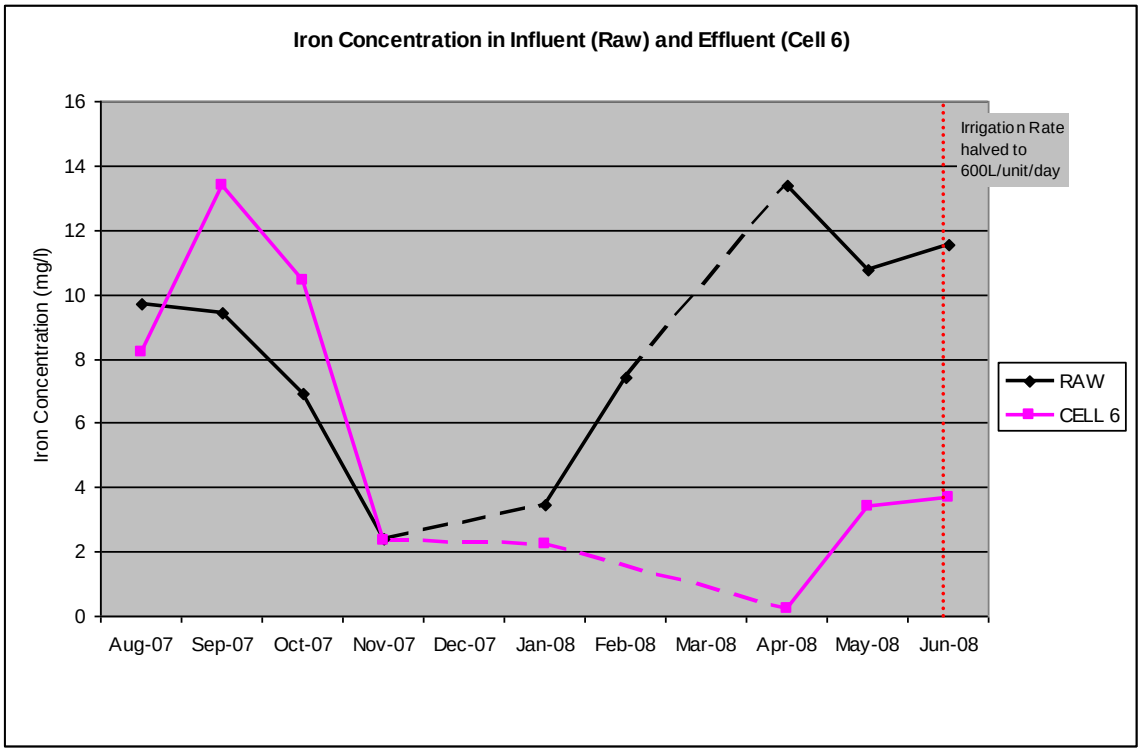


Figure 8.56(a) Iron Concentration in Influent (Raw) and Effluent (Cell 6)

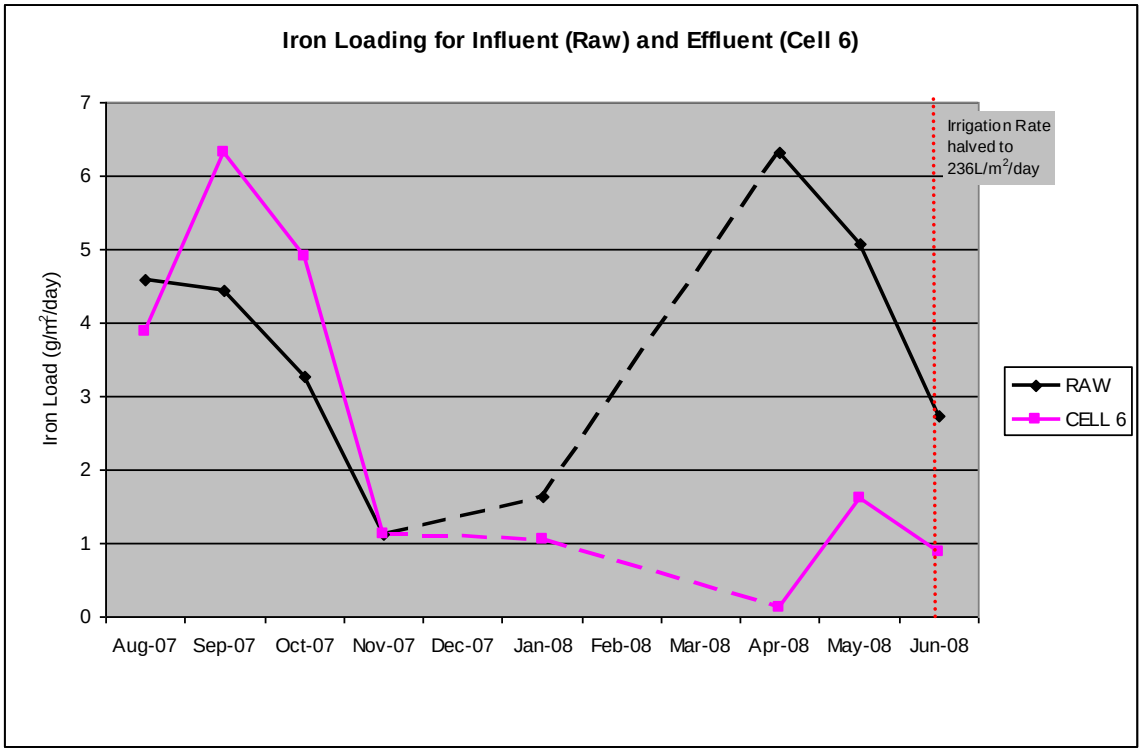


Figure 8.56(b) Iron Loading for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.57(a) Summary of Iron Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Iron	Influent	25	1.81 - 16.85	7.84 (± 4.52)	5.39
Iron	Effluent	11	1.04 - 17.45	5.33 (± 4.72)	3.65

Table 8.57(b) Summary of Iron Load Removal for Cell 7

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Iron	1.74	32

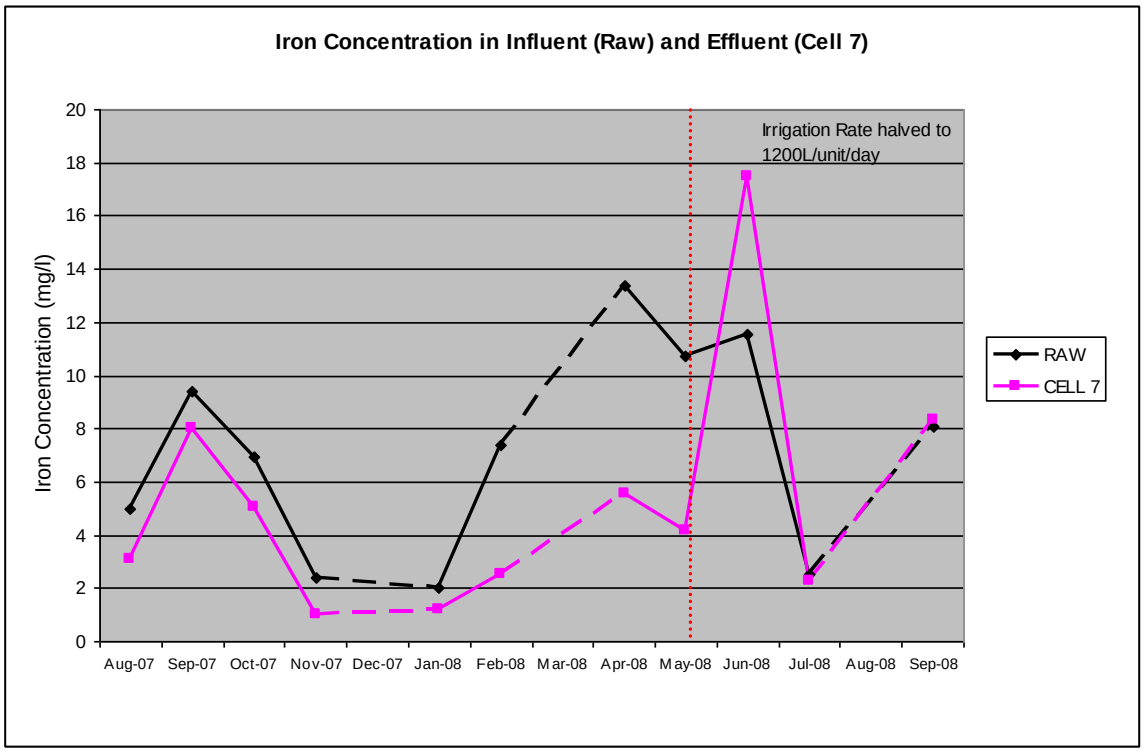


Figure 8.57(a) Iron Concentration in Influent (Raw) and Effluent (Cell 7)

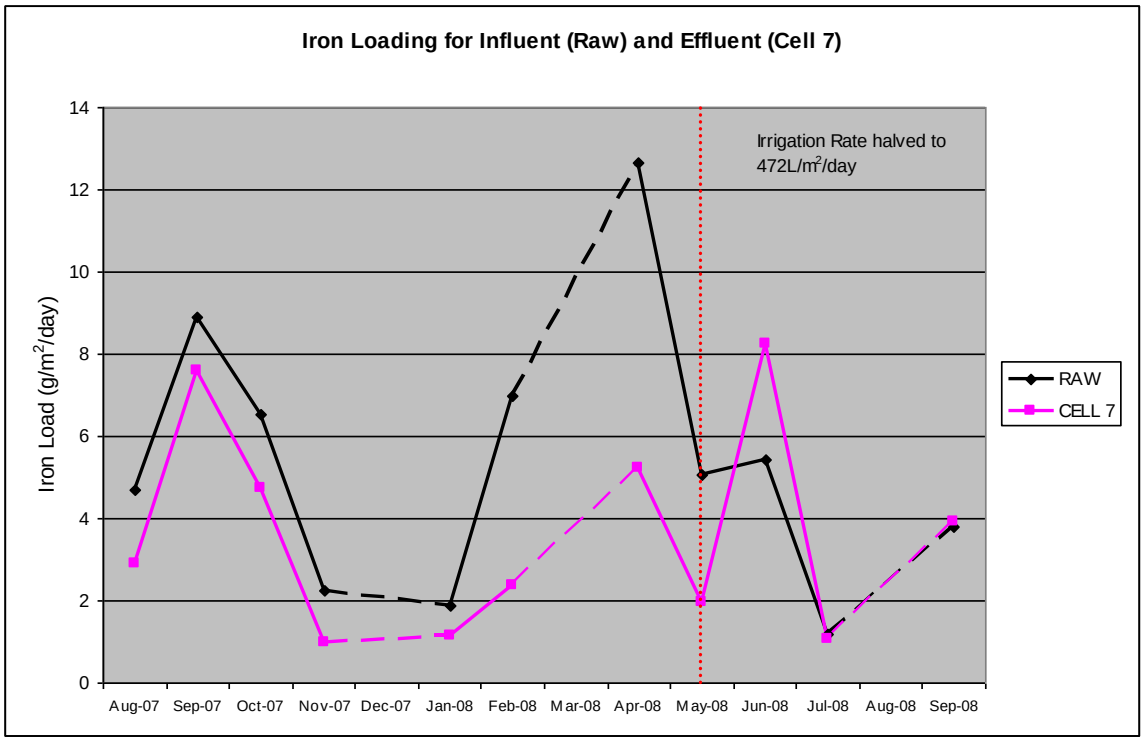


Figure 8.56(b) Iron Loading for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.58(a) Summary of Iron Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Iron	Influent	25	1.81 - 16.85	7.84 (± 4.52)	3.62
Iron	Effluent	8	2.06 - 10.85	5.23 (± 3.98)	2.02

Table 8.58(b) Summary of Iron Load Removal for Cell 8

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Iron	1.60	44

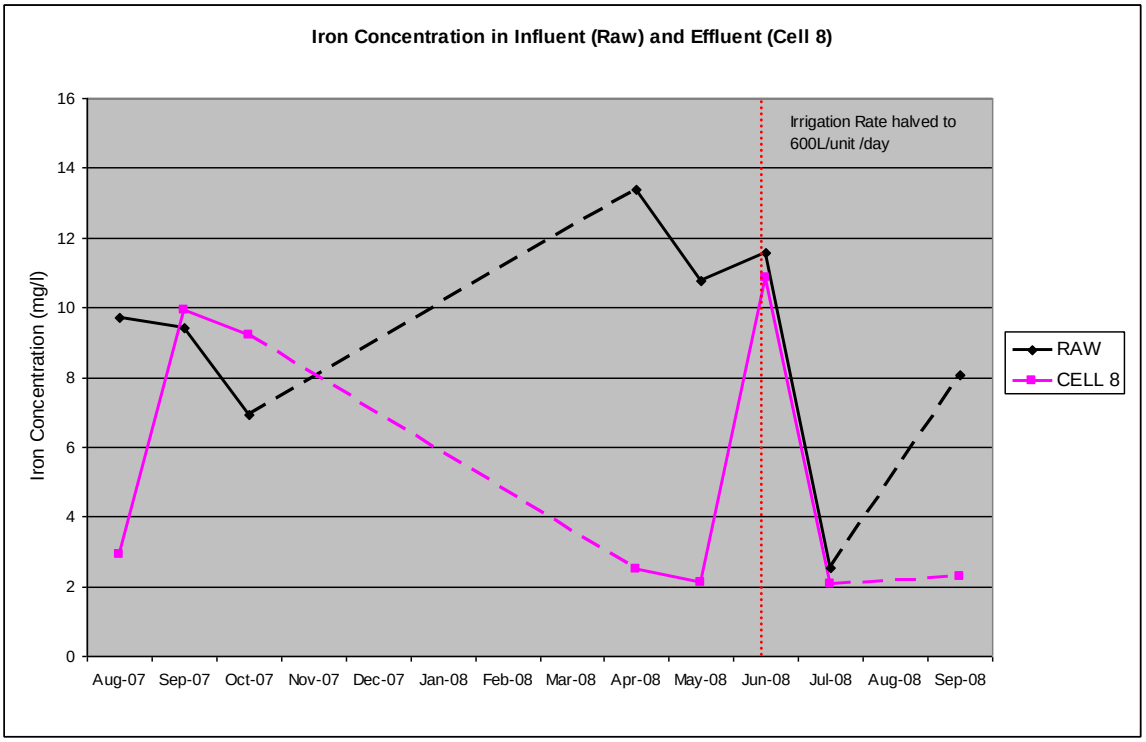


Figure 8.58(a) Iron Concentration in Influent (Raw) and Effluent (Cell 8)

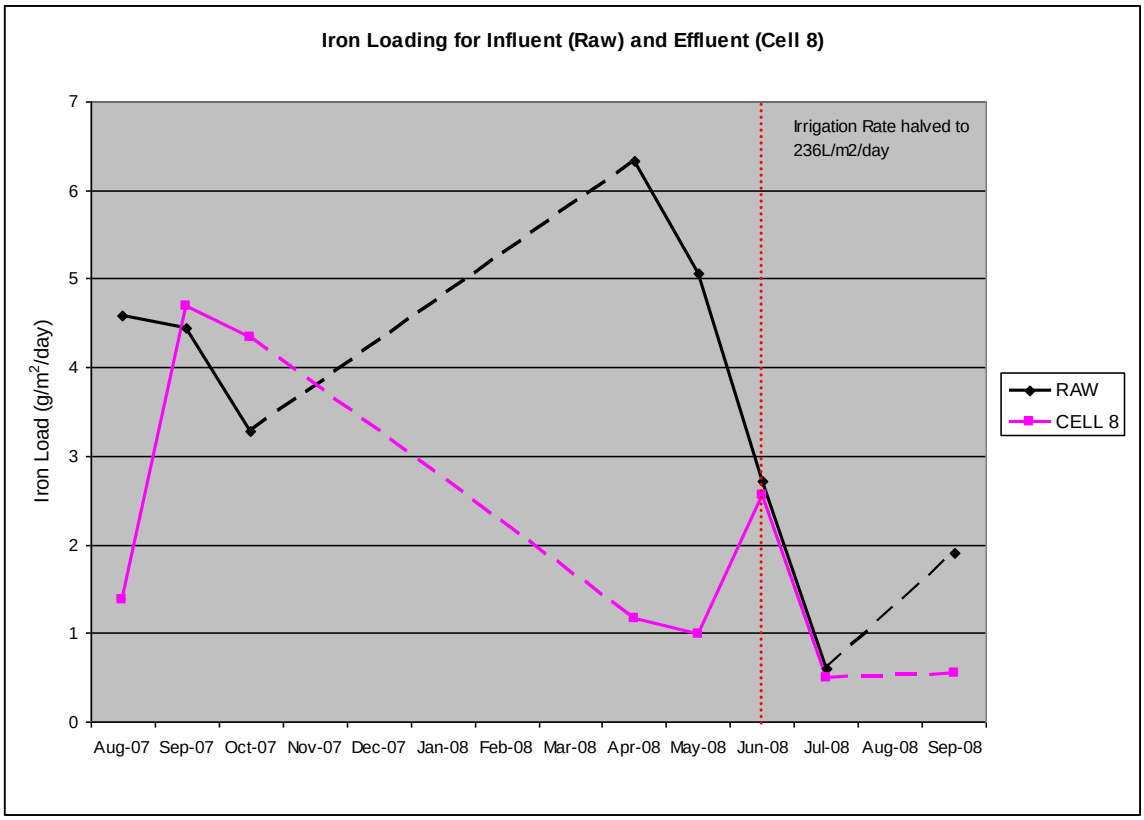


Figure 8.58(b) Iron Loading for Influent (Raw) and Effluent (Cell 8)

8.2.6.2 Manganese Removal in Individual Treatment Units

Manganese (Mn) concentrations and removal efficiencies for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.59(a) to 8.66(b).

Charts detailing the range of manganese concentrations and loadings for cells 1 to 8 are presented in Figures 8.59(a) to 8.66(b).

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.59(a) Summary of Mn Concentrations and Loadings for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Mn	Influent	7	0.93 - 3.50	2.77 (± 0.92)	3.04
Mn	Effluent	3	2.63 - 3.21	2.92 (± 0.41)	2.75

Table 8.59(b) Summary of Mn Load Removal for Cell 1

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Mn	0.29	10

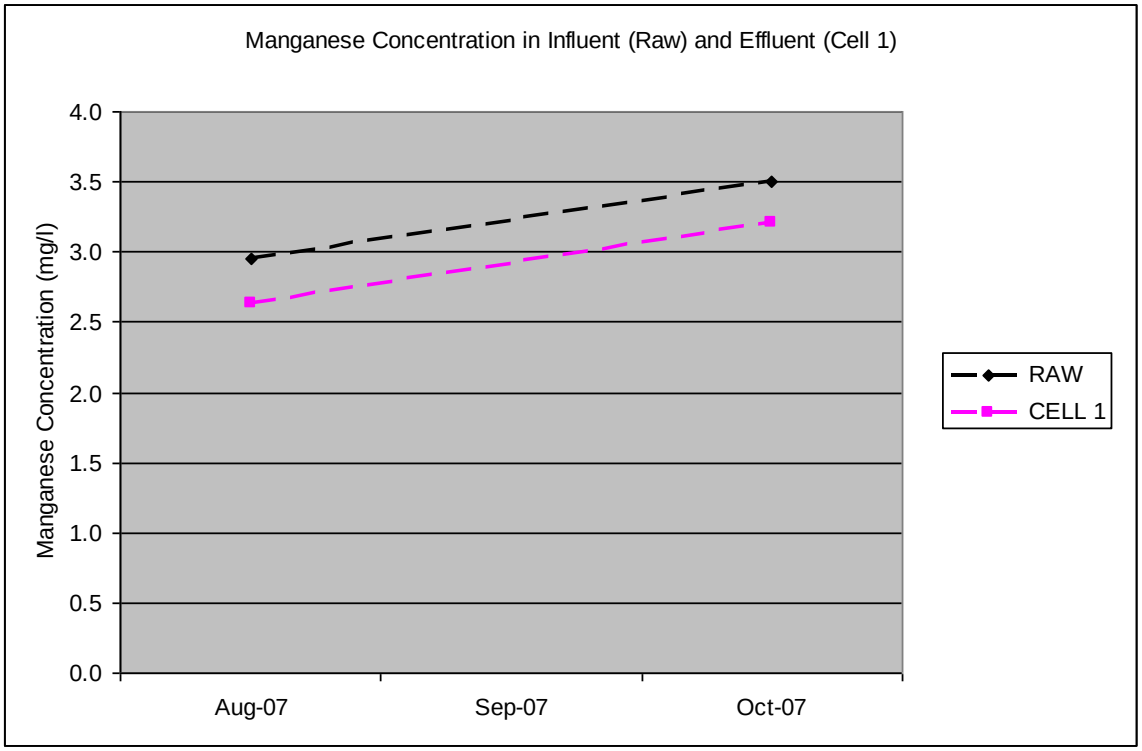


Figure 8.59(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 1)

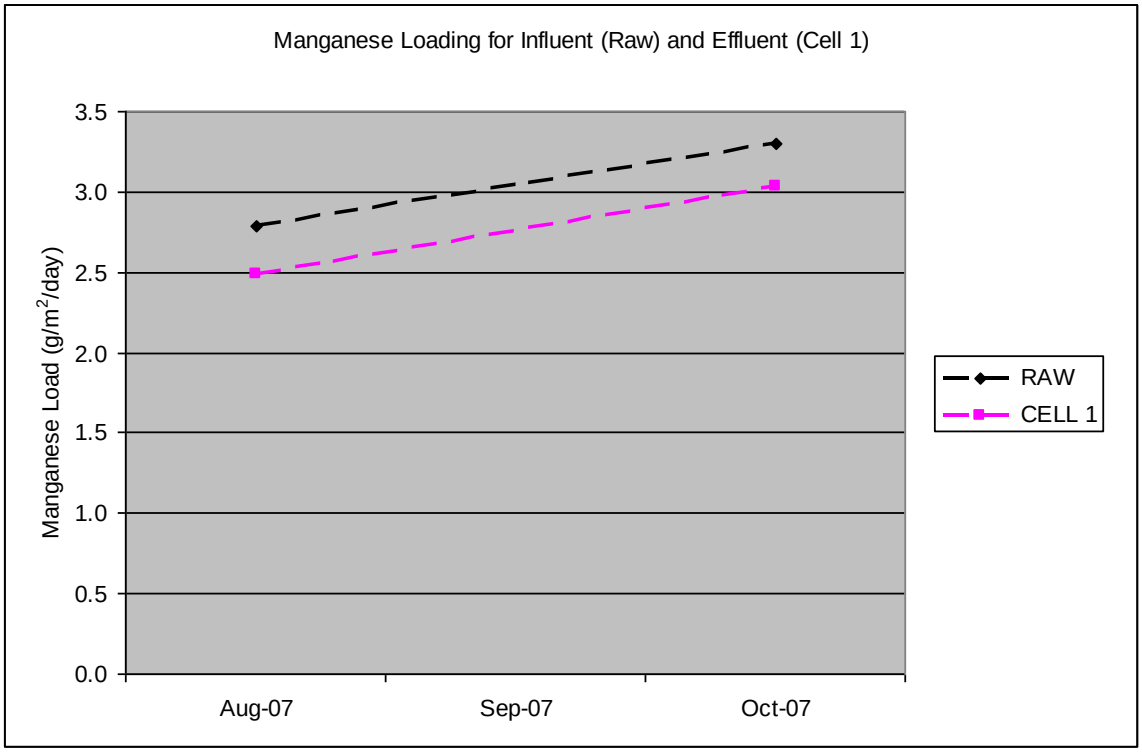


Figure 8.59(b) Manganese Loading for Influent (Raw) and Effluent (Cell 1)

Cell 2 - Medium: Willow Trees in Subsoil

Operational Period: August 2007 – March 2008

Table 8.60(a) Summary of Mn Concentrations and Loadings for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Mn	Influent	16	0.93 - 3.50	2.58 (± 0.65)	2.85
Mn	Effluent	5	2.21 - 3.46	2.85 (± 0.47)	2.68

Table 8.60(b) Summary of Mn Load Removal for Cell 2

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Mn	0.17	6

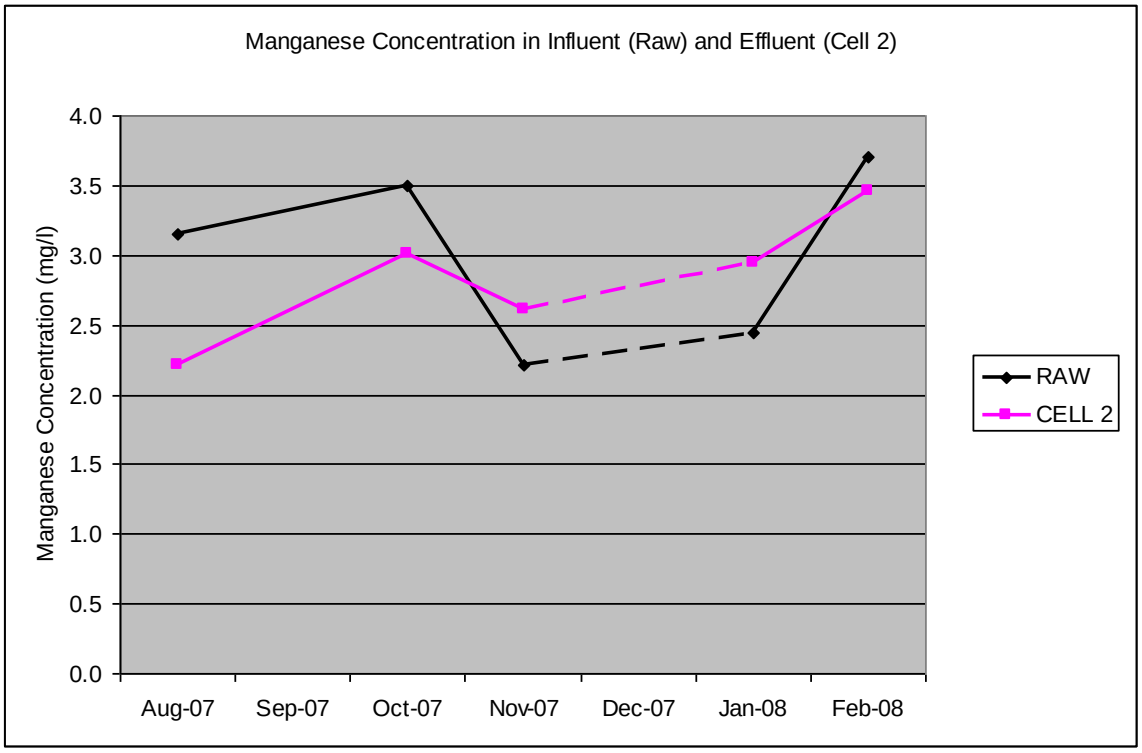


Figure 8.60(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 2)

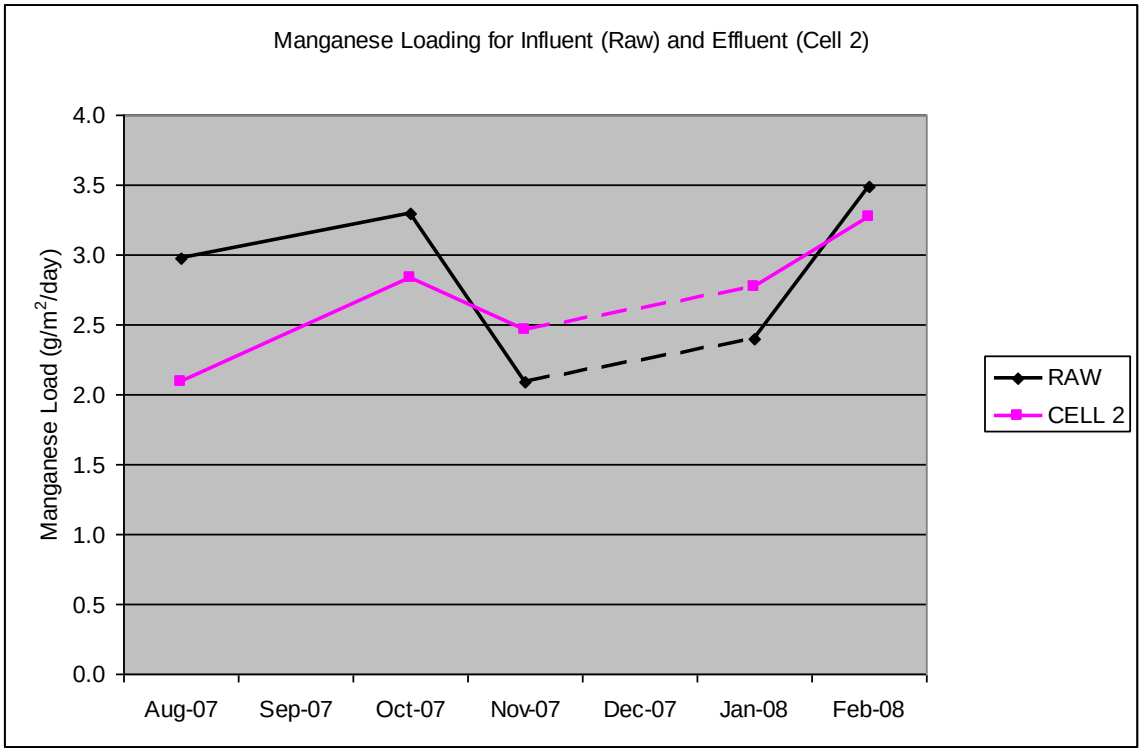


Figure 8.60(b) Manganese Loading for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.61(a) Summary of Mn Concentrations and Loadings for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Mn	Influent	10	0.93 - 3.50	2.58 (± 0.78)	2.72
Mn	Effluent	3	3.03 - 4.10	3.45 (± 0.57)	3.25

Table 8.61(b) Summary of Mn Load Removal for Cell 3

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Mn	-0.53	-19

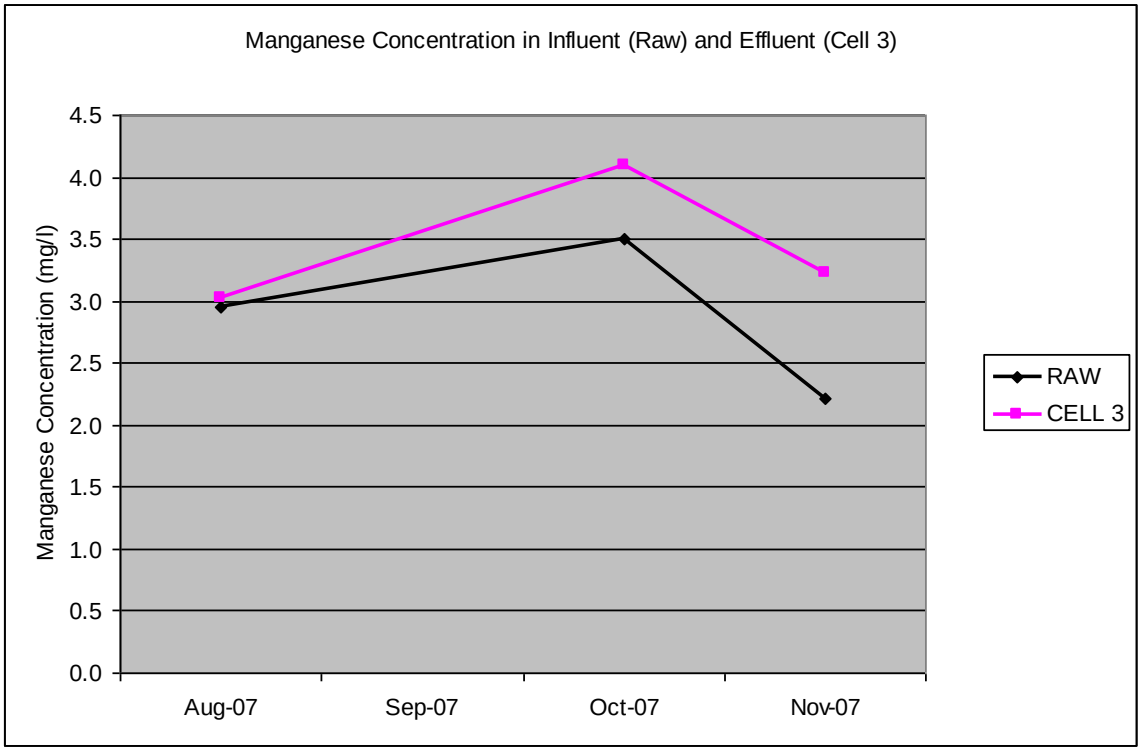


Figure 8.61(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 3)

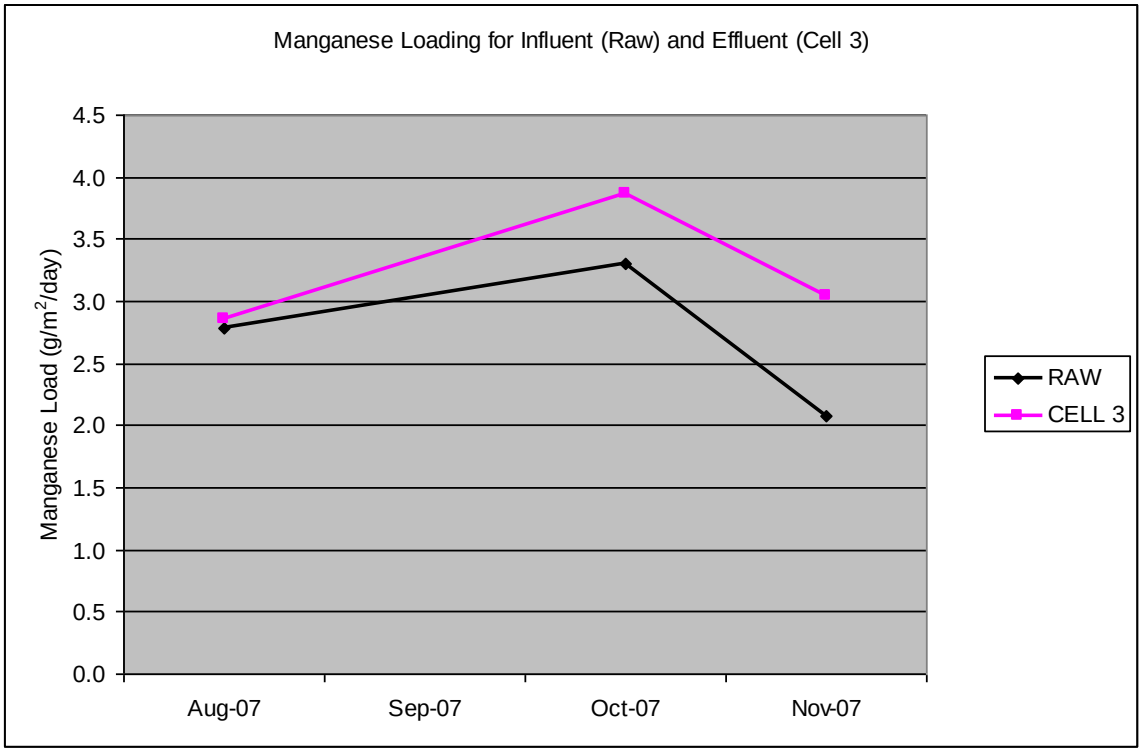


Figure 8.61(b) Manganese Loading for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.62(a) Summary of Mn Concentrations and Loadings for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load ($g/m^2/day$)
Mn	Influent	18	0.93 - 3.93	2.76 (± 0.73)	2.80
Mn	Effluent	6	2.02 - 4.00	2.81 (± 0.71)	2.65

Table 8.62(b) Summary of Mn Load Removal for Cell 4

Parameter	Average Load Removal ($g/m^2/day$)	Average % Load Removal
Mn	0.15	5

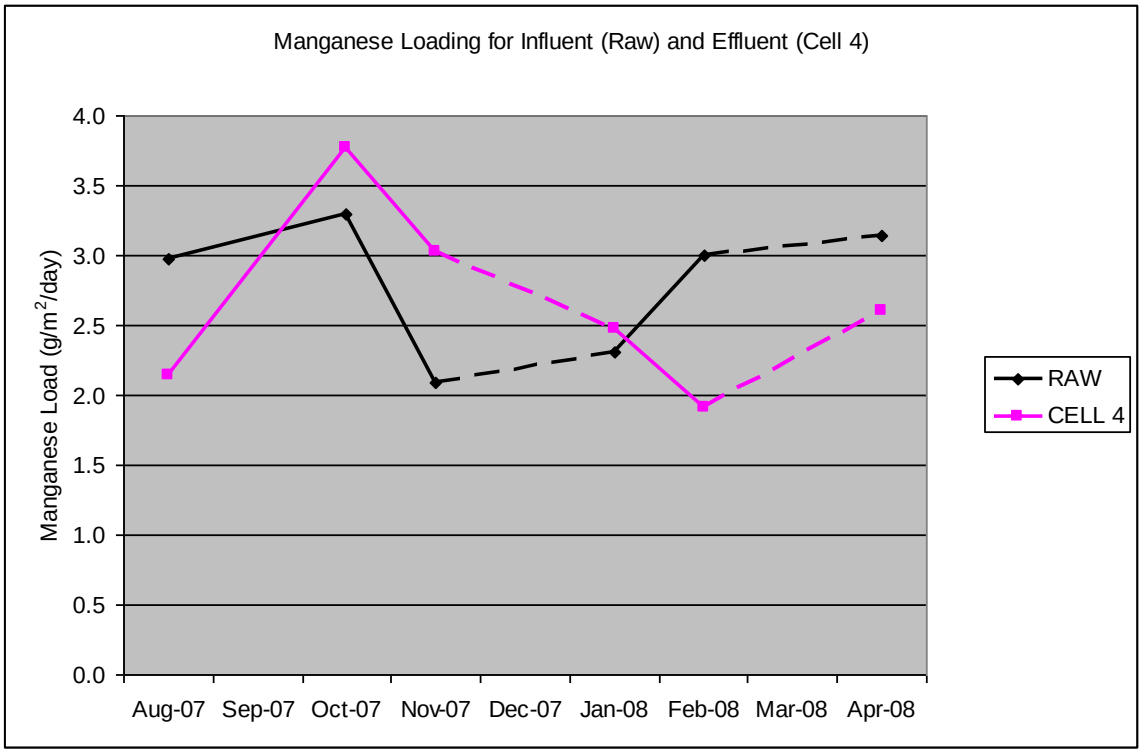


Figure 8.62(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 4)

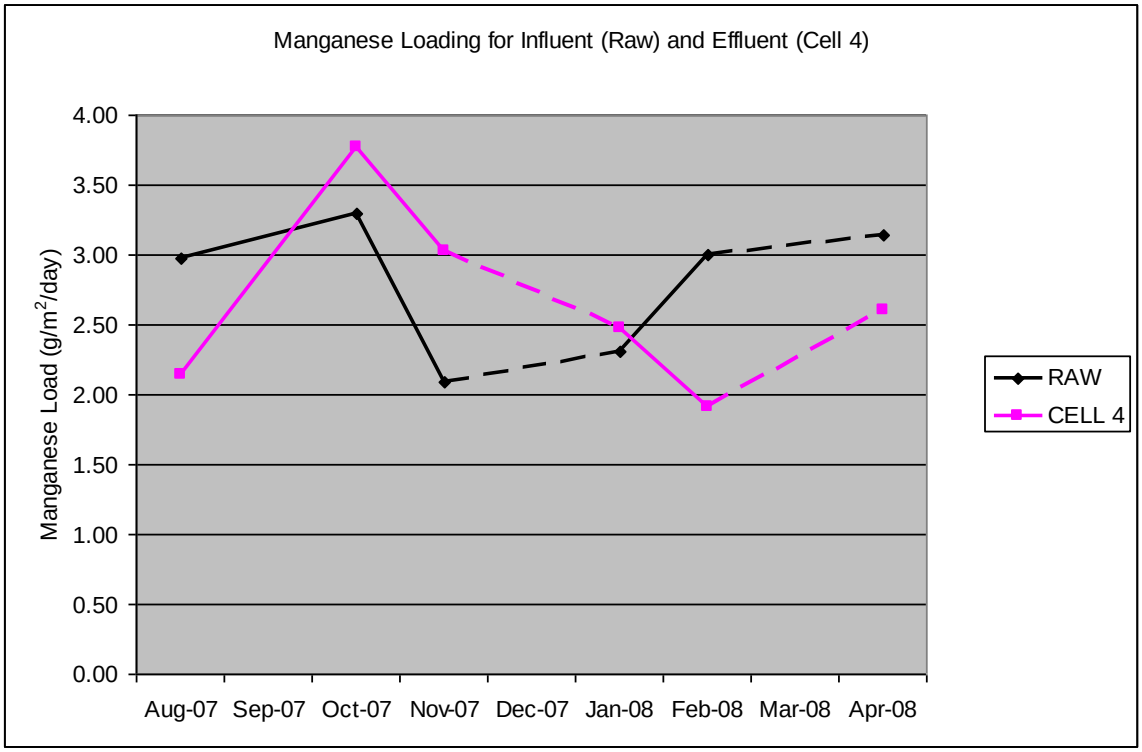


Figure 8.62(b) Manganese Loading for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.63(a) Summary of Mn Concentrations and Loadings for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Mn	Influent	23	0.93 - 3.93	2.86 (± 0.73)	0.40
Mn	Effluent	8	2.68 - 6.40	4.45 (± 1.55)	0.62

Table 8.63(b) Summary of Mn Load Removal for Cell 5

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Mn	-0.22	-55

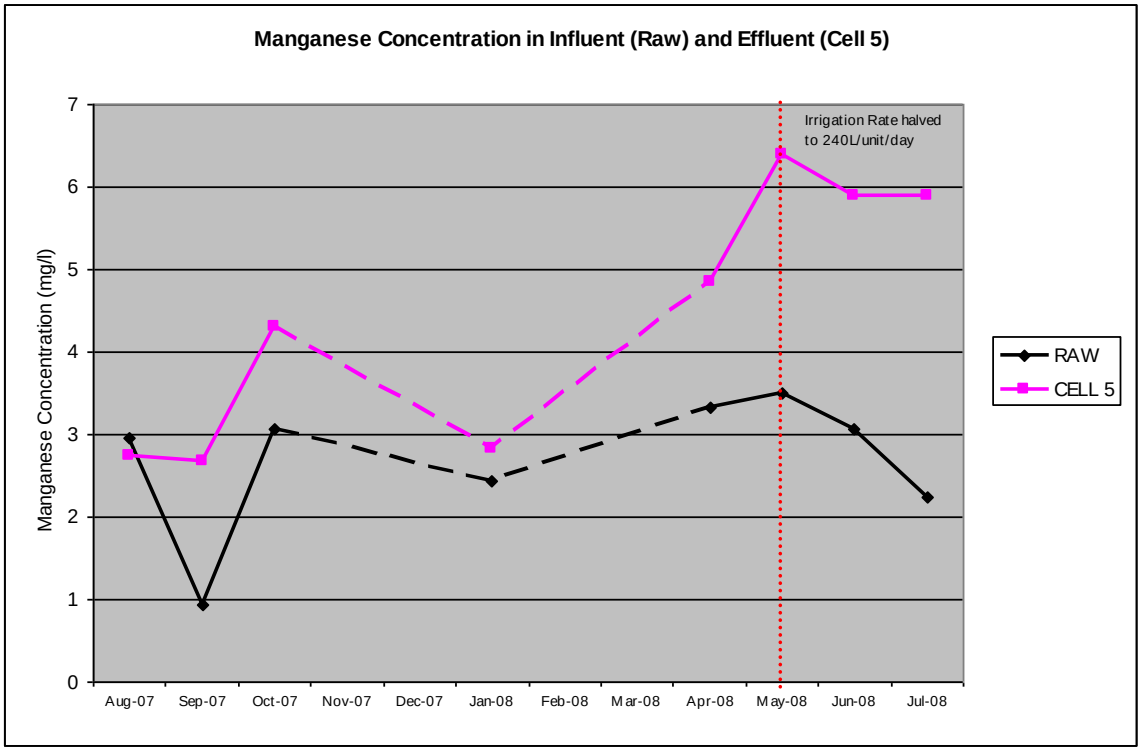


Figure 8.63(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 5)

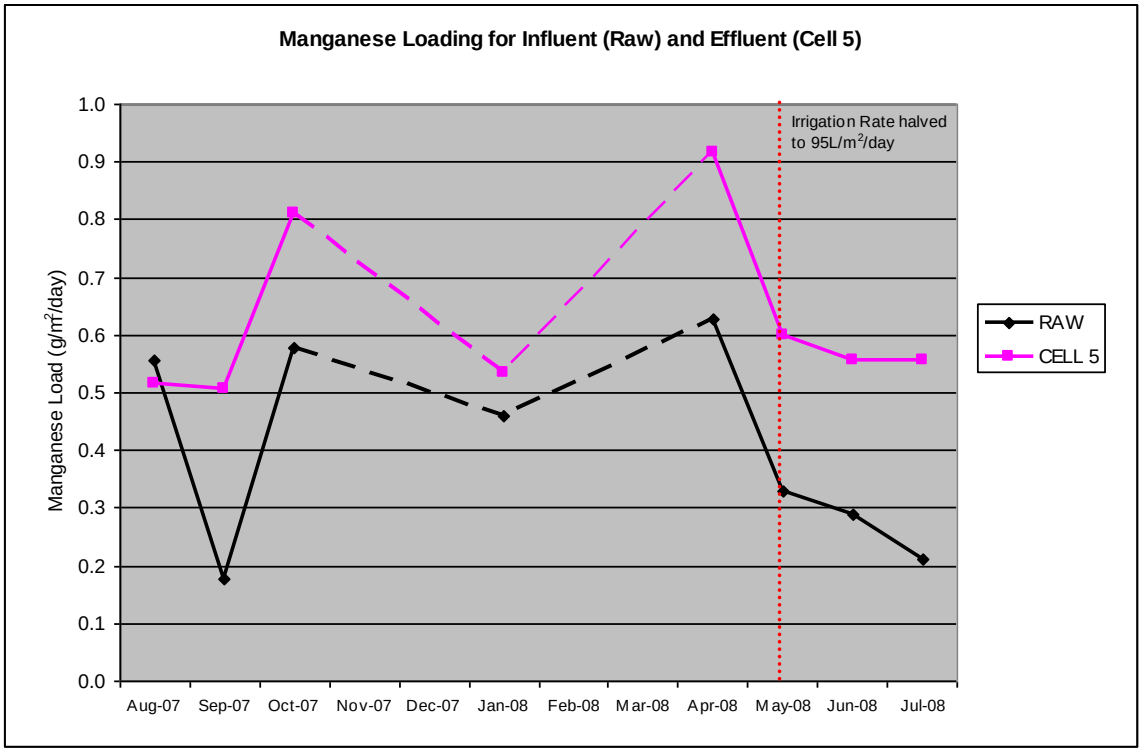


Figure 8.63(b) Manganese Loading for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.64(a) Summary of Mn Concentrations and Loadings for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Mn	Influent	22	0.93 - 3.93	2.89 (± 0.73)	1.19
Mn	Effluent	8	2.06 - 5.60	3.68 (± 1.32)	1.65

Table 8.64(b) Summary of Mn Load Removal for Cell 6

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Mn	-0.46	-39

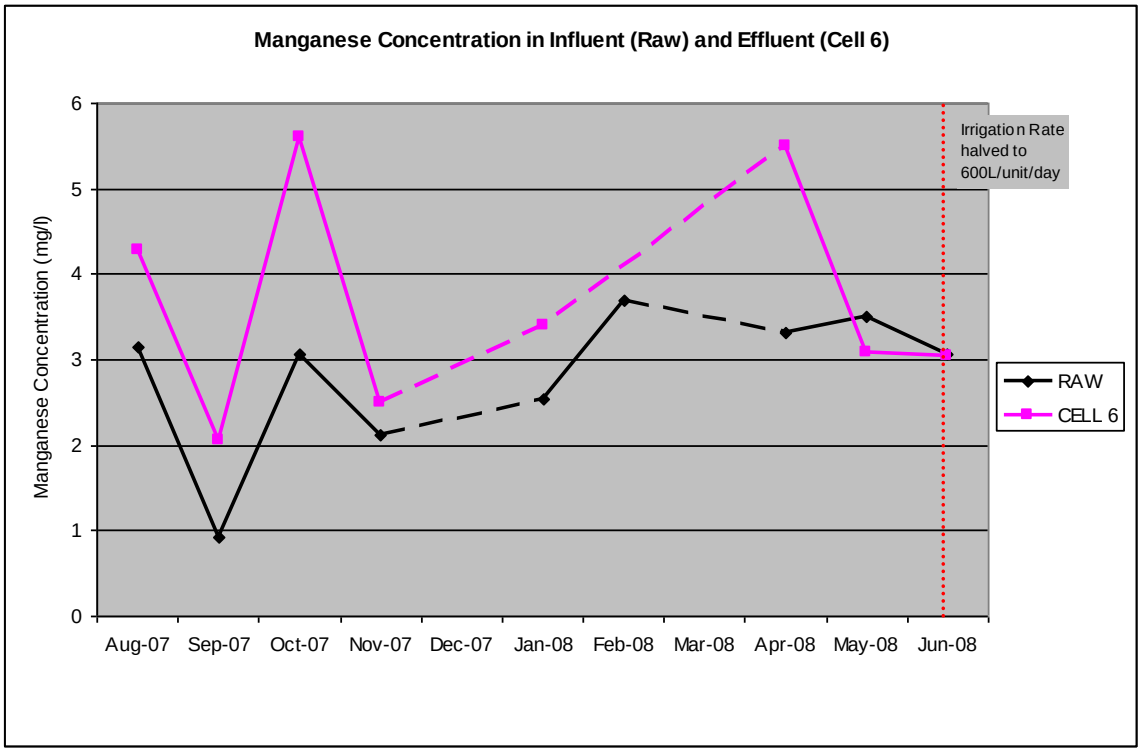


Figure 8.64(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 6)

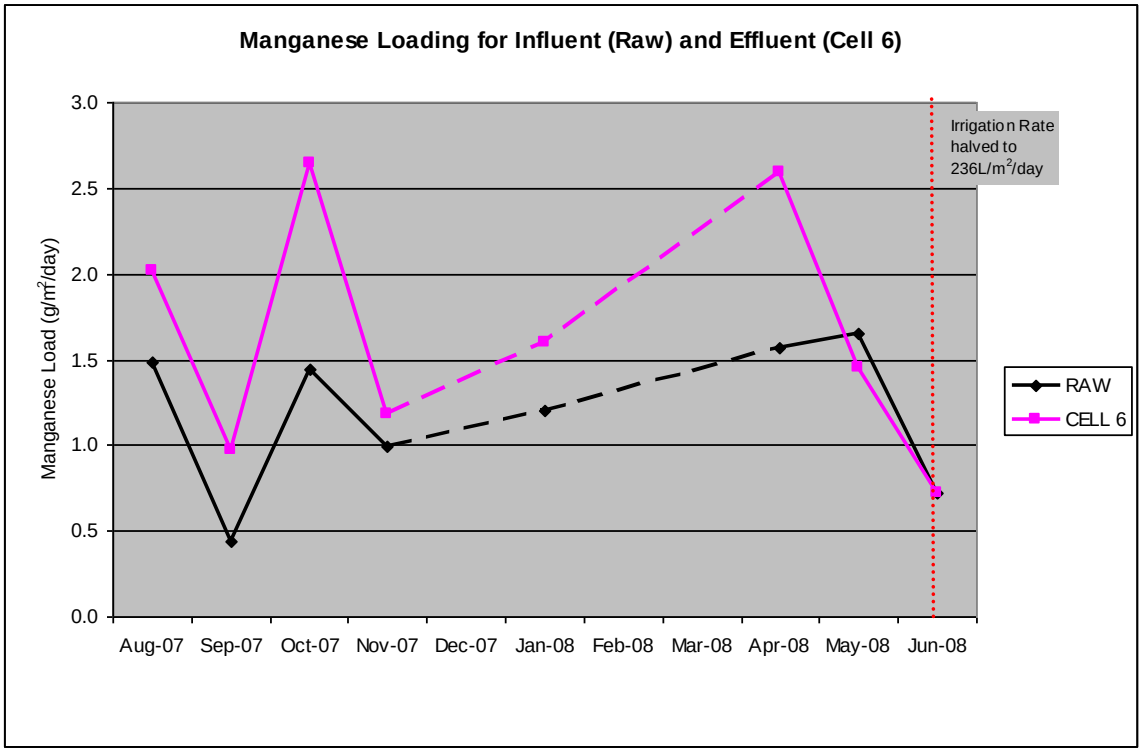


Figure 8.64(b) Manganese Loading for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.65(a) Summary of Mn Concentrations and Loadings for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Mn	Influent	23	0.93 - 3.93	2.87 (± 0.71)	2.09
Mn	Effluent	11	0.81 - 4.24	2.97 (± 0.98)	2.16

Table 8.65(b) Summary of Mn Load Removal for Cell 7

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Mn	-0.07	-3

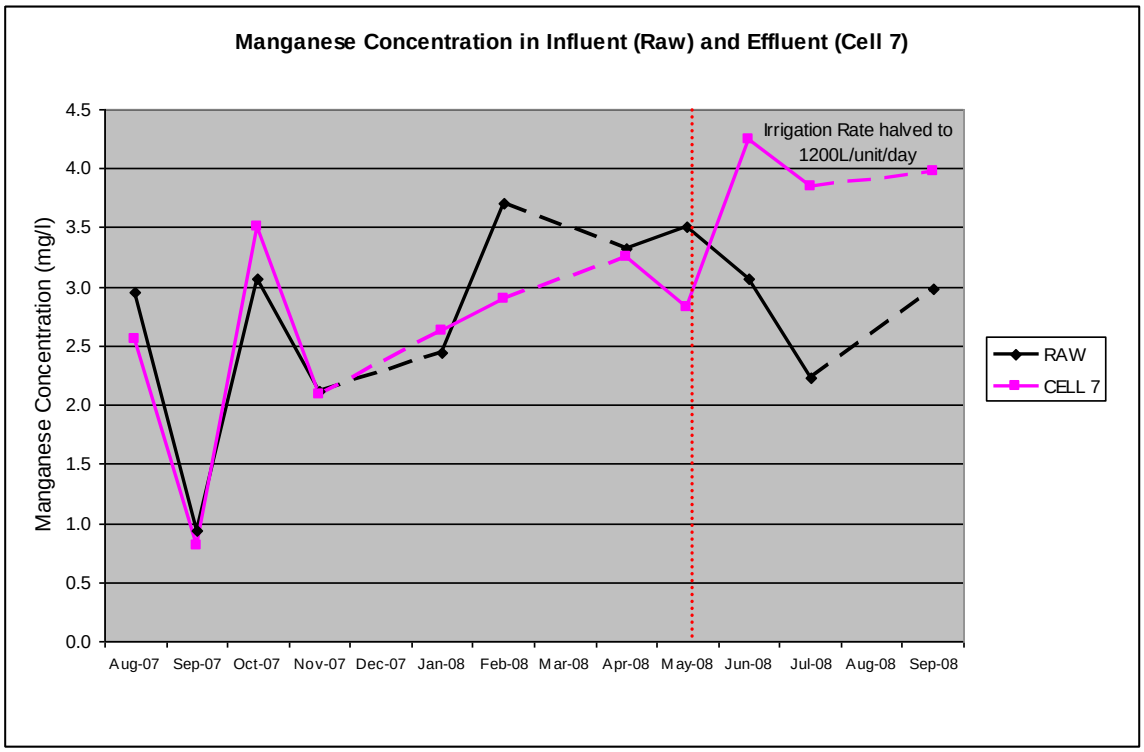


Figure 8.65(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 7)

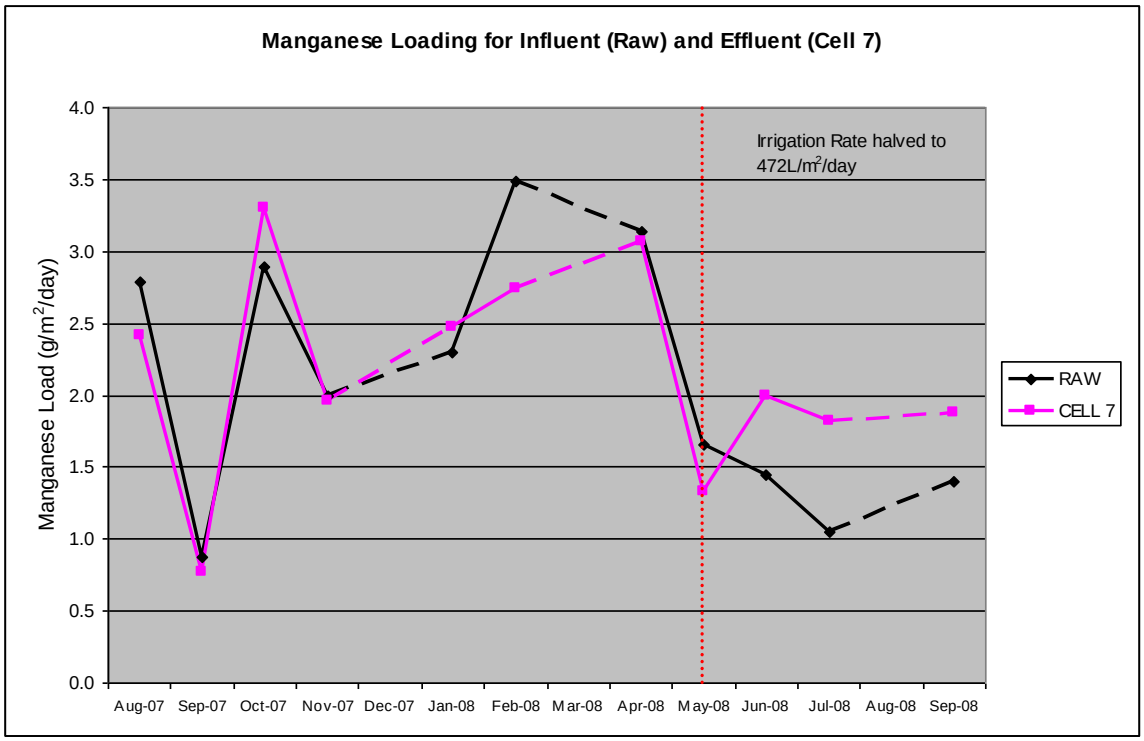


Figure 8.65(b) Manganese Loading for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.66(a) Summary of Mn Concentrations and Loadings for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)	Mean Load (g/m^2/day)
Mn	Influent	24	0.93 - 3.93	2.87 (± 0.71)	1.06
Mn	Effluent	8	2.02 - 5.10	3.84 (± 1.34)	1.54

Table 8.66(b) Summary of Mn Load Removal for Cell 8

Parameter	Average Load Removal (g/m^2/day)	Average % Load Removal
Mn	-0.48	-45

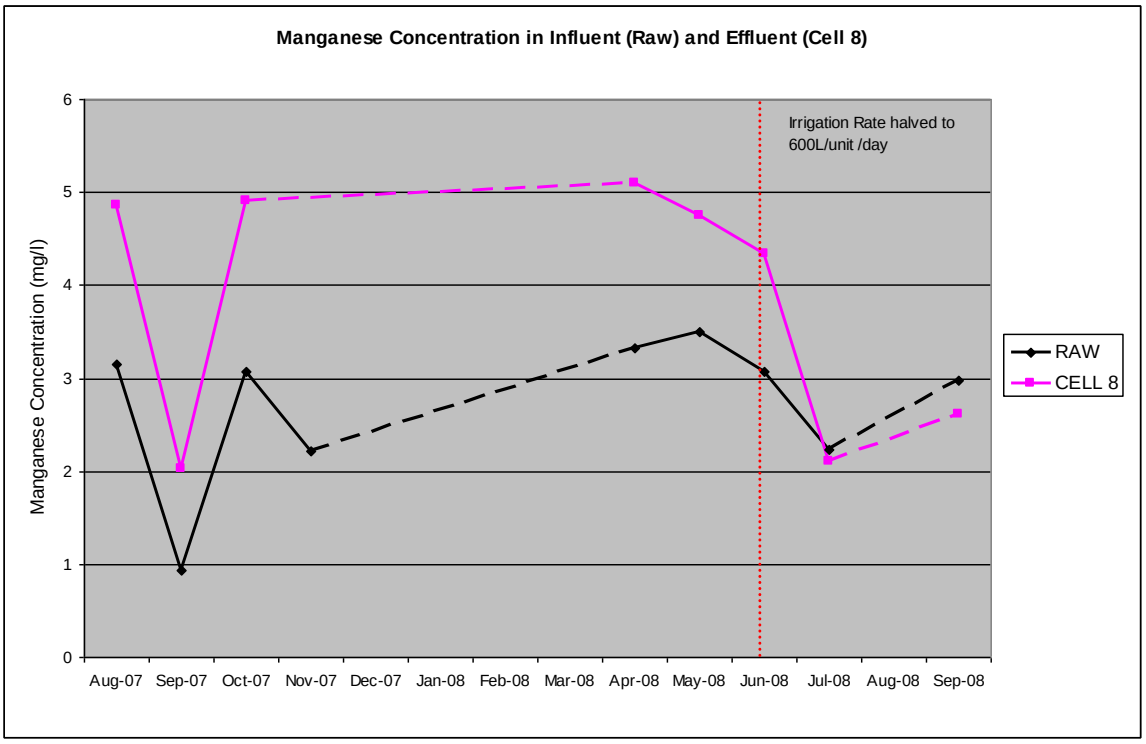


Figure 8.66(a) Manganese Concentration in Influent (Raw) and Effluent (Cell 8)

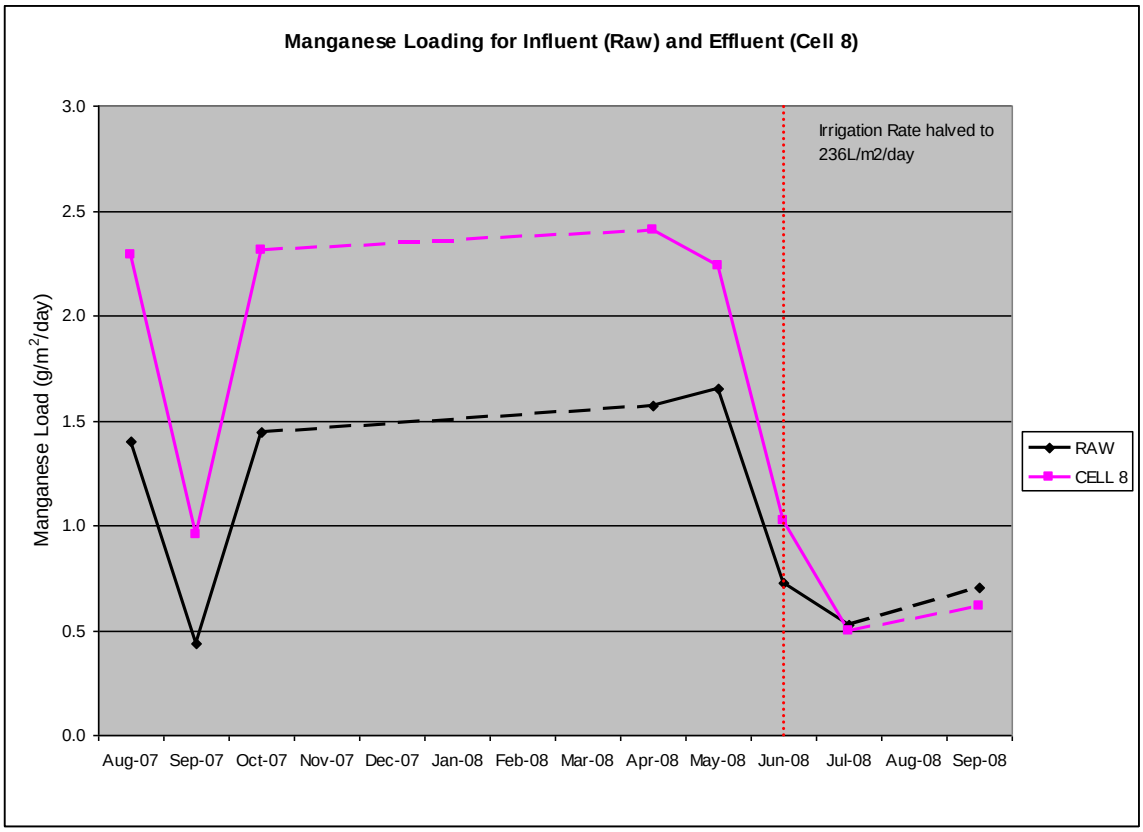


Figure 8.66(b) Manganese Loading for Influent (Raw) and Effluent (Cell 8)

8.2.6.3 Interpretation of Iron and Manganese Removal for Individual Treatment Units

Analysis of the results obtained for load removal rates for iron and manganese within cells 1 to 8 reveals a positive load removal within all units for iron but only a slight positive load removal for manganese in three units.

High average load removal rates were recorded for iron in cells 1, 2, 3 and 4 of 4.21, 5.28, 3.26 and 5.82g/m^2/day (Figures 8.51(b) – 8.54(b)). Cell 5 revealed an average load removal of 0.98g/m^2/day, which accounted for 79% of the influent load (Figure 8.155(b)).

Cells 6, 7 and 8, while still displaying positive load removal rates of 1.17, 1.74 and 1.60g/m^2/day; they were lower than the aforementioned batch as regards total % removal (Figures 8.56(b) - 8.58(b)). The lower removal rates within these units are possibly related to periodic flooding caused by a reduction in media permeability (surface sealing due to swelling of the clay/silt component).

As mentioned above, only three units revealed positive load removal rates for manganese; cell 1 with 0.29g/m^2/day (10%) average load removal, cell 2 with 0.17g/m^2/day (6%) removal and cell 4 with 0.15g/m^2/day (5%) removal (Figures 8.59(b), 8.60(b) and 8.62(b)).

Cells 3, 5, 6, 7 and 8 all displayed negative load removal rates of -0.53g/m^2/day (-19%), -0.22g/m^2/day (-55%), 0.46g/m^2/day (-39%), 0.07g/m^2/day (-3%) and 0.48g/m^2/day (-45%) respectively for Mn (Figures 8.61(b) and 8.63(b) – 8.66(b)).

Although a clear picture cannot always be gained from averaged data it is interesting to note that the cells that presented overall positive average load removal for Mn, all contained compost as the treatment medium. The remainder of the units are comprised entirely or partially of soil, sand or gravels.

High manganese concentrations are quite common in groundwater sourced from sand and gravel aquifers and from locally important sandstone aquifers throughout the south of Cork county. The high Mn concentrations are caused mainly by the natural conditions in the ground and the natural chemistry of the groundwater. The naturally high Mn concentrations occur in areas underlain by peat, muddy limestones, and mainly in the Old Red Sandstones and rocks of the Cork Group, where reducing conditions result in solution of Fe and/or Mn from the geological materials (GSI, 2002).

Based on the evidence presented above, it is likely that on occasions where de-oxygenated conditions persisted in the treatment units (due to temporary surface flooding or at micro-anoxic zones within the media column) the result was the dissolution of Mn from the subsoil and sand/gravels into the effluent.

Removal Mechanisms

The chief removal mechanism for iron within the various treatment units was oxidation followed by precipitation as ferrous oxyhydroxide ($Fe(OH)_3$) as evidenced by the surface cementation in a number of units during the early stages of plant operation. Other likely mechanisms for iron removal from the wastewater stream were complexation, sorption onto and within the media matrix, and plant uptake as well as microbially induced precipitation.

Based on the results presented in Tables 8.59(a) to 8.66(b) manganese removal was achieved mainly by adsorption on to the compost medium. Other removal mechanisms that could account for Mn removal include oxidation (given the high to neutral pH conditions that persist within the leachate stream) leading to co-precipitation with iron (Hallberg *et al.*, 2005), possible microbial oxidation and also precipitation and formation of manganese concretions under local anoxic conditions.

With the exception a slightly higher load reduction in Fe and Mn for cells 6 and 8, it was difficult to discern whether a 50% reduction in the loading rate applied in the latter stages of operation for cells 5, 6, 7 and 8 had any impact in terms of increased treatment efficiency.

8.2.6.4 Iron Removal in Treatment Units Operating in Sequence

Iron concentrations and removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.67(a) to 8.68(c).

Charts detailing the range of iron concentrations and loadings for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.67(a) to 8.68(c).

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.67(a) Summary of Iron Concentrations for sequence Cell 1 – VF 2 – HF 2

Iron Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Iron	Influent	4	2.44 − 7.40	4.44 (± 2.62)
Iron	Effluent Cell 1	4	1.01 − 3.22	1.98 (± 1.13)
Iron	Effluent VF 2	4	0.08 − 0.43	0.31 (± 0.20)
Iron	Effluent HF 2	4	0.07 − 0.19	0.13 (± 0.06)

Table 8.67(b) Summary of Iron Load Removal per m^2 for Cell 1 – VF 2 – HF 2

Iron	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/m^2/day	4.20	0.19	0.03
Effluent Load g/m^2/day	1.87	0.03	0.01
Load removal g/m^2/day	2.33	0.16	0.02
Cumulative Load removal g/m^2/day	2.33	2.49	2.51

Table 8.67(c) Summary of Iron Load Removal per unit for Cell 1 – VF 2 – HF 2

Iron	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/unit/day	10.66	4.74	0.75
Effluent Load g/unit/day	4.74	0.75	0.30
Load removal g/unit/day	5.91	4.00	0.44
Cumulative Load removal g/unit/day	5.91	9.91	10.35
Cumulative Load Removal as % per unit	55	93	97

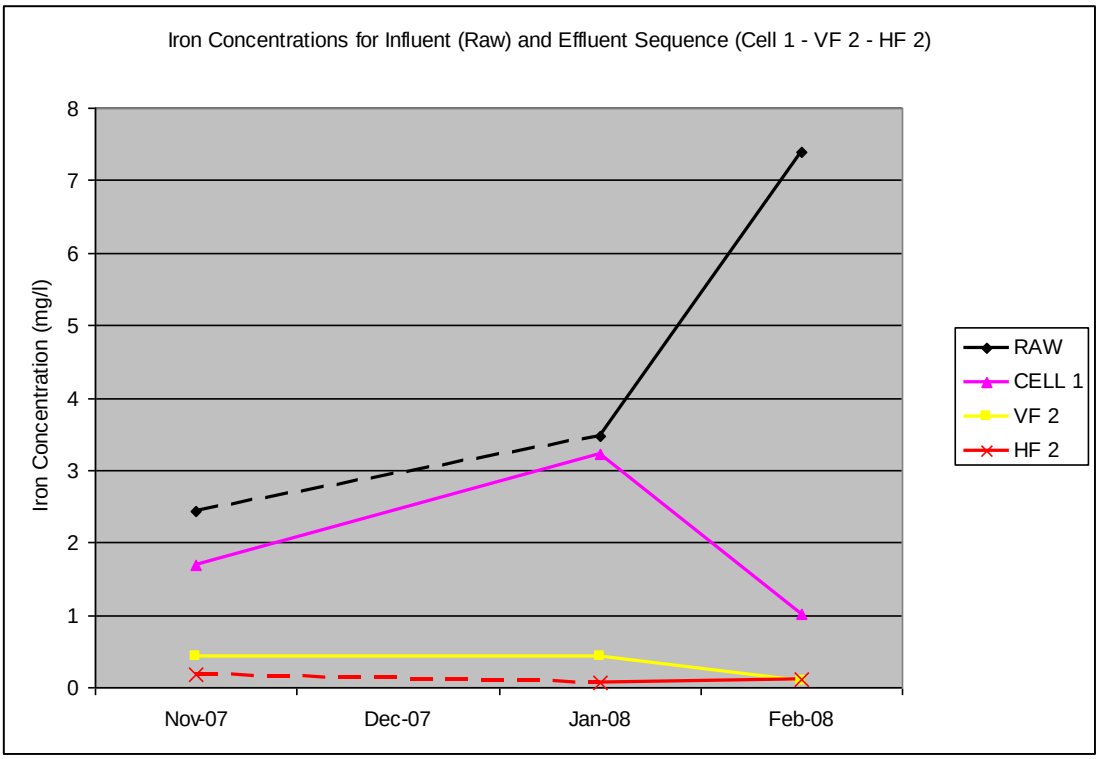


Figure 8.67(a) Iron Concentrations in Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

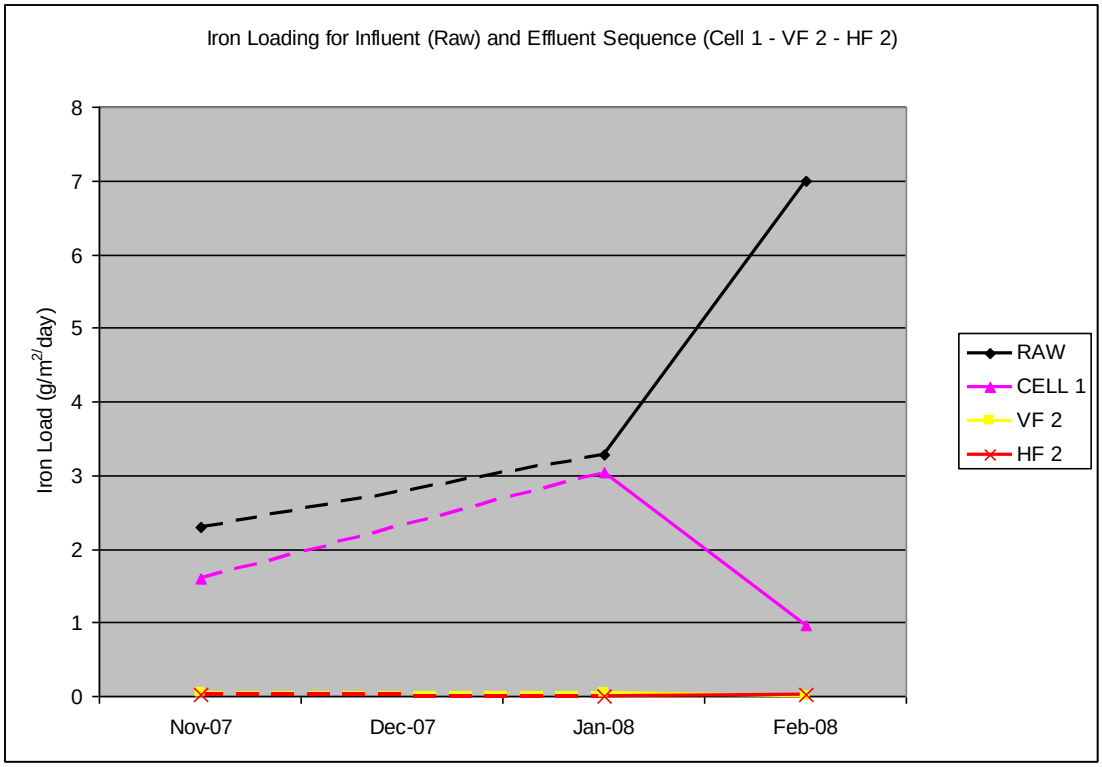


Figure 8.67(b) Iron Loading for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

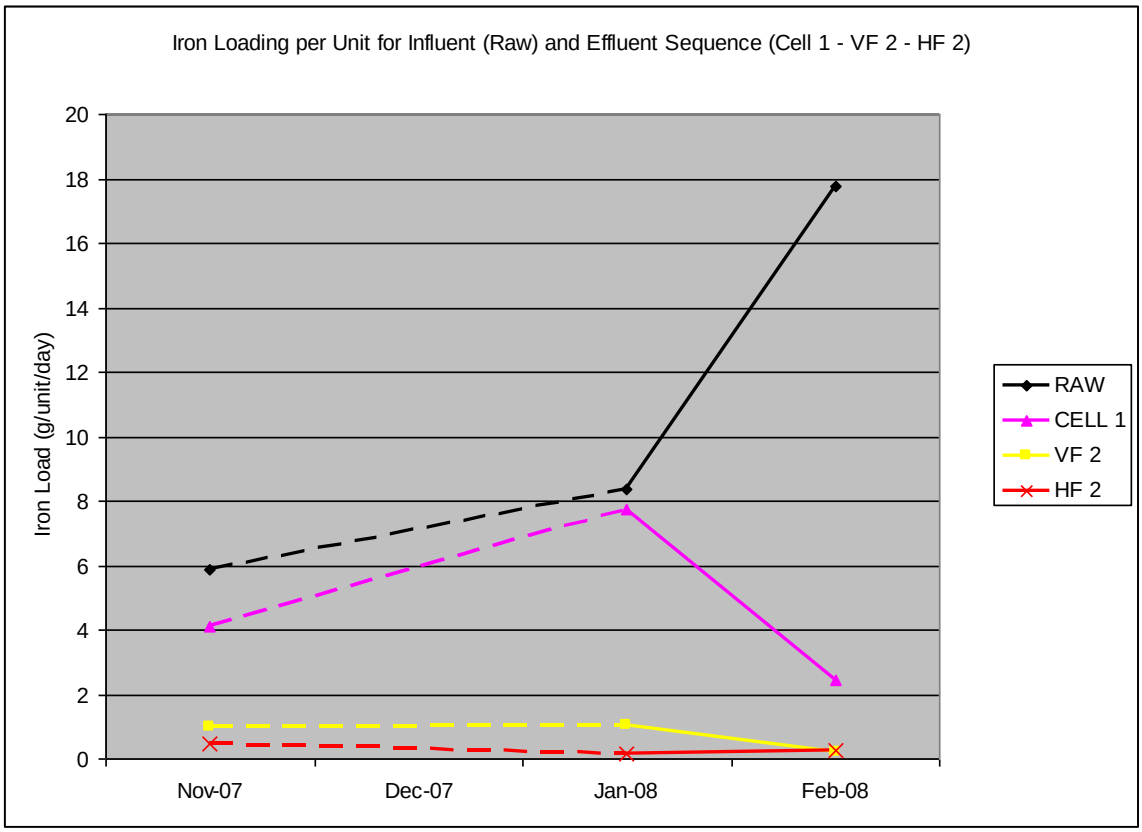


Figure 8.67(c) Iron Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.68(a) Summary of Iron Concentrations for sequence Cell 10 – VF 1 – HF 1

Iron Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Iron	Influent	4	2.37 − 7.40	4.42 (± 2.64)
Iron	Effluent Cell 10	4	0.40 − 0.77	0.58 (± 0.26)
Iron	Effluent VF 1	4	0.14 - 0.38	0.26 (± 0.17)
Iron	Effluent HF 1	4	0.05 - 0.15	0.10 (± 0.07)

Table 8.68(b) Summary of Iron Load Removal per m^2 for Cell 10 – VF 1 – HF 1

Iron	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/m^2/day	4.17	0.06	0.02
Effluent Load g/m^2/day	0.55	0.02	0.01
Load Removal g/m^2/day	3.63	0.03	0.01
Cumulative Load Removal g/m^2/day	3.63	3.66	3.67

Table 8.68(c) Summary of Iron Load Removal per unit for Cell 10 – VF 1 – HF 1

Iron	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/unit/day	10.60	1.39	0.61
Effluent Load g/unit/day	1.39	0.61	0.24
Load Removal g/unit/day	9.21	0.78	0.37
Cumulative Load Removal g/unit/day	9.21	9.99	10.36
Cumulative Load Removal as % per unit	87	94	98

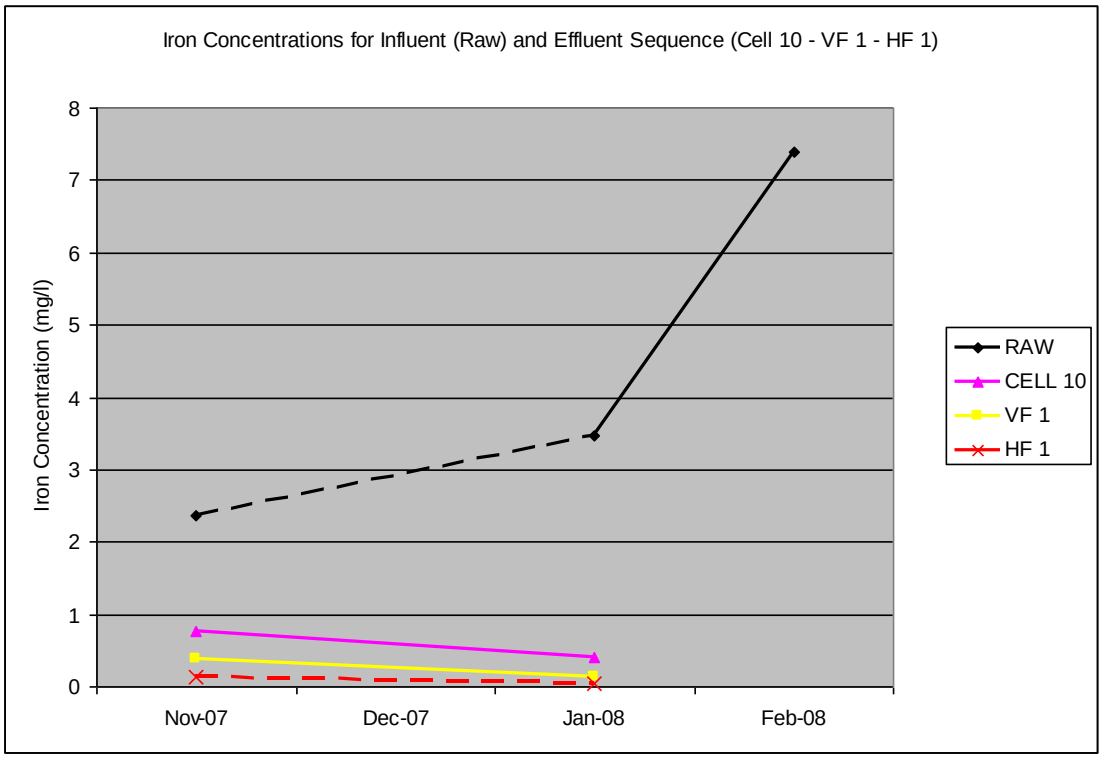


Figure 8.68(a) Iron Concentrations in Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

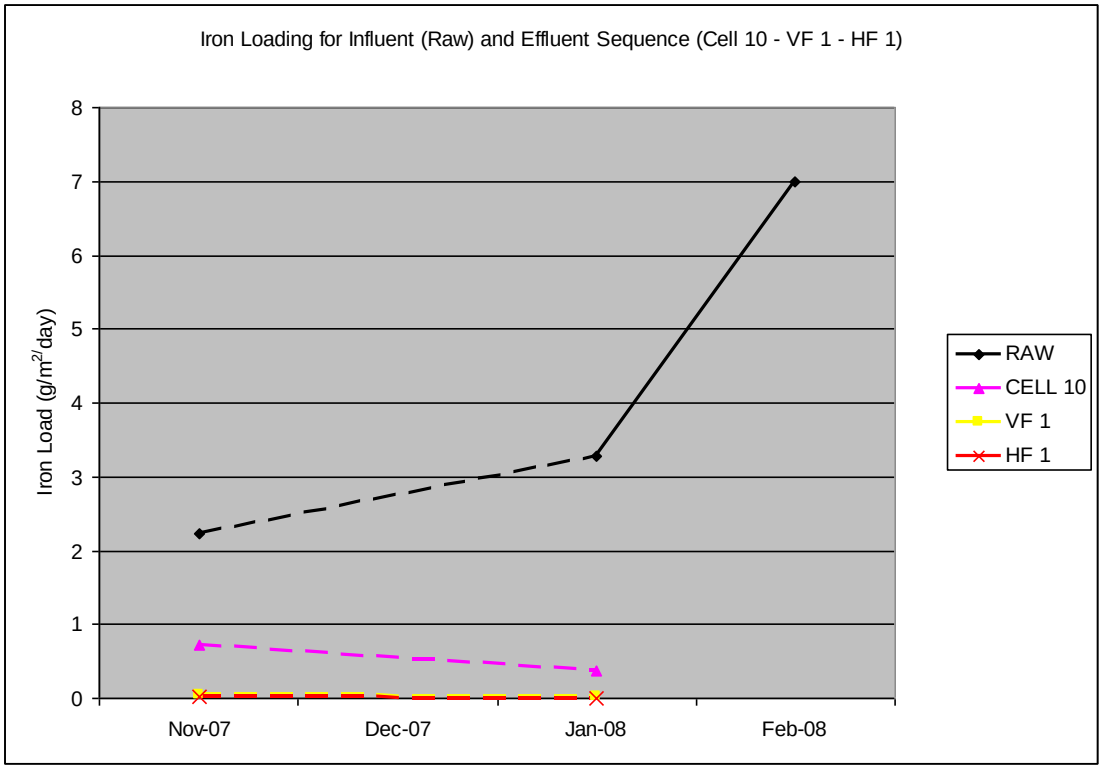


Figure 8.68(b) Iron Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

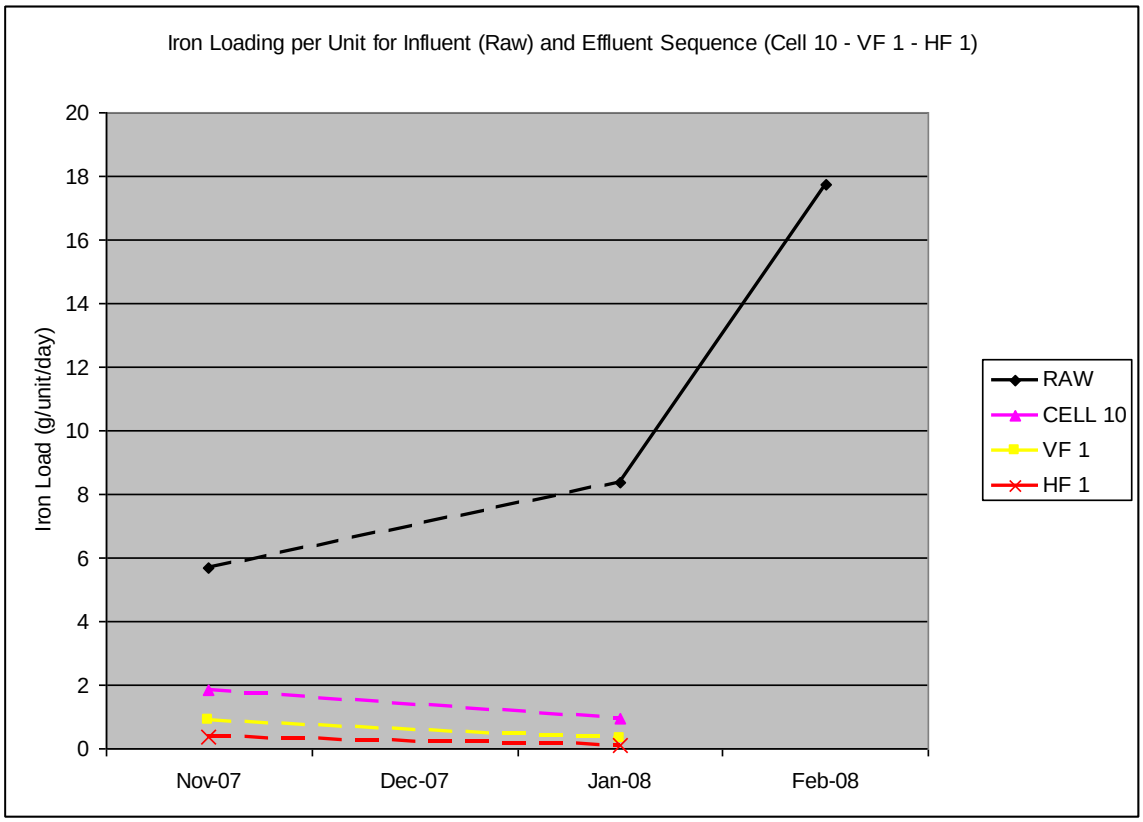


Figure 8.68(c) Iron Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.6.5 Manganese Removal in Treatment Units Operating in Sequence

Manganese concentrations and removal efficiencies for units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.69(a) to 8.70(c).

Charts detailing the range of manganese concentrations and loadings for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.69(a) to 8.70(c).

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.69(a) Summary of Mn Concentrations for sequence Cell 1 – VF 2 – HF 2

Mn Concentration (Raw - Cell 1 - VF 2 - HF 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Mn	Influent	4	2.21 − 3.70	2.78 (± 0.80)
Mn	Effluent Cell 1	4	1.64 − 3.30	2.51 (± 0.83)
Mn	Effluent VF 2	4	2.64 − 4.80	3.48 (± 1.16)
Mn	Effluent HF 2	4	2.01 − 3.60	2.71 (± 0.81)

Table 8.69(b) Summary of Mn Load Removal per m^2 for Cell 1 – VF 2 – HF 2

Mn	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/m^2/day	2.63	0.24	0.33
Effluent Load g/m^2/day	2.37	0.33	0.26
Load Removal g/m^2/day	0.26	-0.09	0.07
Cumulative Load Removal g/m^2/day	0.26	0.16	0.24

Table 8.69(c) Summary of Mn Load Removal per unit for Cell 1 – VF 2 – HF 2

Mn	**CELL 1**	**VF 2**	**HF 2**
Influent Load g/unit/day	6.68	6.03	8.34
Effluent Load g/unit/day	6.03	8.34	6.51
Load Removal g/unit/day	0.65	-2.31	1.83
Cumulative Load Removal g/unit/day	0.65	-1.66	0.17
Cumulative Load Removal as % per unit	9.70	-24.91	2.51

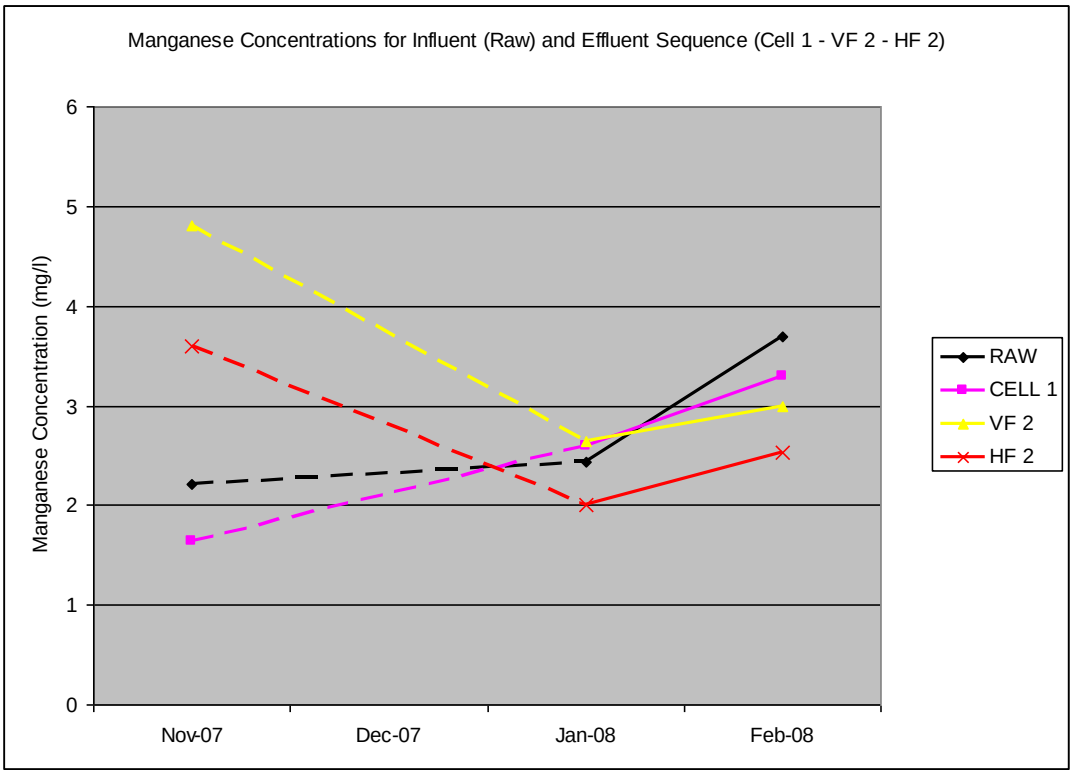


Figure 8.69(a) Manganese Concentrations in Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

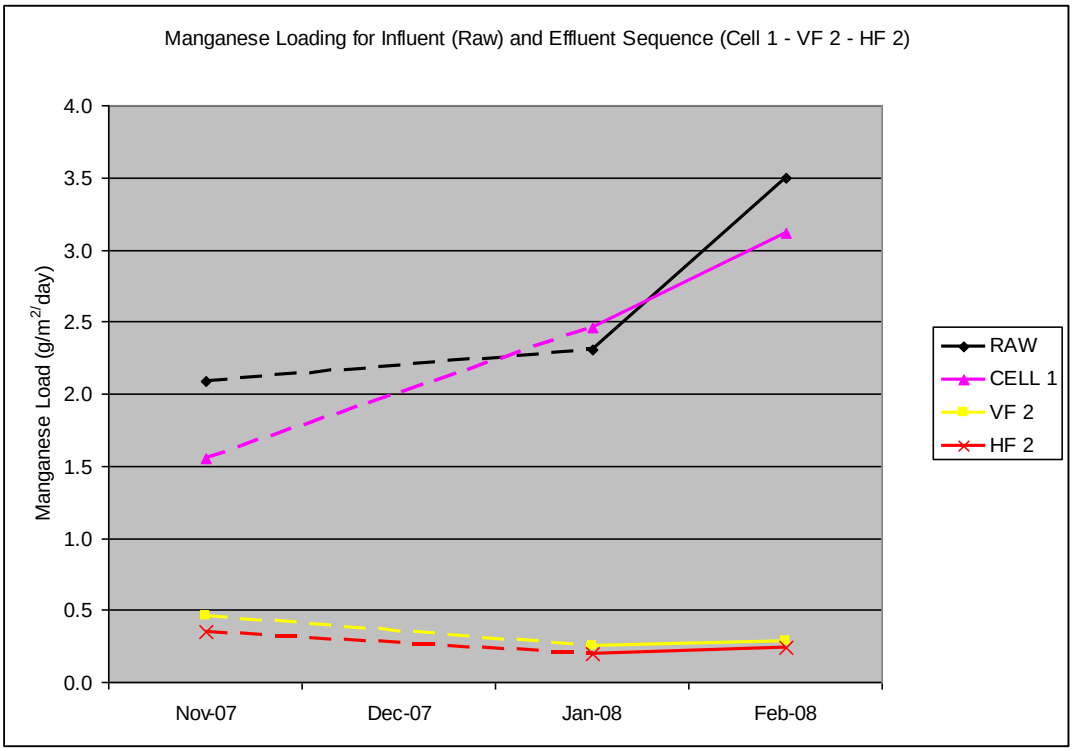


Figure 8.69(b) Manganese Loading for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

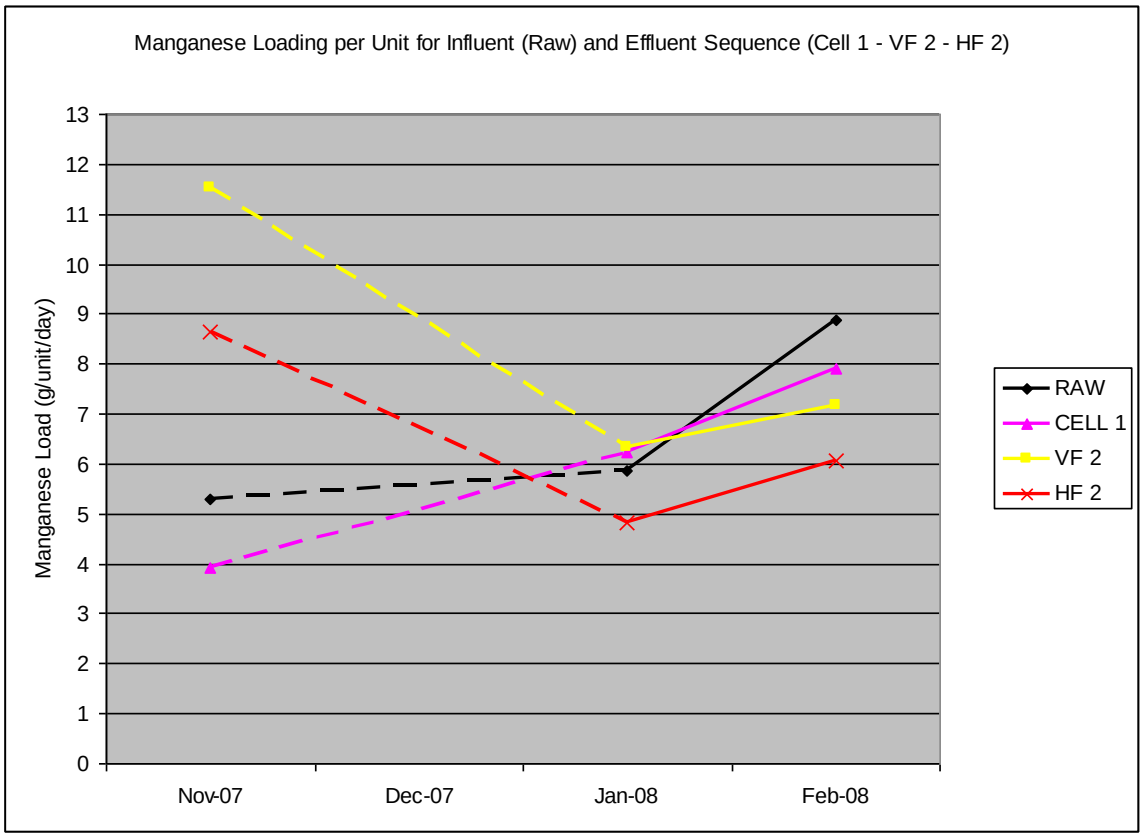


Figure 8.69(c) Manganese Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 1 – VF 2 – HF 2)

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.70(a) Summary of Mn Concentrations for sequence Cell 10 – VF 1 – HF 1

Mn Concentration (Raw - Cell 10 - VF 1 - HF 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Mn	Influent	4	2.11 − 3.17	2.57 (± 0.54)
Mn	Effluent Cell 10	4	1.28 − 2.45	1.90 (± 0.59)
Mn	Effluent VF 1	4	2.41 − 3.80	2.98 (± 0.73)
Mn	Effluent HF 1	4	1.80 − 3.06	2.45 (± 0.63)

Table 8.70(b) Summary of Mn Load Removal per m^2 for Cell 10 – VF 1 – HF 1

Mn	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/m^2/day	2.43	0.18	0.29
Effluent Load g/m^2/day	1.80	0.29	0.23
Load Removal g/m^2/day	0.64	-0.10	0.05
Cumulative Load Removal g/m^2/day	0.64	0.53	0.58

Table 8.70(c) Summary of Mn Load Removal per unit for Cell 10 – VF 1 – HF 1

Mn	**Cell 10**	**VF 1**	**HF 1**
Influent Load g/unit/day	6.18	4.56	7.15
Effluent Load g/unit/day	4.56	7.15	5.87
Load Removal g/unit/day	1.62	-2.59	1.28
Cumulative Load Removal g/unit/day	1.62	-0.98	0.30
Cumulative Load Removal as % per unit	26.17	-15.80	4.92

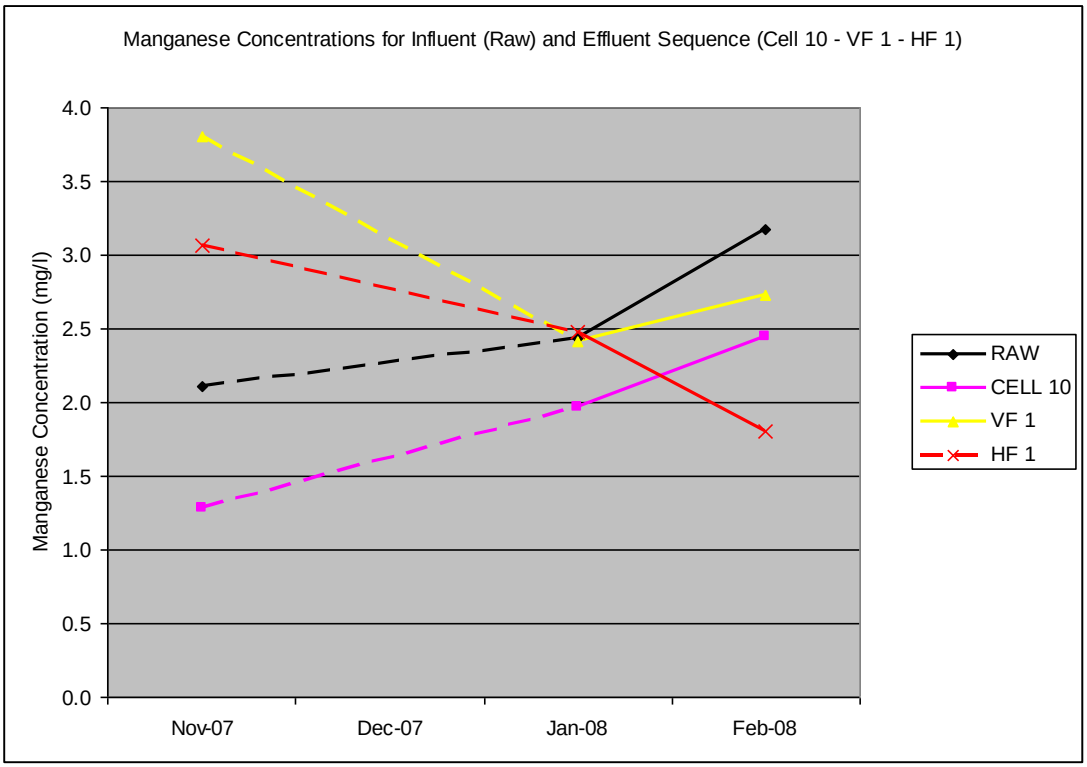


Figure 8.70(a) Manganese Concentrations in Influent (Raw) and Effluent Sequence (Cell 10 – VF 1 – HF 1)

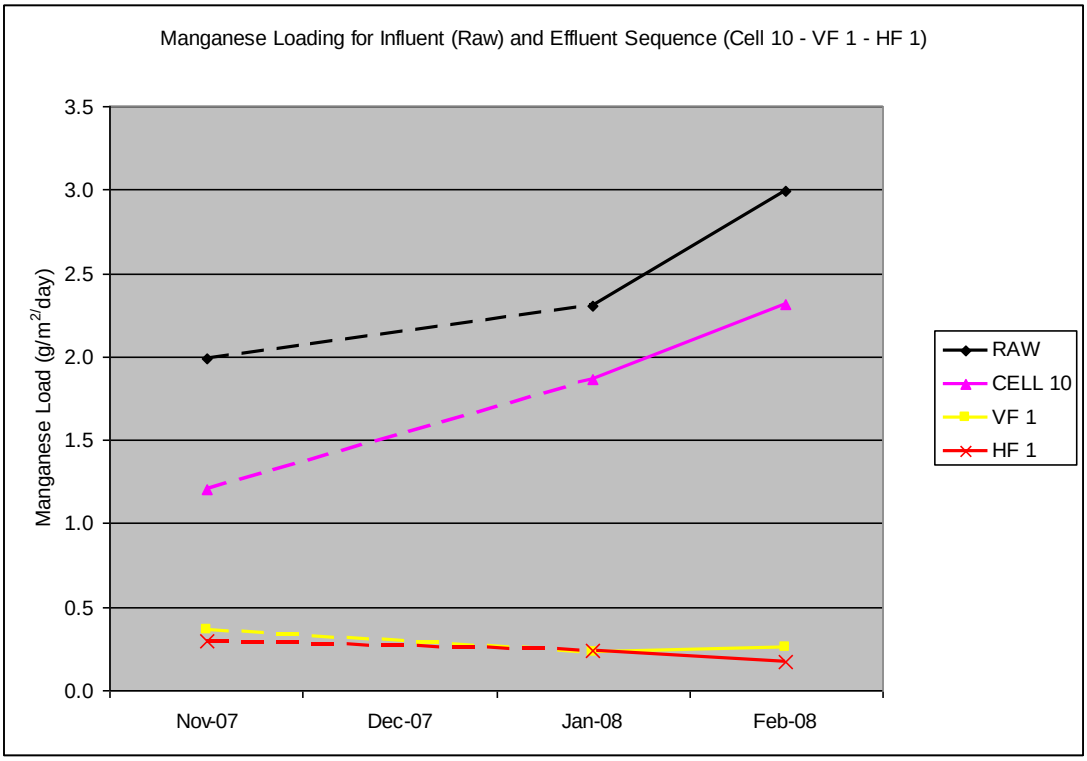


Figure 8.70(b) Manganese Loading for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

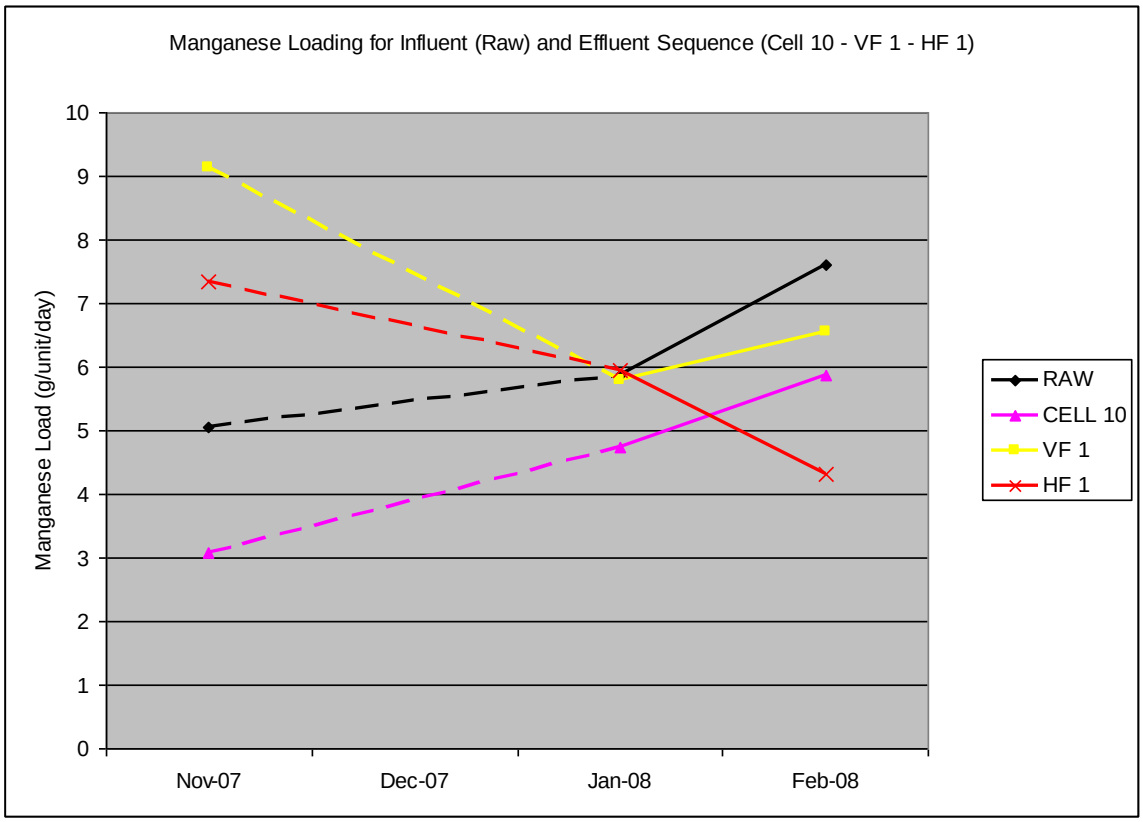


Figure 8.70(c) Manganese Loading per Unit for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.6.6 Interpretation of Iron and Manganese Removal for Treatment Units Operating in Sequence

A breakdown of results for load removal rates for iron and manganese within treatment units operating in sequence; Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1; reveals high load removal rates for iron and a mixed set of results for manganese within each treatment sequence.

Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 show an average cumulative load removal for iron of 10.35g/unit/day (97% removal) and 10.36g/unit/day (98% removal) per sequence with the majority of load removal occurring between the primary and secondary treatment units (Figures 8.67(c) and 8.68(c)).

Results for manganese load removal were much more variable across each sequence. The units containing compost (cells 1 and 10) and the HF reed beds tended to yield positive Mn load removal whilst the VF reed beds each displayed negative load removal (Figures 8.69(c) and 8.70(c)). Despite this variability, there was an average cumulative Mn

removal rate of 0.17g/unit/day (2.5% removal) for Cell 1 – VF 2 – HF 2 and 0.30g/unit/day (4.9% removal) for Cell 10 – VF 1 – HF 1. The negative load removal from the VF reed beds is most likely due to mobilisation of Mn from the locally sourced sand and gravel used in the media.

Removal mechanisms for iron and manganese will be dominated by the same processes previously mentioned.

8.2.7 Methane Concentration

The concentration of dissolved methane within the influent and effluent is detailed in this section. A series of tables outlining dissolved methane concentrations in the influent and effluent from individual treatment units is presented below in section 8.2.7.1. Due to insufficient data sets for treatment units operating in sequence, mean concentrations could not be calculated. Instead, the entire results for the sampling period are presented in section 8.2.7.2.

Interpretation of dissolved methane results is outlined in section 8.2.7.3.

8.2.7.1 Dissolved Methane Concentrations in Individual Treatment Units

Dissolved methane concentrations for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.71 to 8.78.

Charts detailing the range of methane concentrations for cells 1 to 8 are presented in Figures 8.71 to 8.78.

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.71 Summary of Methane Concentrations for Cell 1

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	5	3.50 - 9.20	5.78 (± 2.15)
Methane	Effluent	2	0.20 - 1.20	0.70 (± 0.71)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.72 Summary of Methane Concentrations for Cell 2

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	11	4.20 - 11.00	5.68 (± 2.45)
Methane	Effluent	3	0.10 - 5.00	1.76 (± 2.80)

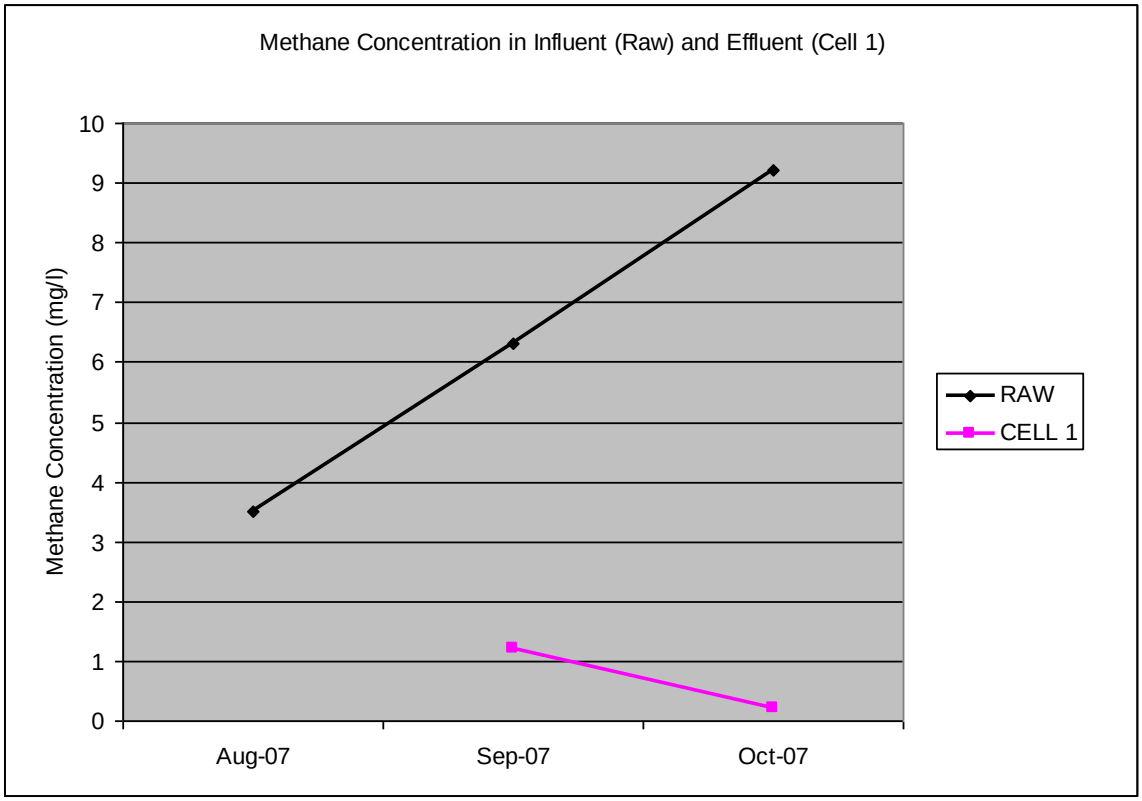


Figure 8.71 Methane Concentrations in Influent (Raw) and Effluent (Cell 1)

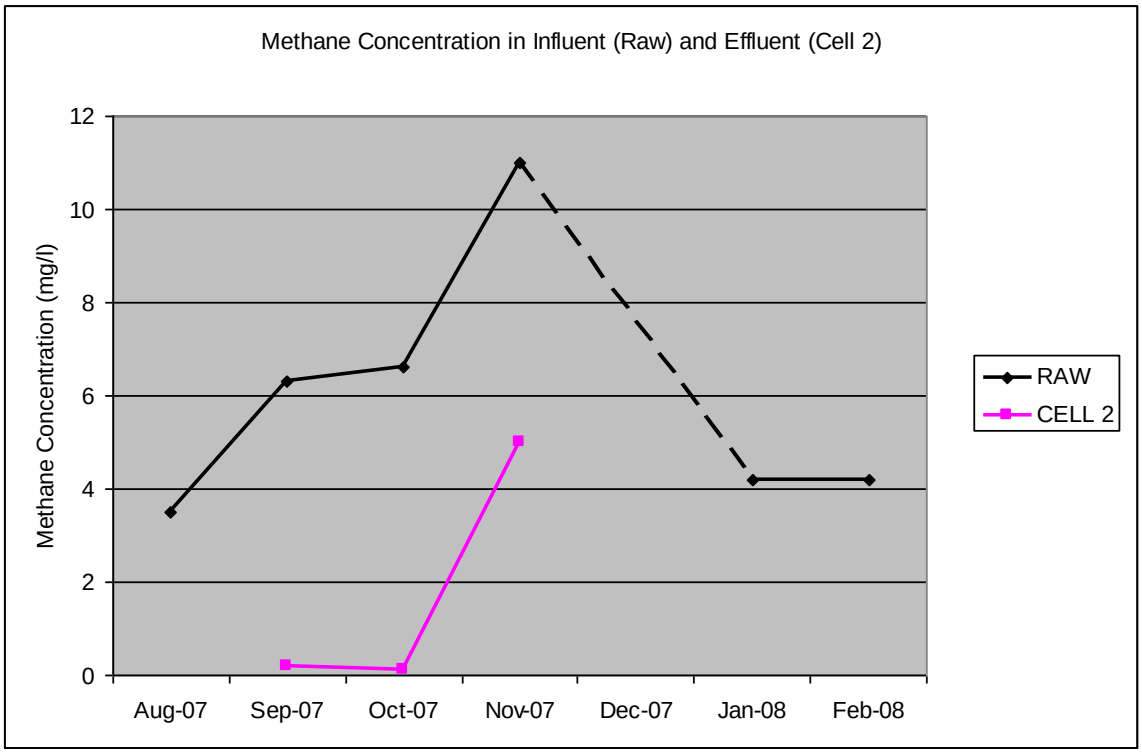


Figure 8.72 Methane Concentrations in Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.73 Summary of Methane Concentrations for Cell 3

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	7	3.50 - 11.00	6.53 (± 2.78)
Methane	Effluent	3	0.02 - 4.00	1.96 (± 1.78)

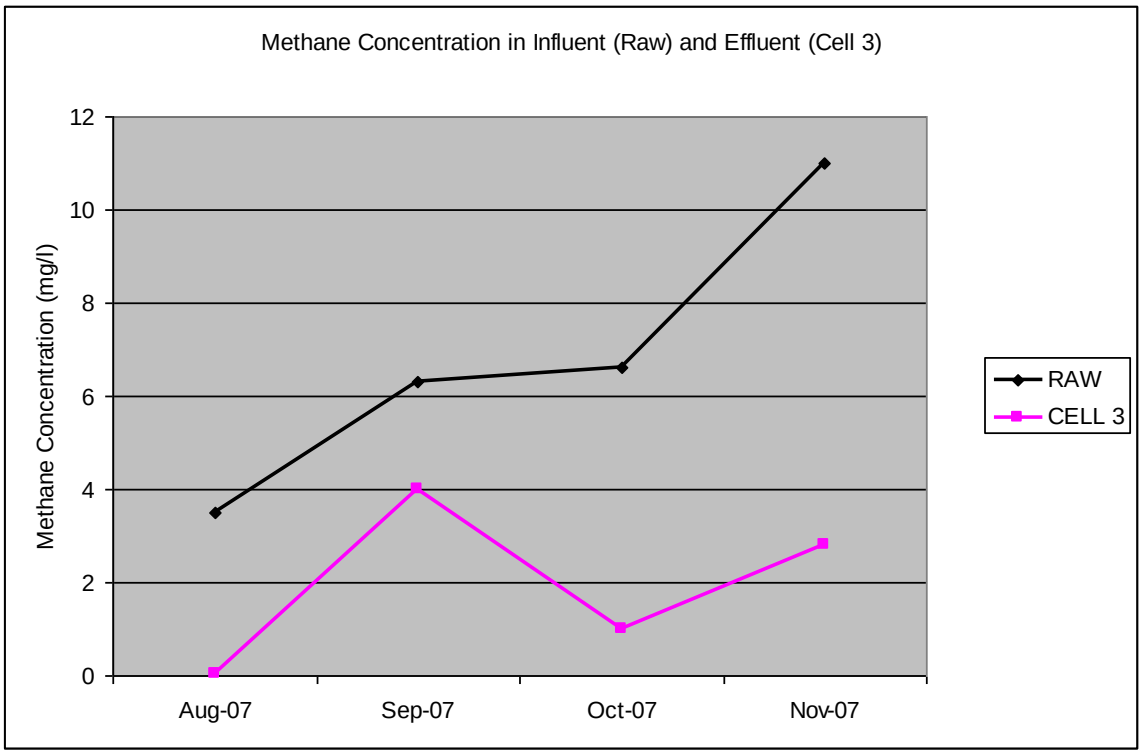


Figure 8.73 Methane Concentrations in Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.74 Summary of Methane Concentrations for Cell 4

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	12	3.50 - 11.00	5.68 (± 2.45)
Methane	Effluent	3	2.40 - 4.40	3.70 (± 1.13)

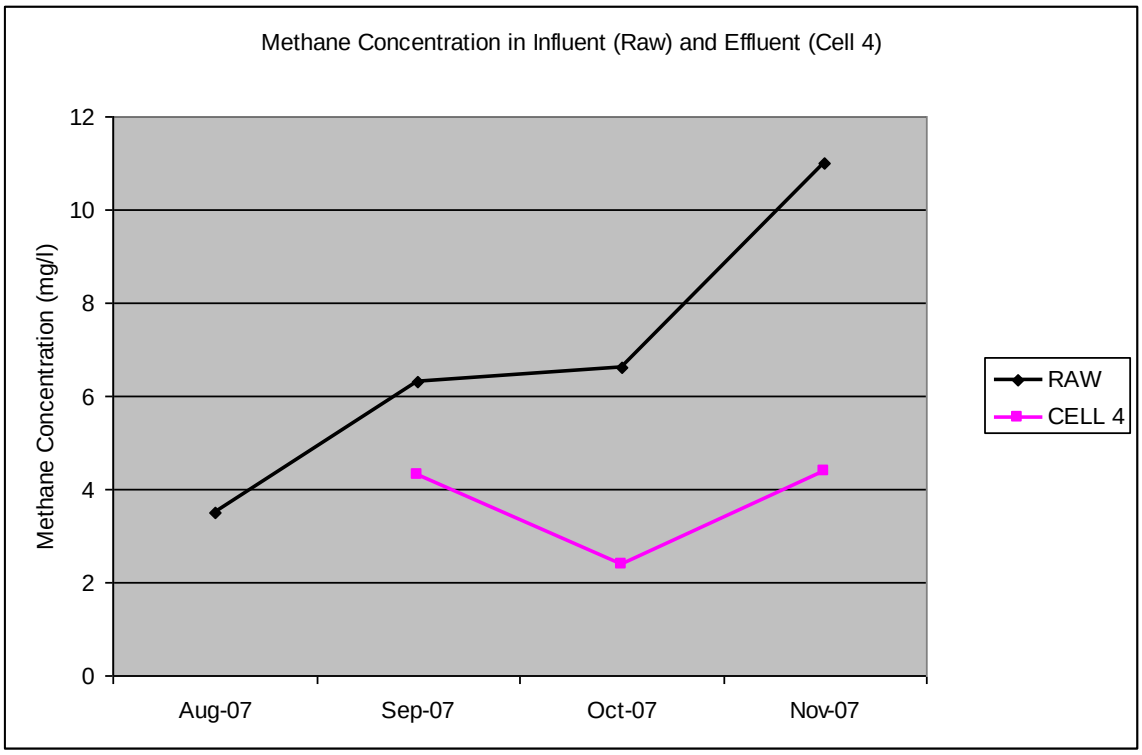


Figure 8.74 Methane Concentrations in Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.75 Summary of Methane Concentrations for Cell 5

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	13	3.50 - 14.00	6.39 (± 3.21)
Methane	Effluent	4	0.001 - 3.50	0.91 (± 1.73)

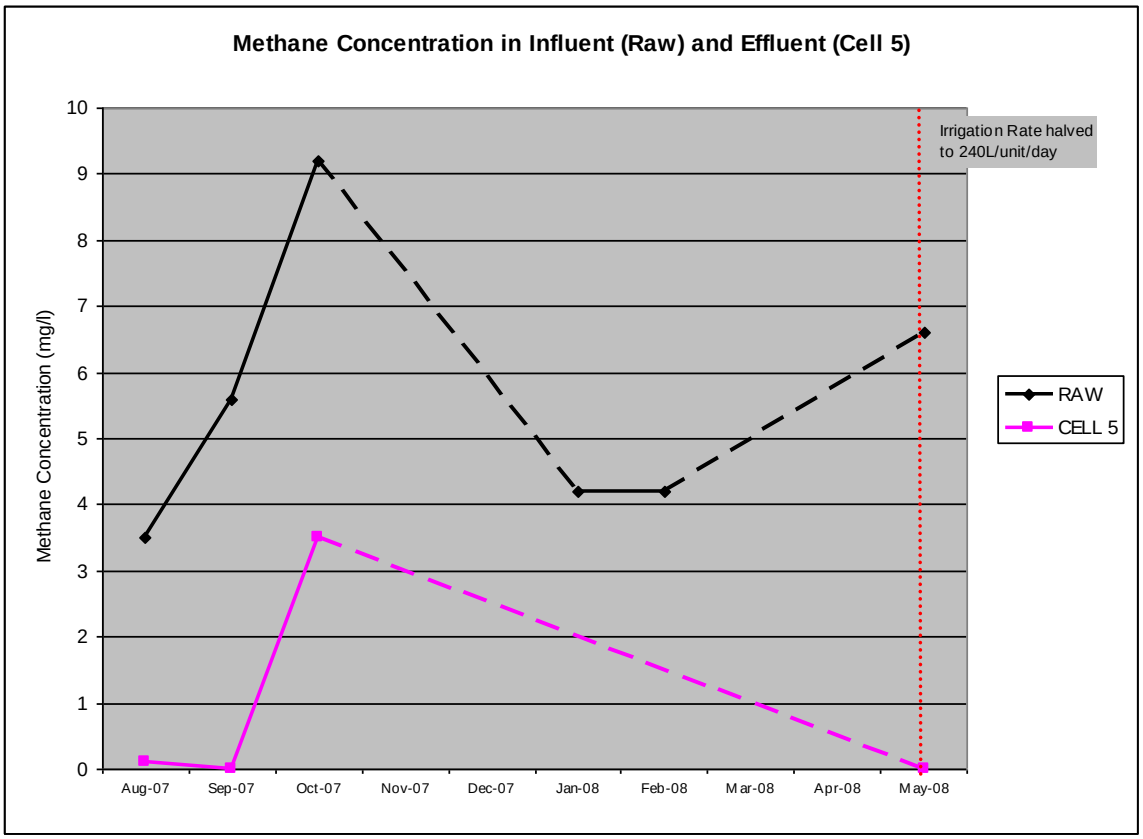


Figure 8.75 Methane Concentrations in Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.76 Summary of Methane Concentrations for Cell 6

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	13	3.50 - 14.00	6.39 (± 3.21)
Methane	Effluent	3	0.80 - 5.30	3.70 (± 2.52)

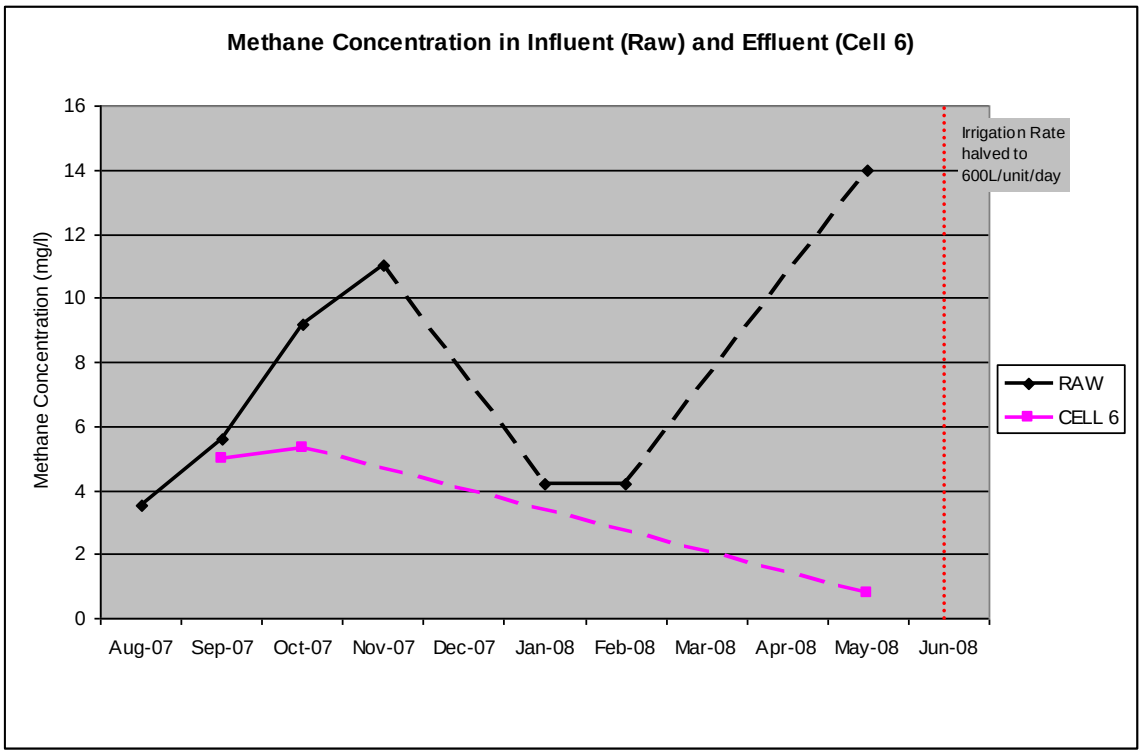


Figure 8.76 Methane Concentrations in Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.77 Summary of Methane Concentrations for Cell 7

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	15	3.50 - 14.00	7.06 (± 3.51)
Methane	Effluent	5	0.10 - 3.80	1.14 (± 1.60)

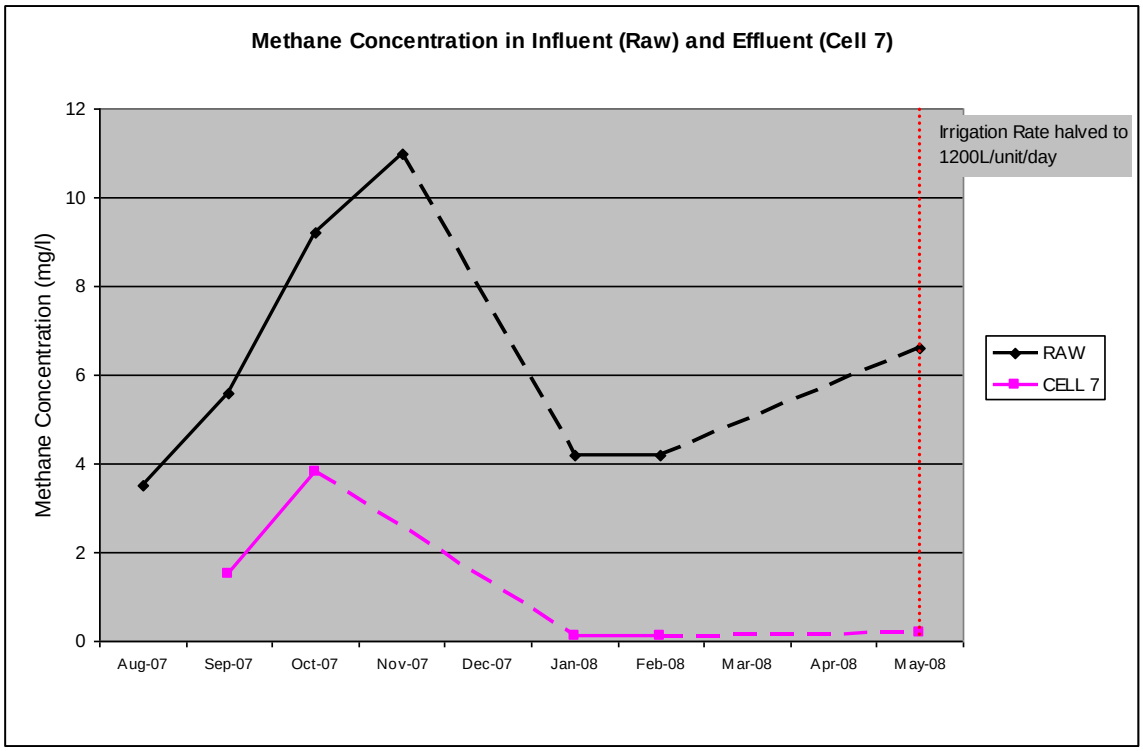


Figure 8.77 Methane Concentrations in Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.78 Summary of Methane Concentrations for Cell 8

Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Methane	Influent	15	3.50 - 14.00	7.06 (± 3.51)
Methane	Effluent	4	0.20 - 6.00	2.83 (± 3.01)

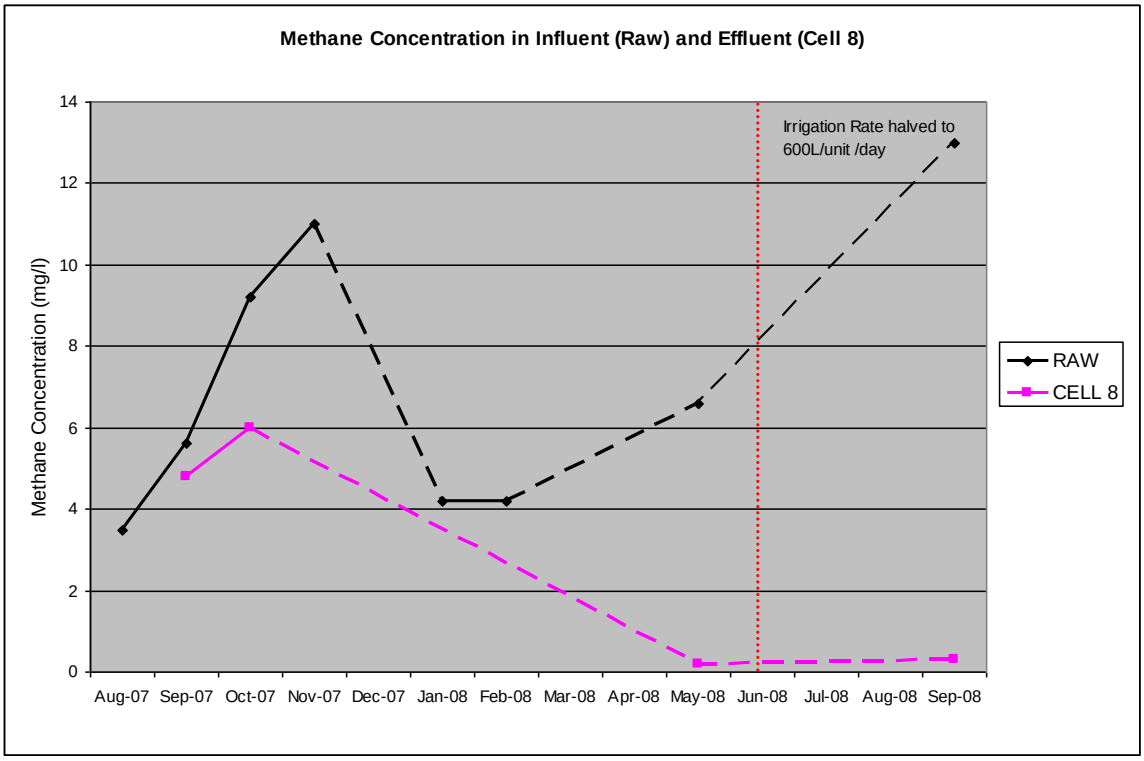


Figure 8.78 Methane Concentrations in Influent (Raw) and Effluent (Cell 8)

8.2.7.2 Dissolved Methane Concentrations in Treatment Units Operating in Sequence

Dissolved methane concentrations for units operating in sequence (Cell 1 – VF 2 – HF2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.79 and 8.80.

Cell 1 - VF 2 - HF 2

Cell 1 – Medium: Coarse Grade Compost

VF2: Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2: Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.79 Dissolved Methane Concentrations for Influent and Effluent (Cell 1 – VF 2 – HF 2)

		Methane Concentration (mg/l)				
Parameter		Nov-07	Dec-07	Jan-08	Feb-08	Mar-08
Methane	Influent (Raw Leachate)	11.00		4.20	4.20	
Methane	Effluent Cell 1	3.50		0.10	0.10	
Methane	Effluent VF 2	0.10				
Methane	Effluent HF 2					

Note: Blank cells = no sample taken

Cell 10 - VF 1 - HF 1

Cell 10 – Medium: Coarse Grade Compost

VF 1: Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 1: Horizontal Flow Reed Bed (*Sparganium sp.)* in Subsoil Matrix

Operational Period: Nov 2007 - March 2008

Note:

Average daily flow = 2400L/unit/day; Area of cells = 2.54m^2; Area of reed beds = 25m^2

Table 8.80 Dissolved Methane Concentrations for Influent and Effluent (Cell 10 – VF 1 – HF 1)

		Methane Concentration (mg/l)				
Parameter		Nov-07	Dec-07	Jan-08	Feb-08	Mar-08
Methane	Influent (Raw Leachate)	11.00		4.20	4.20	
Methane	Effluent Cell 10					
Methane	Effluent VF 1	0.10		≤ 0.01	≤ 0.01	
Methane	Effluent HF 1			≤ 0.01	≤ 0.01	

Note: Blank cells = no sample taken

8.2.7.3 Interpretation of Methane Concentration in Treatment Units

Analysis of the results for dissolved methane concentrations within the influent and effluent from cells 1 to 8 reveals a lower effluent concentration throughout the system.

All cells performed well in reducing dissolved methane concentrations with cells 1, 5 and 7 displaying reduced concentrations of 88%, 86% and 84% respectively (Figures 8.71, 8.75 and 8.77). The remaining units performed good to moderate in reducing dissolved methane concentrations; cells 2 and 3 reduced concentrations by 69% and 70% respectively (Figures 8.72 and 8.73), cell 4 by 35%, cell 6 by 42% and cell 8 by 60% (Figures 8.74, 8.76 and 8.78).

There is a possible seasonal variation in the amount by which dissolved methane effluent concentrations are reduced. The sampling period August to November 2007 displays reductions in effluent concentrations of 30–50% whereas May 2008 reveals up to 99% concentration reduction in a number of cells. Initial influent concentration is likely to play a major role in the treatment efficiency of the various units whereby raw leachate with dissolved methane concentrations in excess of 6mg/l during cooler periods seems to stunt methane oxidation and volatilisation rates within the treatment units.

A 50% reduction in the hydraulic loading rate in the latter stages of operation for cells 5, 6, 7 and 8 seem to have had a positive effect in terms of lower methane concentrations in the treated effluent from cells 5 and 8.

However caution is warranted in making absolute assumptions on a seasonal/influent concentration link due to the low sampling number (typically n = 4).

Looking at the data in Tables 8.79 and 8.80 for influent and effluent concentrations for units operating in sequence, there is an obvious reduction in effluent concentrations as the wastewater moves through the system. However due to the data gaps and low number of samples, no statistical significance can be attached to the results.

Removal Mechanisms

There are two probable mechanisms at work throughout the treatment units for reducing dissolved methane in the wastewater stream; (1) Volatilisation and (2) Bio-Oxidation.

Volatilisation

Volatilisation is the conversion of a liquid to a gas. In relation to dissolved methane in leachate, it refers to the liberation or gassing-off of all or a portion of the methane from the liquid. Methane is more soluble in water than oxygen and in leachate can achieve up to 15mg/l concentration. It is however relatively easy to gas off through the process of air stripping (as explained previously) and through volatilization.

It is likely that the majority of the dissolved methane in the raw leachate dosed to the treatment units was volatilised to atmosphere. The process was enhanced by the splash effect and creation of droplets via the sprinkler system used for effluent distribution throughout the treatment units.

Bio-Oxidation

Bio-oxidation of methane occurs when methanotrophic microorganisms are able to utilise methane in the presence of oxygen. The methane is used as a source of energy and carbon, and is broken down to CO_2 and water. The majority of methanotrophs are mesophilic and occur in abundance, often in narrow bands at the anaerobic – aerobic interface zone.

Bio-oxidation has been used in a number of countries (Austria, Germany, Czech Republic) for the management of low calorific landfill gas (i.e. landfill gas with a methane content below 30%). Typically, the gas is channelled upwards through the biofilter or biocover host material (usually compost) where the methane is oxidized.

The sequence is reversed in the trial treatment plant (methane is delivered in solution from the top down), however, having visited two landfill sites in Austria where methane oxidizing bio-covers were in operation, and conversed with experts in this area, the author is satisfied that bio-oxidation is responsible for reducing a small, as yet unquantified, proportion of the dissolved methane concentrations throughout the trial treatment plant.

8.2.8 Analysis of pH Results

The results from analysis of the pH of the system's influent and effluents are detailed in this section. A series of tables outlining pH results for individual treatment units is presented below in section 8.2.8.1.

Similar tables for pH results for treatment units operating in sequence are presented in section 8.2.8.2 followed by interpretation.

8.2.8.1 pH Results for Individual Treatment Units

pH results for cells 1, 2, 3, 4, 5, 6, 7 and 8 for phase 1 and phase 2 are presented below in Tables 8.81 to 8.88.

Charts detailing the range of pH results for cells 1 to 8 are presented in Figures 8.79 to 8.86.

Cell 1 - Medium: Coarse Grade Compost

Operational Period: August – October 2007

Table 8.81 Summary of pH Results for Cell 1

Parameter		n	Range	Mean (± sd)
pH	Influent	7	7.22 - 7.88	7.41 - (± 0.19)
pH	Effluent	3	7.09 - 7.50	7.28 (± 0.21)

Cell 2 - Medium: Willow Trees in Compost

Operational Period: August 2007 – March 2008

Table 8.82 Summary of pH Results for Cell 2

Parameter		n	Range	Mean (± sd)
pH	Influent	17	7.07 - 7.81	7.35 (± 0.16)
pH	Effluent	7	6.80 - 7.65	7.19 (± 0.29)

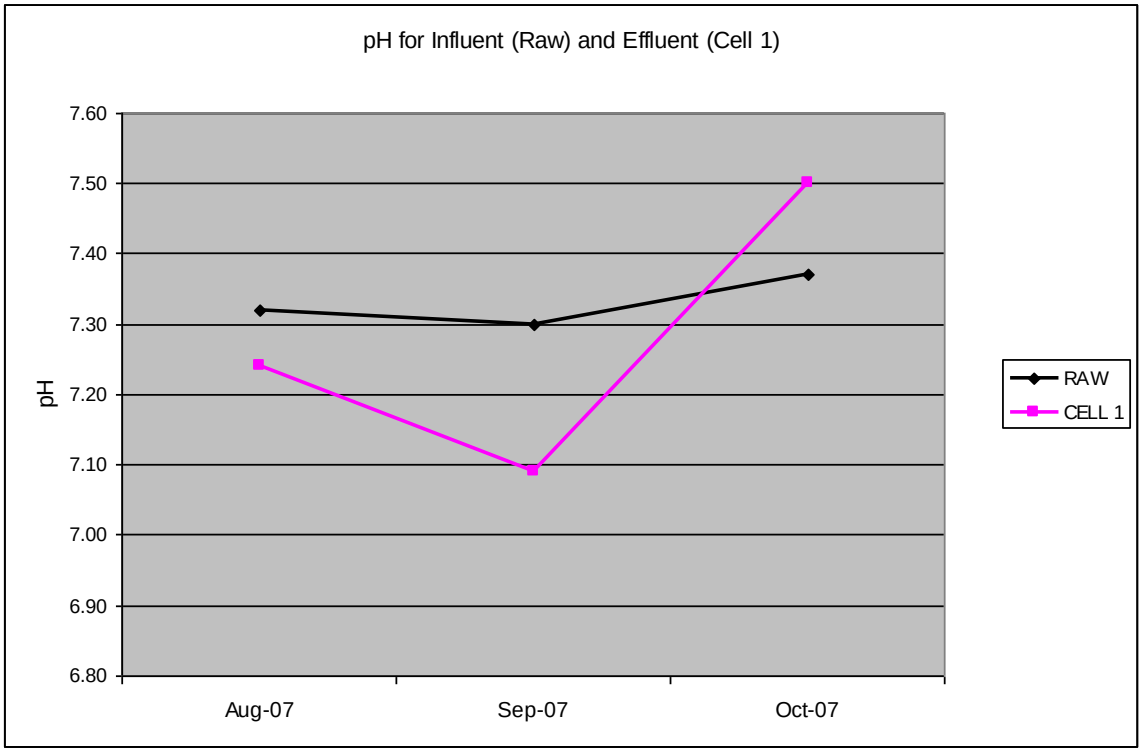


Figure 8.79 pH for Influent (Raw) and Effluent (Cell 1)

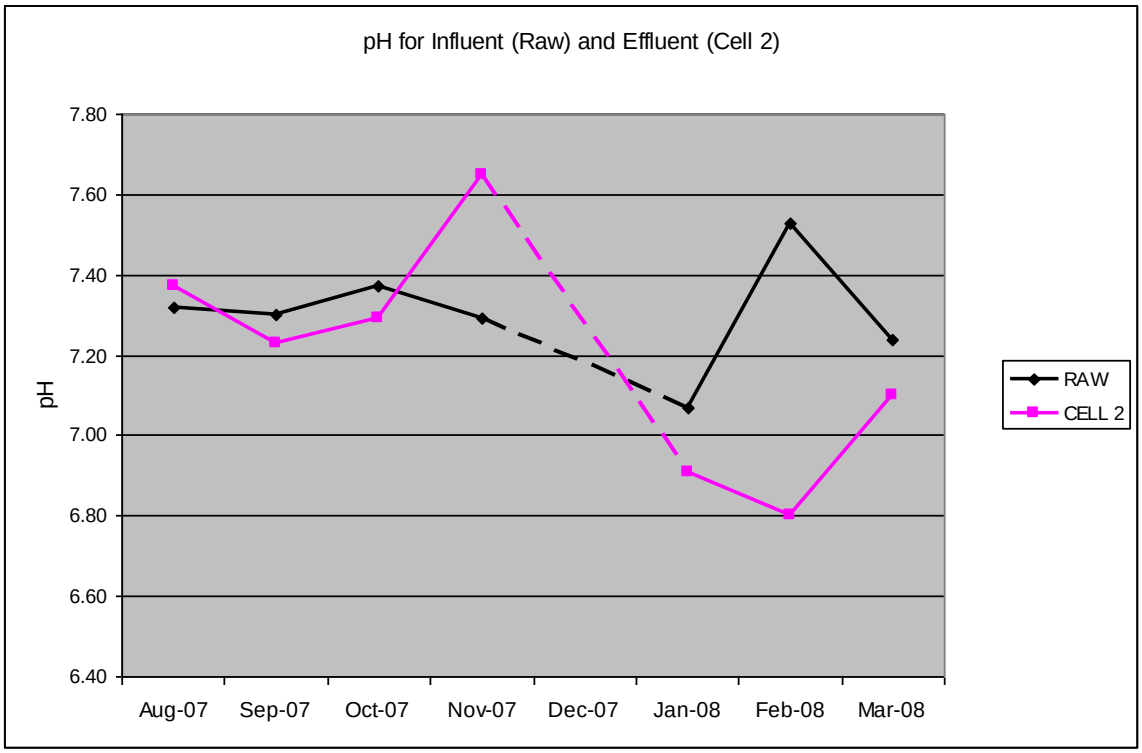


Figure 8.80 pH for Influent (Raw) and Effluent (Cell 2)

Cell 3 – Media: Stratified Sand and Compost

Operational Period: August 2007 – December 2007

Table 8.83 Summary of pH Results for Cell 3

Parameter		n	Range	Mean (± sd)
pH	Influent	10	7.22 - 7.81	7.40 (± 0.17)
pH	Effluent	4	7.12 - 7.84	7.59 (± 0.32)

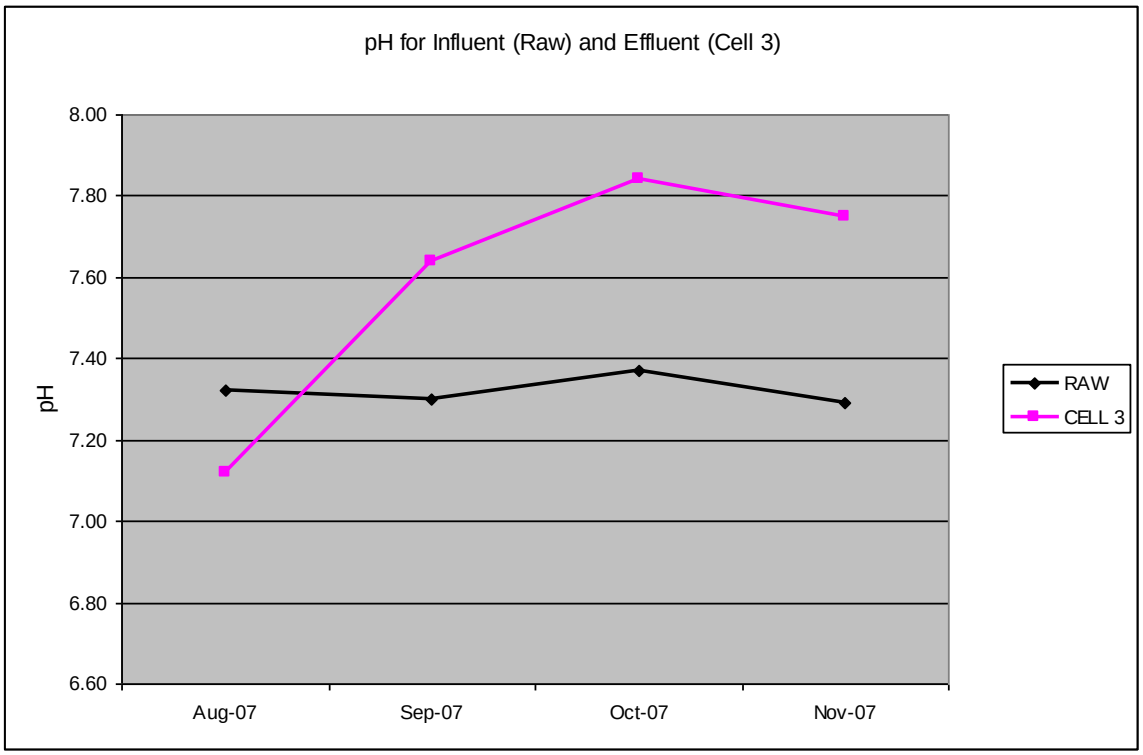


Figure 8.81 pH for Influent (Raw) and Effluent (Cell 3)

Cell 4 – Medium: Fine Grade Compost

Operational Period: August 2007 – April 2008

Table 8.84 Summary of pH Results for Cell 4

Parameter		n	Range	Mean (± sd)
pH	Influent	19	7.07 - 7.81	7.33 (± 0.16)
pH	Effluent	8	7.33 - 7.81	7.52 (± 0.17)

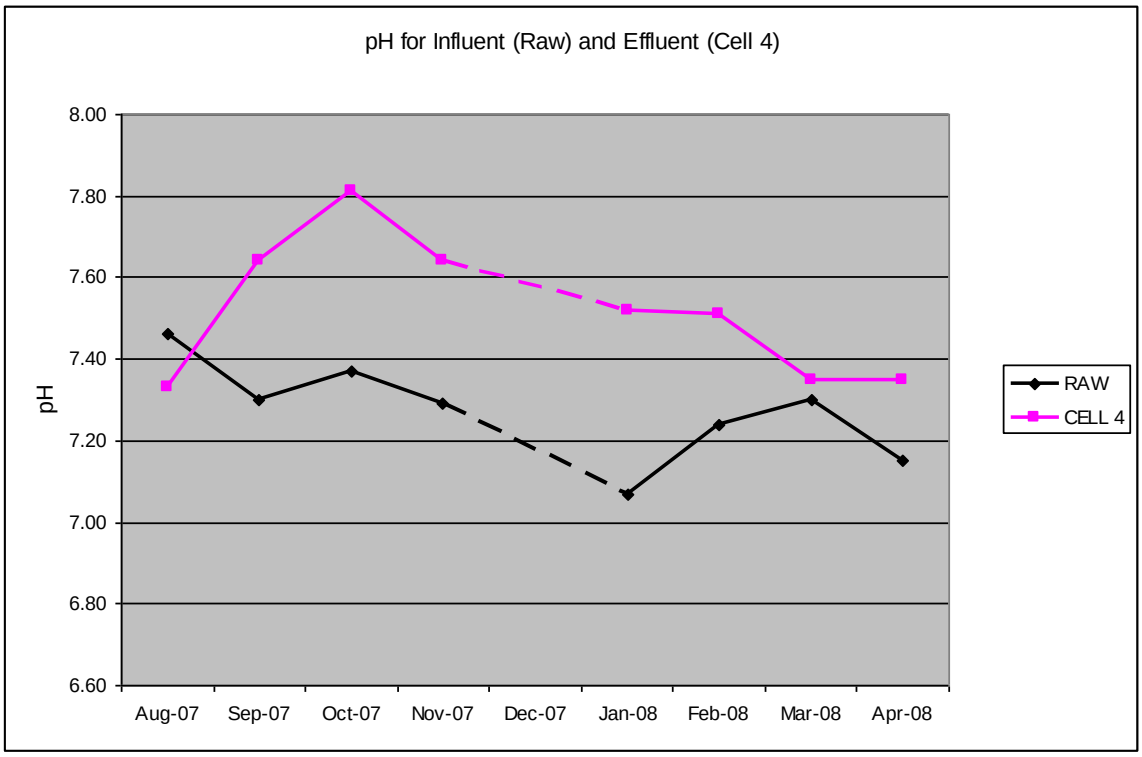


Figure 8.82 pH for Influent (Raw) and Effluent (Cell 4)

Cell 5 - Media: Sand, Grit, Gravel

Operational Period: August 2007 - July 2008

Table 8.85 Summary of pH Results for Cell 5

Parameter		n	Range	Mean (± sd)
pH	Influent	23	7.07 - 7.81	7.33 (± 0.17)
pH	Effluent	7	7.11 - 7.66	7.36 (± 0.20)

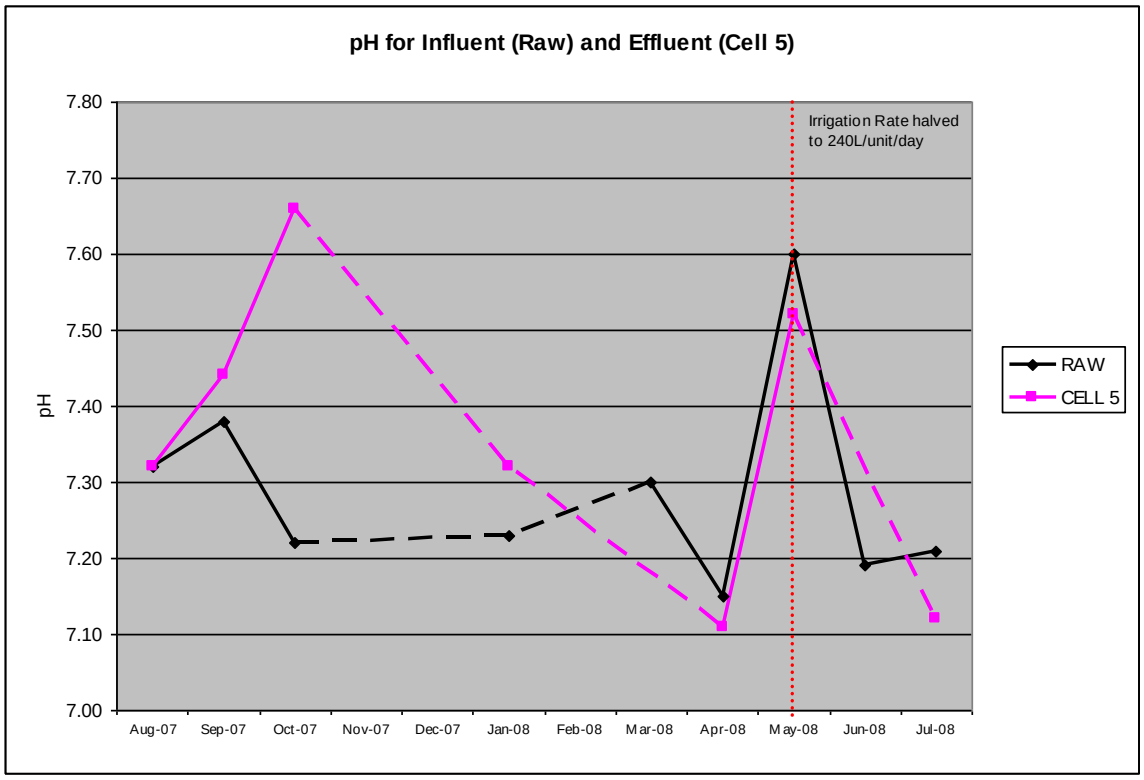


Figure 8.83 pH for Influent (Raw) and Effluent (Cell 5)

Cell 6 – Medium: Willow Trees in Subsoil

Operational Period: August 2007 - June 2008

Table 8.86 Summary of pH Results for Cell 6

Parameter		n	Range	Mean (± sd)
pH	Influent	22	7.07 - 7.81	7.33 (± 0.17)
pH	Effluent	8	7.35 - 7.84	7.61 (± 0.16)

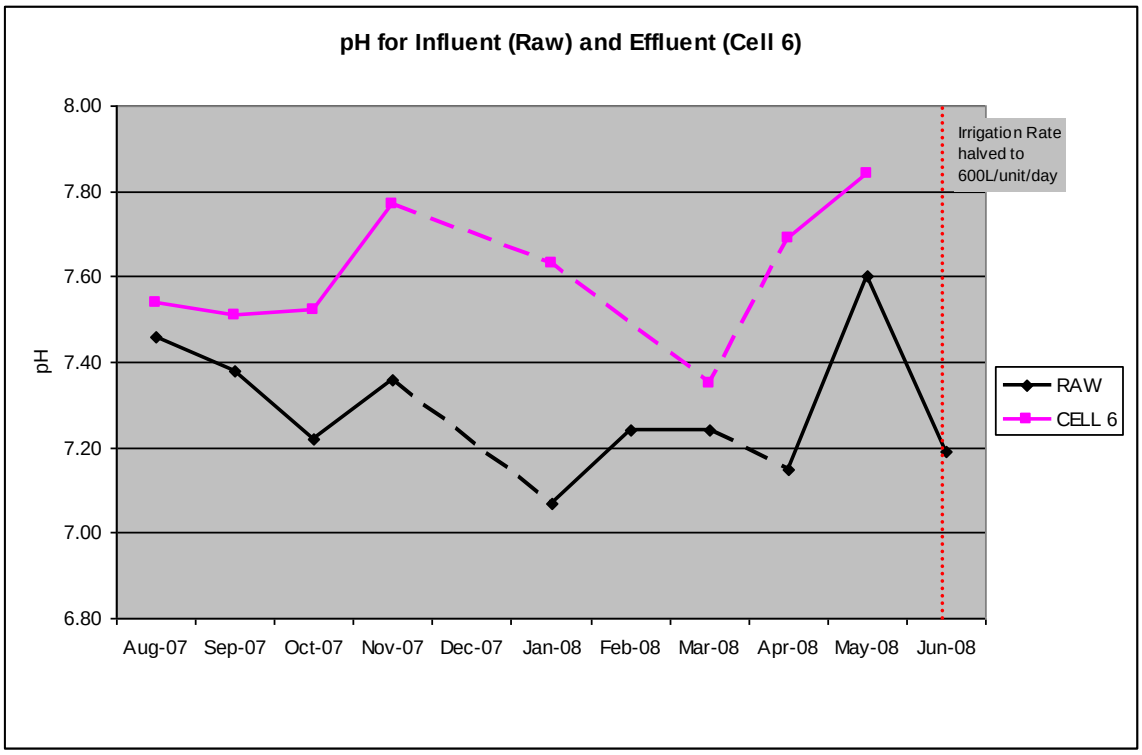


Figure 8.84 pH for Influent (Raw) and Effluent (Cell 6)

Cell 7 - Medium: Subsoil

Operational Period: August 2007 - October 2008

Table 8.87 Summary of pH Results for Cell 7

Parameter		n	Range	Mean (± sd)
pH	Influent	25	7.07 - 7.81	7.32 (± 0.16)
pH	Effluent	11	7.36 - 7.97	7.57 (± 0.18)

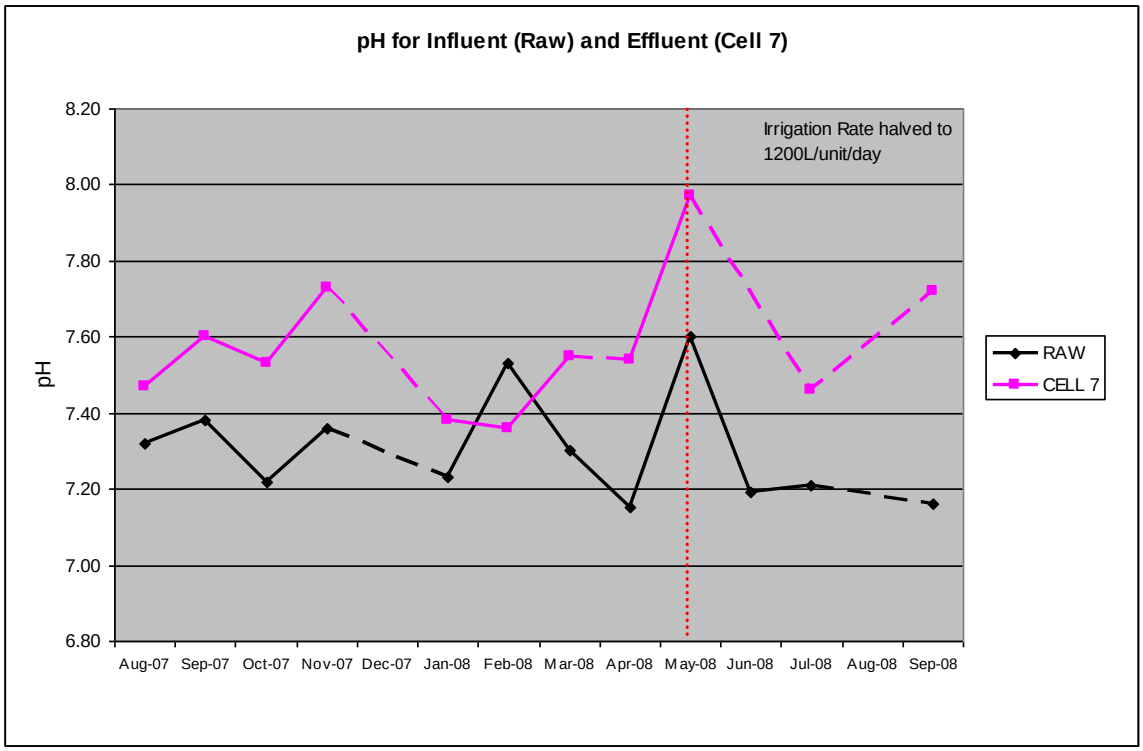


Figure 8.85 pH for Influent (Raw) and Effluent (Cell 7)

Cell 8 - Media: Mixed Soil / Sand / Compost

Operational Period: August 2007 - October 2008

Table 8.88 Summary of pH Results for Cell 8

Parameter		n	Range	Mean (± sd)
pH	Influent	26	7.07 - 7.81	7.32 (± 0.16)
pH	Effluent	8	7.56 - 8.01	7.70 (± 0.16)

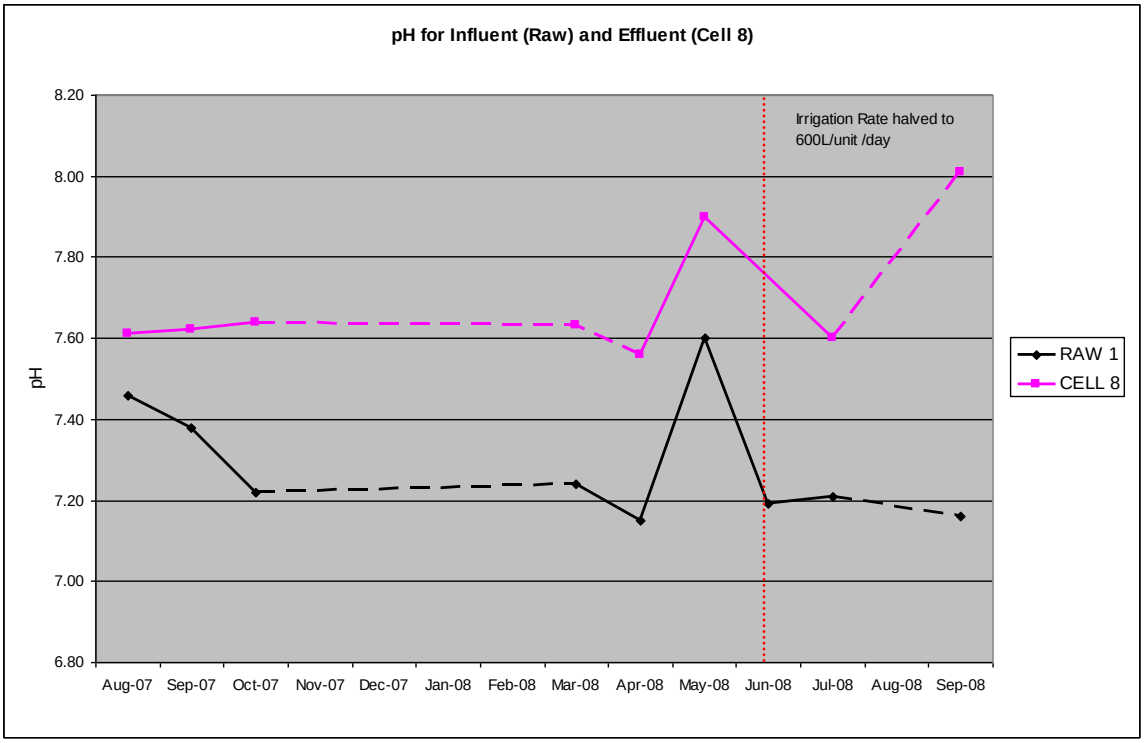


Figure 8.86 pH for Influent (Raw) and Effluent (Cell 8)

8.2.8.2 pH Results for Treatment Units Operating in Sequence

pH results for units operating in sequence (Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1) for phase 2 are presented below in Tables 8.89 and 8.90.

Charts detailing the range of pH results for sequences Cell 1 – VF 2 – HF 2 and Cell 10 – VF 1 – HF 1 are presented in Figures 8.87 and 8.88.

Table 8.89 pH Results for Influent and Effluent (Cell 1 – VF 2 – HF 2)

Parameter		n	Range	Mean (± sd)
pH	Influent (Raw Leachate)	4	7.2 – 7.5	7.3 (± 0.1)
pH	Effluent Cell 1	4	7.3 – 7.8	7.5 (± 0.2)
pH	Effluent VF 2	4	6.9	6.9
pH	Effluent HF 2	4	7.1 – 7.3	7.2 (± 0.1)

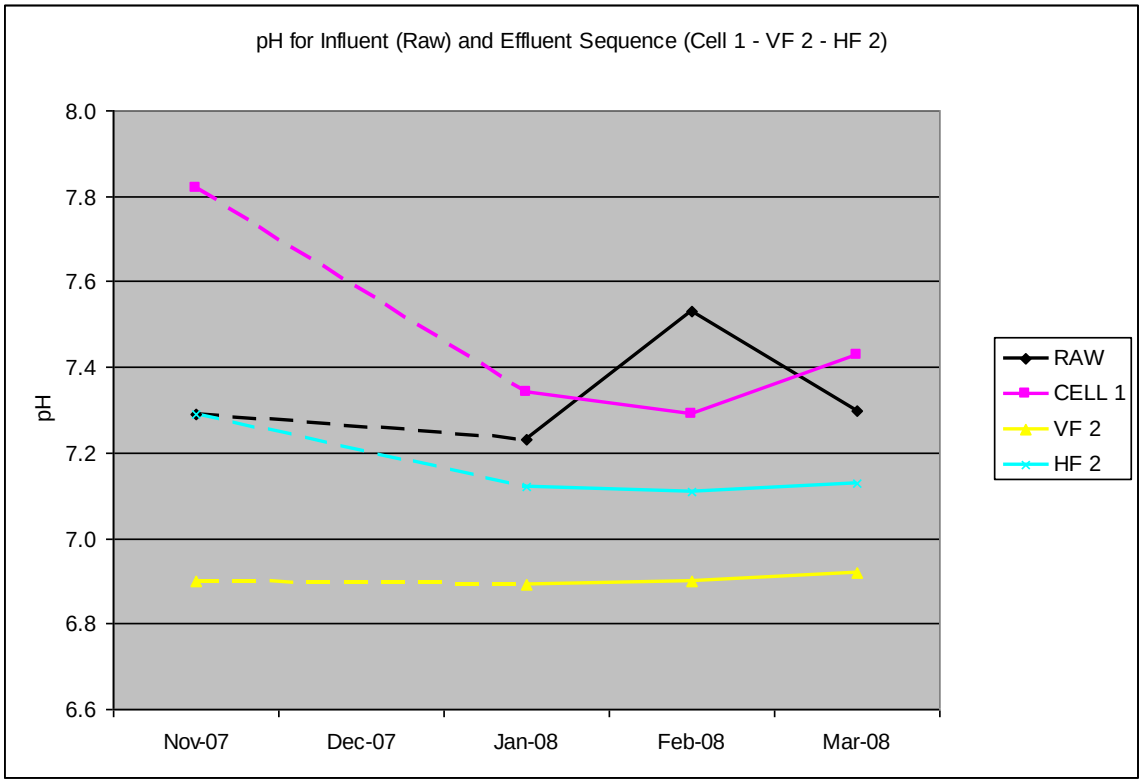


Figure 8.87 pH for Influent (Raw) and Effluent Sequence (Cell 1 – VF 2 – HF 2)

Table 8.90 pH Results for Influent and Effluent (Cell 10 – VF 1 – HF 1)

Parameter		n	Range	Mean (± sd)
pH	Influent (Raw Leachate)	10	7.1 – 7.4	7.2 (± 0.1)
pH	Effluent Cell 10	4	7.2 – 7.6	7.4 (± 0.2)
pH	Effluent VF 1	4	6.8 – 7.0	6.9 (± 0.1)
pH	Effluent HF 1	4	7.2 – 7.5	7.3 (± 0.2)

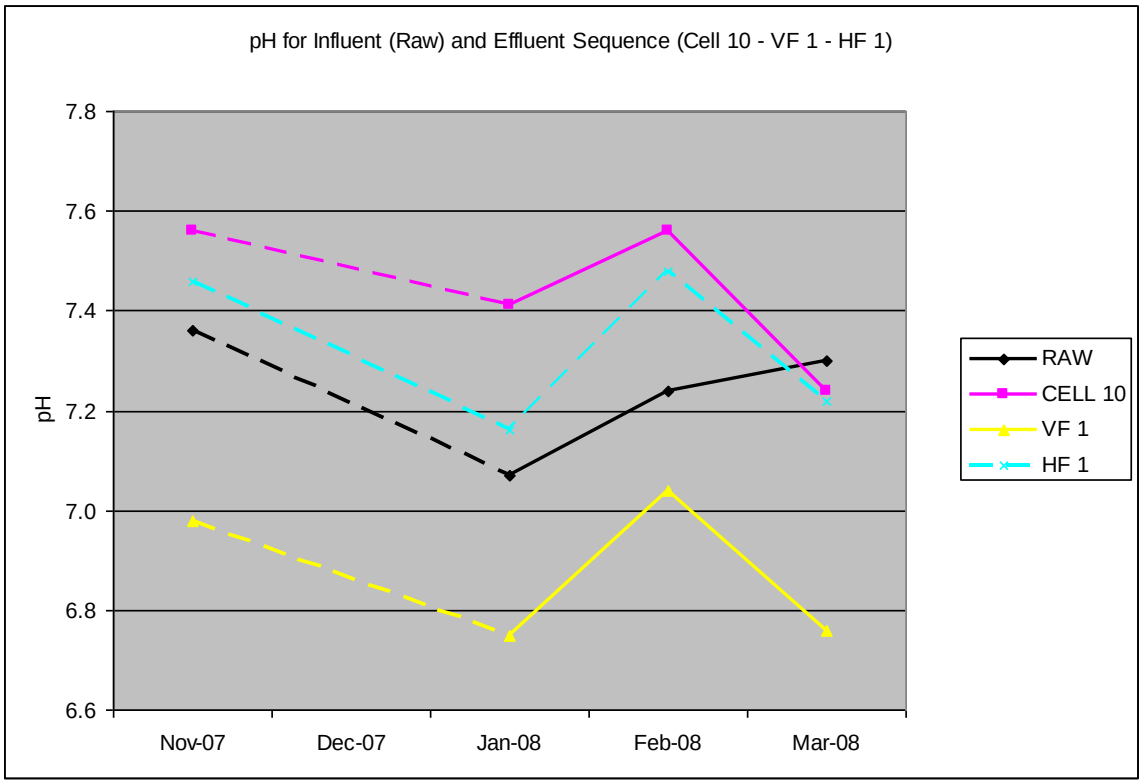


Figure 8.88 pH for Influent (Raw) and Effluent for Sequence (Cell 10 – VF 1 – HF 1)

8.2.8.3 Interpretation of pH Results for Treatment Units

Analysis of the results for pH within the influent and effluent from cells 1 to 8 reveals a lower average pH in the effluent for cells 1 and 2 (Figures 8.79 and 8.80) and a higher average pH value for cells 3 to 8 (Figures 8.81 – 8.86).

Effluent pH for cells 1, 2 and 5 all display fluctuations above and below influent pH throughout the period of sampling whereas cells 3, 4, 6, 7 and 8 all display an increase in effluent pH (with three exceptions).

The pH results for units operating in sequence exhibit fluctuations across the treatment units from influent to effluent. In general, there is a rise in effluent pH from the primary units, followed by a sudden drop in the secondary units' effluent (VF reed beds) with pH again rising in the tertiary effluent (Figures 8.87 and 8.88).

There is likely to be a multitude of explanations for the increase and decrease in effluent pH involving complex biogeochemical reactions between the leachate (often varying in composition and concentration), the treatment media and microbial activity. However, in general for this trial system, fluctuations in pH can be explained by the following mechanisms:

- Nitrification of ammonium to nitrite and nitrate will result in a decrease in pH. For every gram of ammonium oxidised to nitrate, 4.3g of O_2 and 7.14g of alkalinity as $CaCO_3$ is consumed (USEPA, 2000(b));
- Denitrification will cause an increase in pH as alkalinity is recovered by the system;
- Reactions of carbon dioxide (dissolved in leachate) with calcium and magnesium carbonate will create bicarbonates in the soil medium and increase pH;
- Organic acids (humic and fulvic acids) will react to form salts and increase alkalinity (Georgia EPD, 2001);
- Decaying organic matter, algal growth and photosynthesis will tend to raise the pH.

8.3 Phase 3 and Phase 4 Plant Operations – Results and Interpretation

8.3.1 Introduction

Phases 3 and 4 plant operations encompassed the main body of work carried out during the trial treatment project. Results from phases 1 and 2 provided the initial experimental set up for the project during which time treatment units were trialled individually and later in sequence. Lessons were learned regarding leachate application rates, requirements for system maintenance and a significant amount of background knowledge had been gained vis-à-vis pollutant removal efficiencies and non-performing treatment units.

Phases 3 and 4 plant operations ran from August 2008 to October 2010. Throughout this period, new treatment media were trialled, further adjustments to flow rates and sequencing between units was carried out as well as experimentation with denitrification and nitrogen removal techniques.

All fourteen treatment units were in operation at varying stages throughout phases 3 and 4 plant operations and sampling continued until the end of the trial. All results from laboratory analyses are available in Appendix 1. However, in order to avoid repetition, the remainder of this section will focus on units operating in sequence that provided high treatment efficiencies.

The section will be structured as follows:

- Results and interpretation of key wastewater constituents for units operating in sequence
- Results and interpretation of nitrate uptake trials
- Results and interpretation of de-nitrification trials
- Analysis and interpretation of metals and salts
- Analysis and interpretation of List I and List II Substances
- Results and interpretation of Toxicity Tests.

8.3.2 Results and Interpretation of Key Wastewater Constituents for Units Operating in Sequence

Results, analysis and interpretation of key wastewater constituents will be presented for the following units operating in sequence:

- Cell 3 – Cell 5
- Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2
- Cell 7 – Cell 8
- Cell 7 – Cell 8 – VP 1.

Concentrations and interpretation for similar wastewater parameters will also be presented for fresh leachate from the active area (raw active) and for the Tramore River.

It should be noted that sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 operated as three sub-sequences, namely;

- Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2); operated from August 2008 – May 2009 (HF 2 was abandoned in January 2009)
- Cell 9 – Cell 10 – VF 1 – VF 2 –VP 1 – VP2; operated from May 2009 – May 2010
- Cell 9 – Cell 10 – VF 1 – VF 2 –VP2; operated from June 2010 – October 2010

Consequently, some of the figures for influent loading to the succeeding unit within the sequence contain minor errors due to averaging of data (this occurs between VF 2 - VP 1 and VP 1 - VP 2).

8.3.2.1 Ammonium Removal in Treatment Units

Ammonium concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.91(a) to 8.93(f). Concentrations for raw active and the Tramore River are detailed in Tables 8.94 and 8.95. Charts detailing the range of ammonium concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented in Figures 8.89(a) to 8.92(c).

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.91(a) Summary of Ammonium Concentrations for sequence Cell 3 – Cell 5

Ammonium Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	Influent	22	163 - 461	323 (± 85)
Ammonium	Effluent Cell 3	22	7 - 302	86 (± 79)
Ammonium	Effluent Cell 5	21	0 - 197	31 (± 48)

Table 8.91(b) Summary of Ammonium Load Removal per m^2 for Cell 3 – Cell 5

Ammonium	**CELL 3**	**CELL 5**
Influent Load g/m^2/day	32	9
Effluent Load g/m^2/day	9	3
Load Removal g/m^2/day	23	6
Cumulative Load Removal g/m^2/day	23	29
Cumulative Load Removal as % per m^2	71	90

Table 8.91(c) Summary of Ammonium Load Removal per unit for Cell 3 – Cell 5

Ammonium	**CELL 3**	**CELL 5**
Influent Load g/unit/day	82	23
Effluent Load g/unit/day	23	8
Load Removal g/unit/day	58	15
Cumulative Load Removal g/unit/day	58	73
Cumulative Load Removal as % per unit	71	90

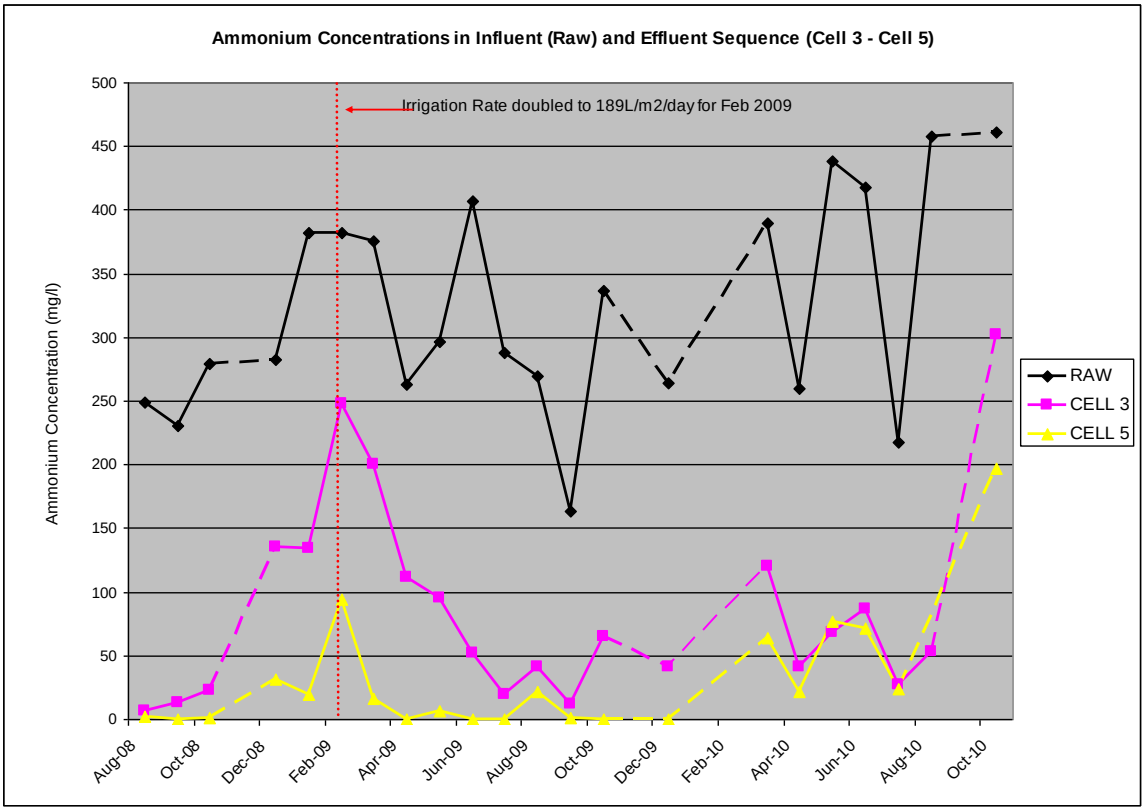


Figure 8.89(a) Ammonium Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

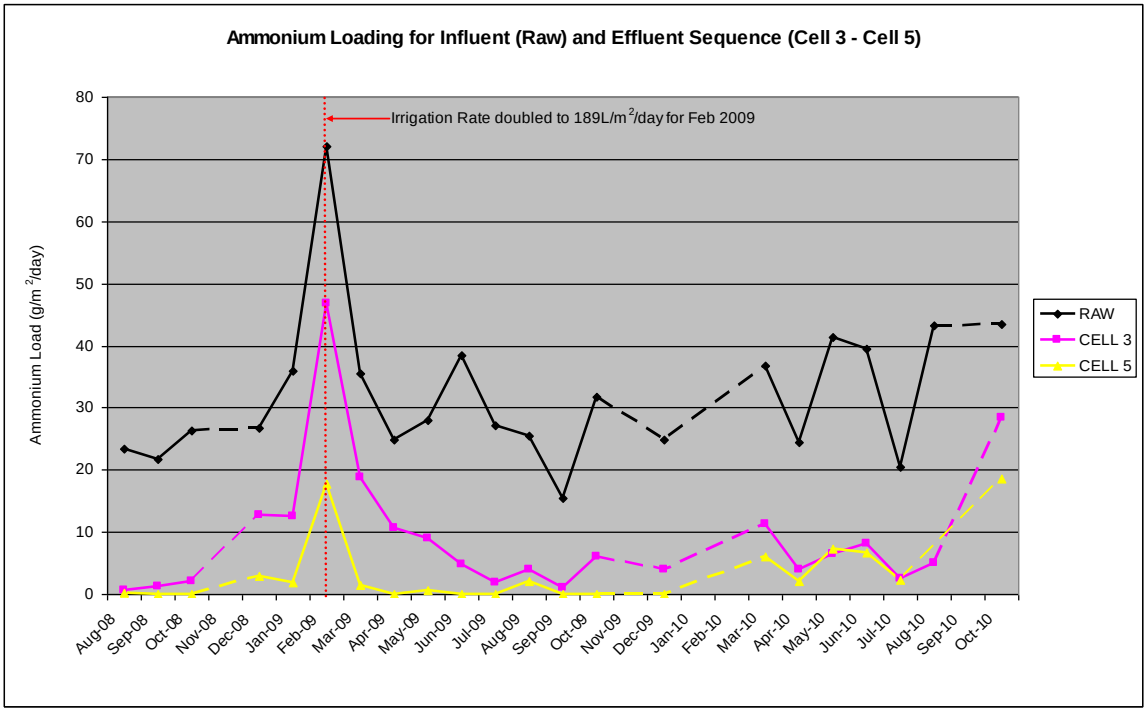


Figure 8.89(b) Ammonium Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost/Coarse Compost and Timber Chippings*

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix*

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Note* Media change in Cell 10 in June 2009 from Coarse Compost to Coarse Compost and Timber Chippings

Media change in HF 2 in April 2009, converted to Vegetated Grass Plane (VP 2)

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.92(a) Summary of Ammonium Concentration for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Ammonium Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	Influent	22	163 - 461	323 (± 85)
Ammonium	Effluent Cell 9	22	76 - 444	246 (± 104)
Ammonium	Effluent Cell 10	22	3 - 309	132 (± 86)
Ammonium	Effluent VF 1	22	0 - 207	42 (± 55)
Ammonium	Effluent VF 2	22	0 - 73	12 (± 18)
Ammonium	Effluent HF 2	5	1.0 - 41	21 (± 18)
Ammonium	Effluent VP 1	10	0 - 25	7 (± 9)
Ammonium	Effluent VP 2	14	0 - 18	3 (± 5)

Table 8.92(b) Summary of Ammonium Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Ammonium	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load $g/m^2/day$	284	218	12	4	1	1.12	0.62
Effluent Load $g/m^2/day$	218	118	4	1	2	0.62	0.28
Load Removal $g/m^2/day$	66	100	8	3	-1	0.49	0.34
Cumulative Load Removal $g/m^2/day$	66	165	173	176	175	177	177.03

Table 8.92(c) Summary of Ammonium Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Ammonium	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Influent Load g/unit/day	720	553	300	99	28	28	16
Effluent Load g/unit/day	553	300	99	28	50	16	7
Load Removal g/unit/day	167	253	202	71	-22	12	9
Cumulative Load Removal g/unit/day	167	420	621	692	670	705	713
Cumulative Load Removal as % per unit	23	58	86	96	93	98	99

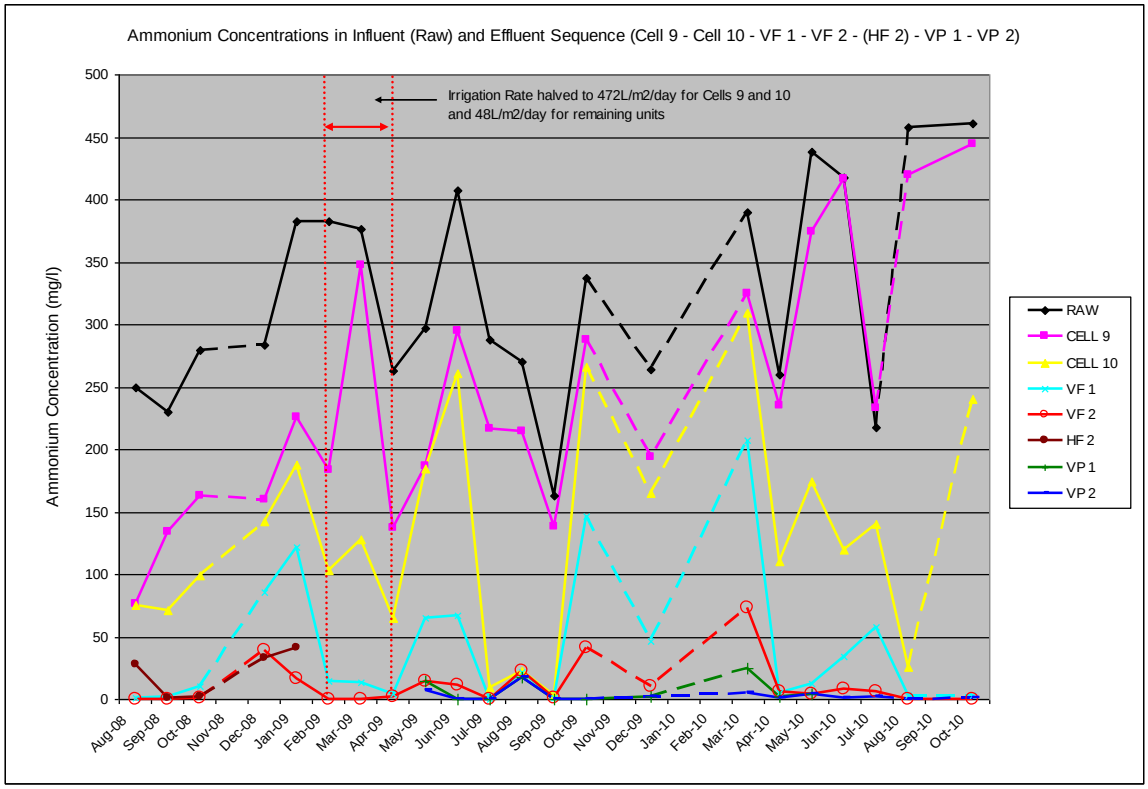


Figure 8.90(a) Ammonium Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

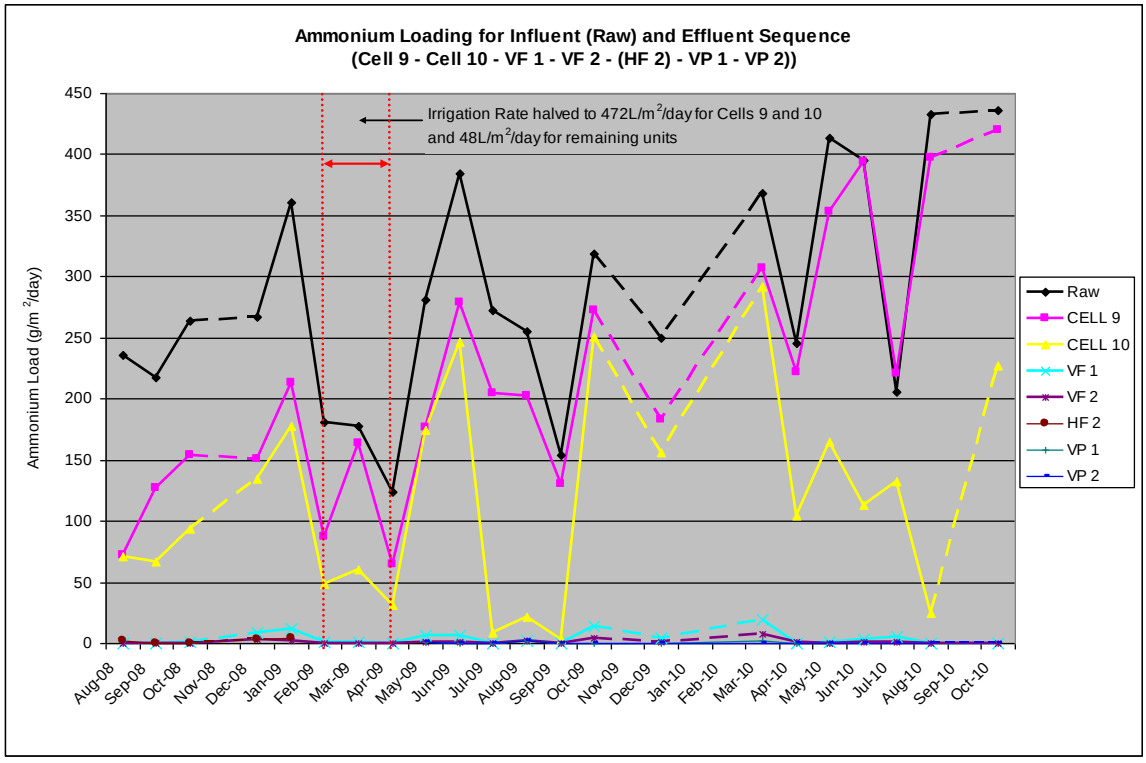


Figure 8.90(b) Ammonium Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

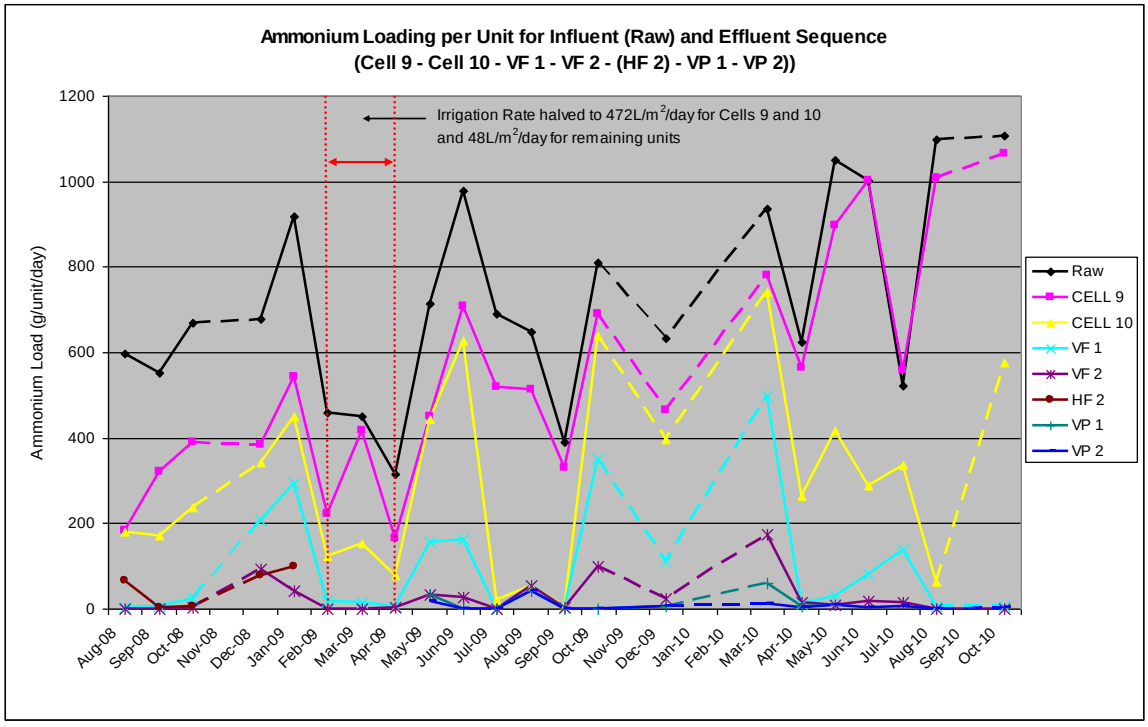


Figure 8.90(c) Ammonium Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.93(a) Summary of Ammonium Concentrations for sequence Cell 7 – Cell 8

Ammonium Concentration (Raw - Cell 7 – Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	Influent	9	163 - 438	313 (± 87)
Ammonium	Effluent Cell 7	9	59 - 229	141 (± 58)
Ammonium	Effluent Cell 8	9	16 - 114	59 (± 36)

Table 8.93(b) Summary of Ammonium Load Removal per m^2 for Cell 7 – Cell 8

Ammonium	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	295	133
Effluent Load g/m^2/day	133	56
Load Removal g/m^2/day	162	77
Cumulative Load Removal g/m^2/day	162	239
Cumulative Load Removal as % per m^2	55	81

Table 8.93(c) Summary of Ammonium Load Removal per unit for Cell 7 – Cell 8

Ammonium	**CELL 7**	**CELL 8**
Influent Load g/unit/day	751	338
Effluent Load g/unit/day	338	143
Load Removal g/unit/day	413	195
Cumulative Load Removal g/unit/day	413	609
Cumulative Load Removal as % per unit	55	81

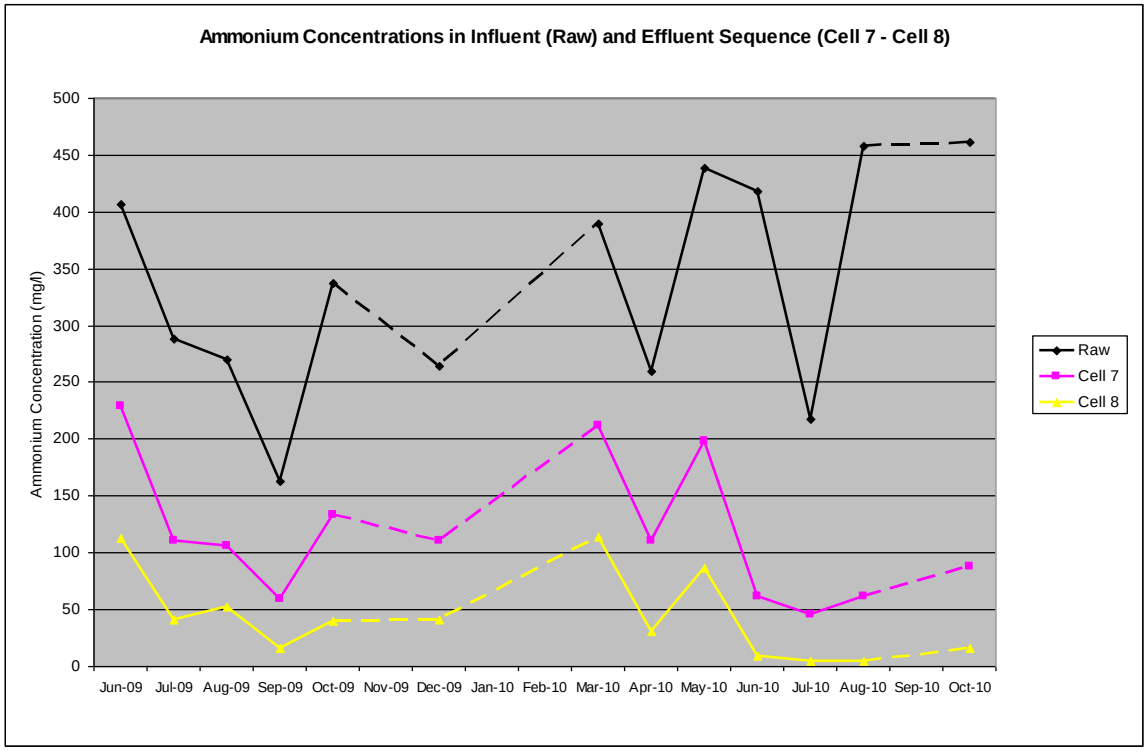


Figure 8.91(a) Ammonium Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

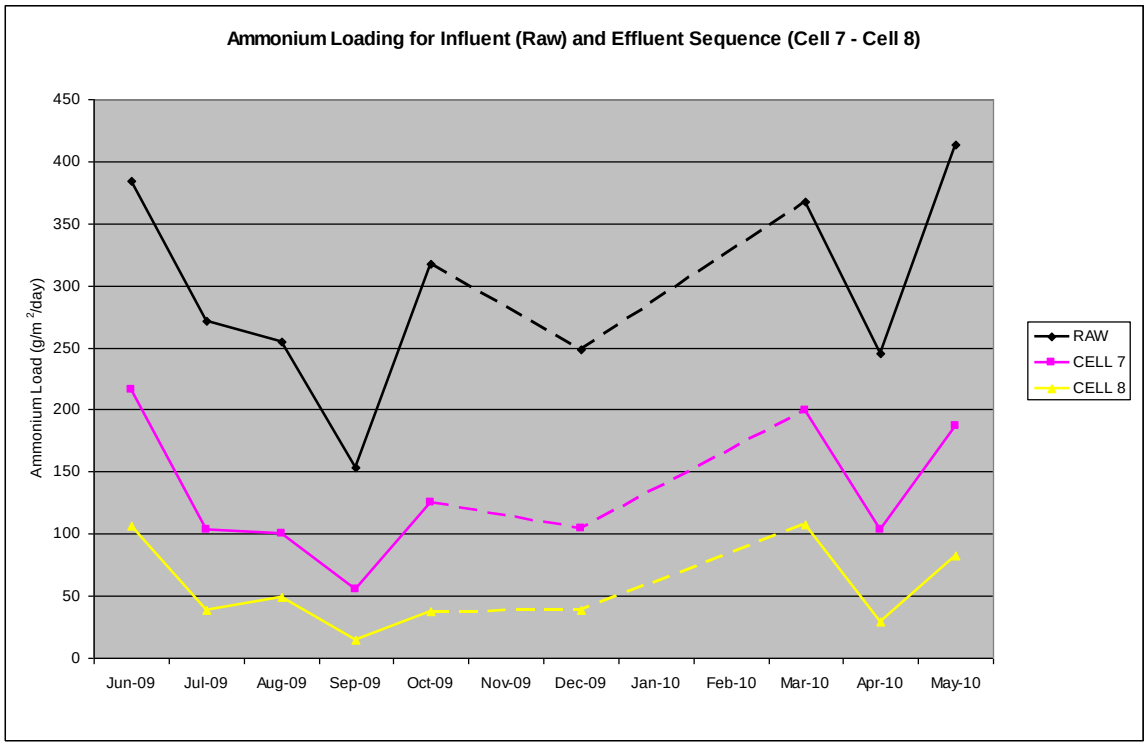


Figure 8.91(b) Ammonium Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Operational Period: June 2010 – October 2010

Average daily flow = 600L/unit/day

Table 8.93(d) Summary of Ammonium Concentrations for sequence Cell 7 – Cell 8 – VP 1

Ammonium Concentration (Raw - Cell 7 - Cell 8 - (VP 1))				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	Influent	4	218 - 461	389 (± 116)
Ammonium	Effluent Cell 7	4	45 - 88	64 (± 18)
Ammonium	Effluent Cell 8	4	4 - 16	8 (± 6)
Ammonium	Effluent VP 1	4	0 - 1	1 (± 1)

Table 8.93(e) Summary of Ammonium Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

Ammonium	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/m^2/day	92	15	0.20
Effluent Load g/m^2/day	15	2	0.01
Load Removal g/m^2/day	77	13	0.2
Cumulative Load Removal g/m^2/day	77	90	90

Table 8.93(f) Summary of Ammonium Load Removal per unit for Cell 7 – Cell 8 – VP 1

Ammonium	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/unit/day	233	38	5
Effluent Load g/unit/day	38	5	0.3
Load Removal g/unit/day	195	33	4.7
Cumulative Load Removal g/unit/day	195	228	233
Cumulative Load Removal as % per unit	84	98	99.9

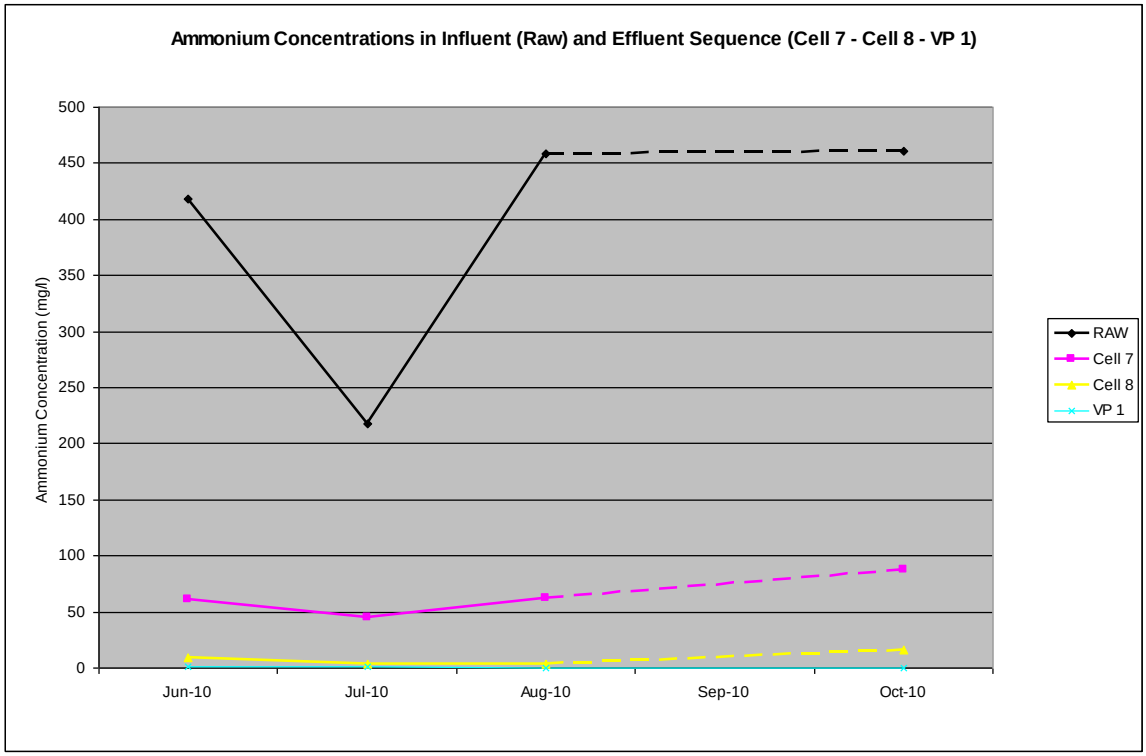


Figure 8.92(a) Ammonium Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

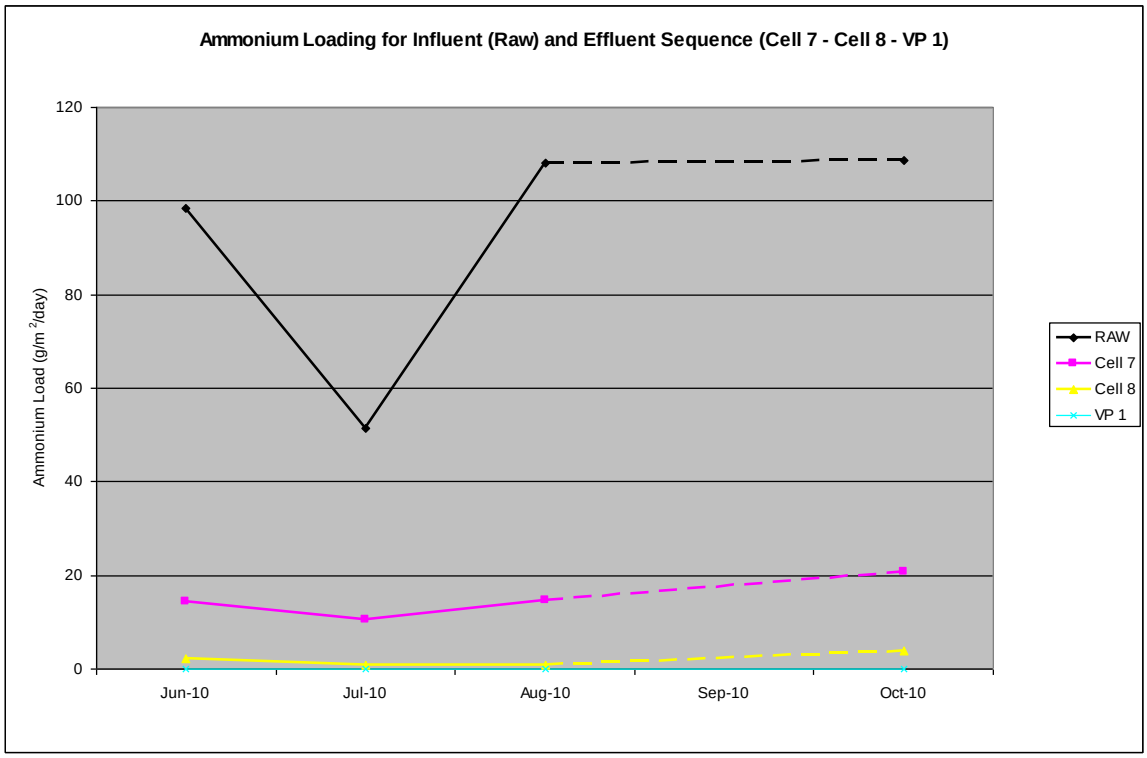


Figure 8.92(b) Ammonium Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

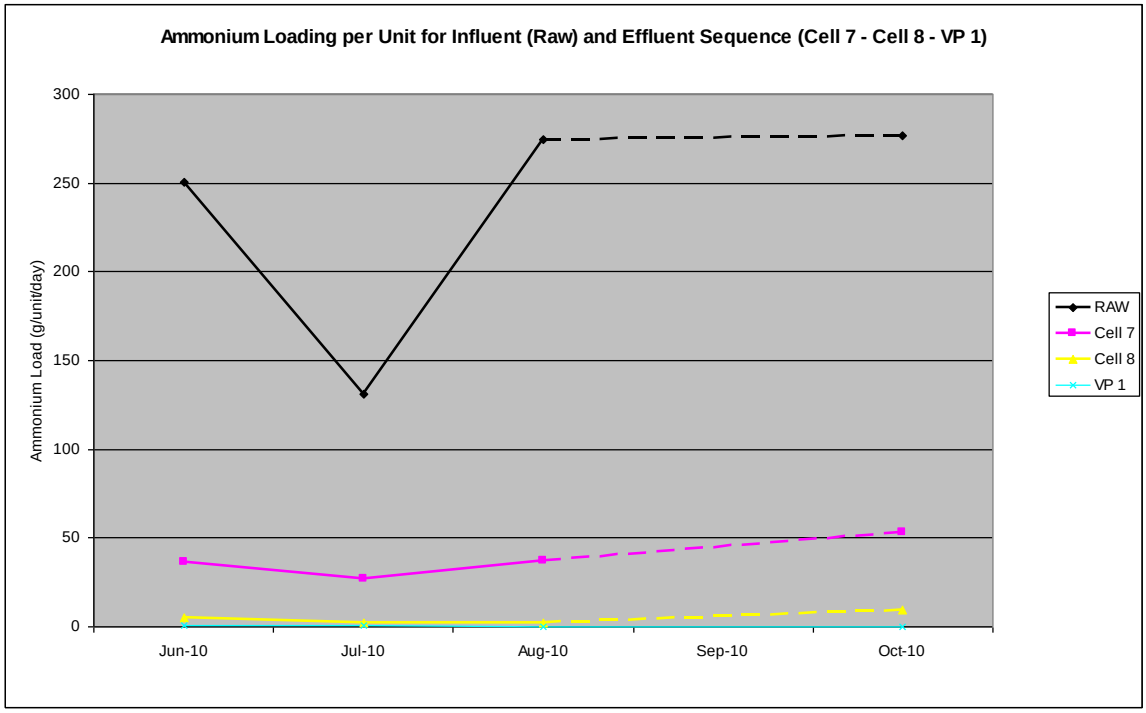


Figure 8.92(c) Ammonium Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Fresh Leachate (Raw Active)

Monitoring Period: May 2009 - August 2010

Table 8.94 Summary of Ammonium Concentrations for Fresh Leachate from Active Area

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	13	70 - 1380	459 (± 432)

Tramore River

Monitoring Period: June 2009 - October 2010

Table 8.95 Summary of Ammonium Concentrations in Tramore River

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
Ammonium	13	0.03 - 3	1.16 (± 0.89)

Interpretation of Ammonium Removal in Treatment Units

Inspection of the results obtained for ammonium load removal rates for all treatment units operating in sequence for phases 3 and 4 reveals a high degree of treatment efficiency throughout.

Average load removal for Cells 3 and 5 amounted to 23g/m^2/day and 6g/m2/day respectively with a cumulative load removal of 29g/m^2/day (90% NH_4 load removal) at an average application rate of 98l/m^2/day.

Charts detailing the range of ammonium concentrations and loadings to Cell 3 – Cell 5 are presented in Figures 8.89(a) and 8.89(b). Effluent loads from cell 3 and cell 5 display positive load removal throughout the trial period (August 2008 – October 2010) with a maximum load removal of 38g/m^2/day achieved in cell 3 effluent in August 2010 and a maximum load removal of 29g/m^2/day recorded in cell 5 effluent in February 2009. The obvious spike in influent and effluent loads in February 2009 was due to a doubling of the irrigation rate to 189L/m^2/day. This irrigation rate was trialled for one month only to access the treatment potential of each unit in the sequence. Due to higher than expected ammonium concentration in the final effluent (cell 5) of 94mg/l, it was decided to revert back to the original application rate of 94.5L/m^2/day.

The average ammonium load removal at sequence end for Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 was 713g/unit/day, down from an average influent load of 720g/unit/day. This represents a 99% load removal rate with an average NH_4 concentration of 3mg/l in the final effluent.

The majority of ammonium load removal was effected in the primary, secondary and tertiary units (cell 9, cell 10 and VF 1) where average load removal rates of 167g/unit/day (23% removal), 253g/unit/day (46% removal) and 202g/unit/day (67% removal) were recorded respectively.

The charts detailing the range of ammonium concentrations and loadings to sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2; presented in Figures 8.90(a) to 8.90(c); display a high variability in terms of load removal across the trial period with the results for the first four treatment units in the sequence tending to follow the peaks and troughs of the influent load at progressively lower loading levels.

The final two units in the sequence (VP 1 and VP 2) displayed much less variability throughout the trial, providing steady load removal with final effluent loads ranging from 43g/unit/day (one off high) to below detection levels. Complete load removal was accomplished in five of the 14 tested samples.

The irrigation rate to the sequence was halved to 1200L/unit/day for a three month period (February to April 2009) to assess the effect in terms of system treatment efficiency. This resulted in a significant increase in treatment efficiency (Figure 8.90(c)), with two of the three samples tested revealing complete NH_4 load removal in the final effluent in VF 2 (i.e. the fourth unit in the sequence).

In May 2009, with the further addition of two treatment units to the sequence (vegetated grass planes, VP 1 and VP 2), it was decided to revert back to the original application rate of 2400L/unit/day

Cells 7 and 8 revealed a load removal of 162gNH_4/m^2/day (55% removal) and 77g NH_4/m^2/day (58% removal) respectively. The cumulative load removal was 239g/m^2/day, representing a removal rate of 81% at an irrigation rate of 945L/m^2/day.

The range of ammonium concentrations and loadings to sequence Cell 7 – Cell 8 are presented in Figures 8.91(a) and 8.91(b).

The average cumulative load removal from sequence Cell 7 – Cell 8 - VP 1 was 232.95g/unit/day, down from an initial influent load of 233g/unit/day. This represents a 99.9% load removal rate with an average NH_4 concentration of 1mg/l in the final effluent. The primary treatment unit, cell 7, was responsible for 84% load removal from the system (77g/m^2/day or 195g/unit/day) with cell 8 and VP 1 providing final effluent polishing. This high degree of treatment was achieved at an irrigation rate of 600L/unit/day (236L/m^2/day for cells 7 and 8, 24L/m^2/day for VP 1).

The range of ammonium concentrations and loadings to sequence Cell 7 – Cell 8 – VP 1 are presented in Figures 8.92(a) to 8.92(c).

The final average NH_4 effluent concentrations for the sequences were as follows:

- Cell 3 – Cell 5, NH_4 = 31mg/l
- Cell 9 – 10 – VF 1 – VF 2 – VP 1 – VP 2, NH_4 = 3 mg/l
- Cell 7 – Cell 8, NH_4 = 59mg/l
- Cell 7 – Cell 8 – VP 1, NH_4 = 1mg/l

The average final effluent concentrations for sequences Cell 9 ↛ VP 2 and Cell 7 ↛ VP 1 would meet the EPA emission limit value (ELV) of 5mg/l NH_4 for discharge to river provided that the quality of the receiving water is not impaired and assuming a minimum of 5 dilutions (in the receiving water) during dry weather flow (EPA, 2008).

However, a note of caution is called for in reading the averaged results for these sequences of high performing treatment units; for Cell 7 ↛ VP 1, all three units operated for five months (June – October 2010) at a much reduced irrigation rate of 600l/unit/day and it is unlikely that VP 1 effluent would have been within the ELV for river discharge at the higher average application rate of 2400 l/unit/day. The averaged data are reflective of the actual results for sequence Cell 9 ↛ VP 2 with an added reminder that for the period August 2008 to January 2009 the sequence comprised of only five units, Cells 9 and 10, VF 1, VF 2 and HF 2. The average final effluent NH_4 concentration from HF 2 (21 mg/l) did not attain the ELV for discharge to river.

Results for the Tramore River, i.e. the potential receiving medium in the event of trial plant up-scaling and granting of a discharge consent, showed average ammonium concentrations of 1.16 mg/l with a range of 0.03 – 3mg/l.

A measurement of river flow taken on the 29th June 2009 revealed that ammonium discharge concentration from VP 2 (0.1mg/l) would have met the EPA discharge criteria. River flow on the day was measured using a handheld flow probe (FP111 Digital Handheld Water Velocity Meter – www.globalw.com) at 139 litres per second (12,052m^3/day) and river NH_4 concentration was measured at 1 mg/l. Given that total leachate discharge from the landfill site was 396m^3 on the day, the five dilutions requirement was also satisfied. The author realises that this was just a one-off snapshot of the situation (typically dry weather flow and the 95 percentile flow would be required for

an assessment of river flow); it is however an indicator of the potential treatment efficiencies of the system.

Fresh leachate emanating from the waste tipping area was sampled from a nearby sump for the period May 2009 - August 2010. The aim of sampling this leachate stream was to compare and contrast results from leachate that had filtered through the waste body and was later collected for treatment in the methane stripping plant (with a portion siphoned off for treatment in the trial plant).

A comparison of each leachate stream shows a much higher strength leachate from the active area with an average ammonium concentration of 459mg/l as opposed to 323mg/l for the filtered leachate. More interesting is the variability in the concentration range; leachate from the active tipping area (raw active) ranged from 70mg/l to 1380mg/l and the filtered leachate ranged from 163mg/l to 461mg/l. It is likely that the raw active leachate had a faster response time to changes in local conditions; i.e. high pulse rainfall events (resulting in a diluted leachate) and high organic inputs in the waste stream. The filtered leachate on the other hand was much less variable and had time to mix with leachate of different ages and from different locations across the site. The strength of this leachate stream was also reduced through biogeochemical reactions within the waste body and at the clay/gravel interface zone at the base of the landfill.

8.3.2.2 Organics Removal in Treatment Units

The removal of organics from the system in the form of Biological Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) is detailed in this section. A series of tables outlining BOD_5 and COD removal within treatment units operating in sequence is presented below followed by interpretation.

BOD_5 Removal

BOD_5 concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.96(a) to 8.98(f). Concentrations for raw active and the Tramore River are detailed in Tables 8.99 and 8.100.

Charts detailing the range of BOD concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented in Figures 8.93(a) to 8.96(c).

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.96(a) Summary of BOD Concentrations for sequence Cell 3 – Cell 5

BOD Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
BOD	Influent	18	5.0 - 40	20 (± 8)
BOD	Effluent Cell 3	18	2.0 - 95	22 (± 23)
BOD	Effluent Cell 5	18	1.0 - 35	11 (± 13)

Table 8.96(b) Summary of BOD Load Removal per m^2 for Cell 3 – Cell 5

BOD	**CELL 3**	**CELL 5**
Influent Load g/m^2/day	1.99	2.56
Effluent Load g/m^2/day	2.56	1.27
Load Removal g/m^2/day	-0.57	1.30
Cumulative Load Removal g/m^2/day	-0.57	0.73
Cumulative Load Removal as % per m^2	-29	36

Table 8.96(c) Summary of BOD Load Removal per unit for Cell 3 – Cell 5

BOD	CELL 3	CELL 5
Influent Load g/unit/day	4.80	6.17
Effluent Load g/unit/day	6.17	3.05
Load Removal g/unit/day	-1.37	3.12
Cumulative Load Removal g/unit/day	-1.37	1.75
Cumulative Load Removal as % per unit	-29	36

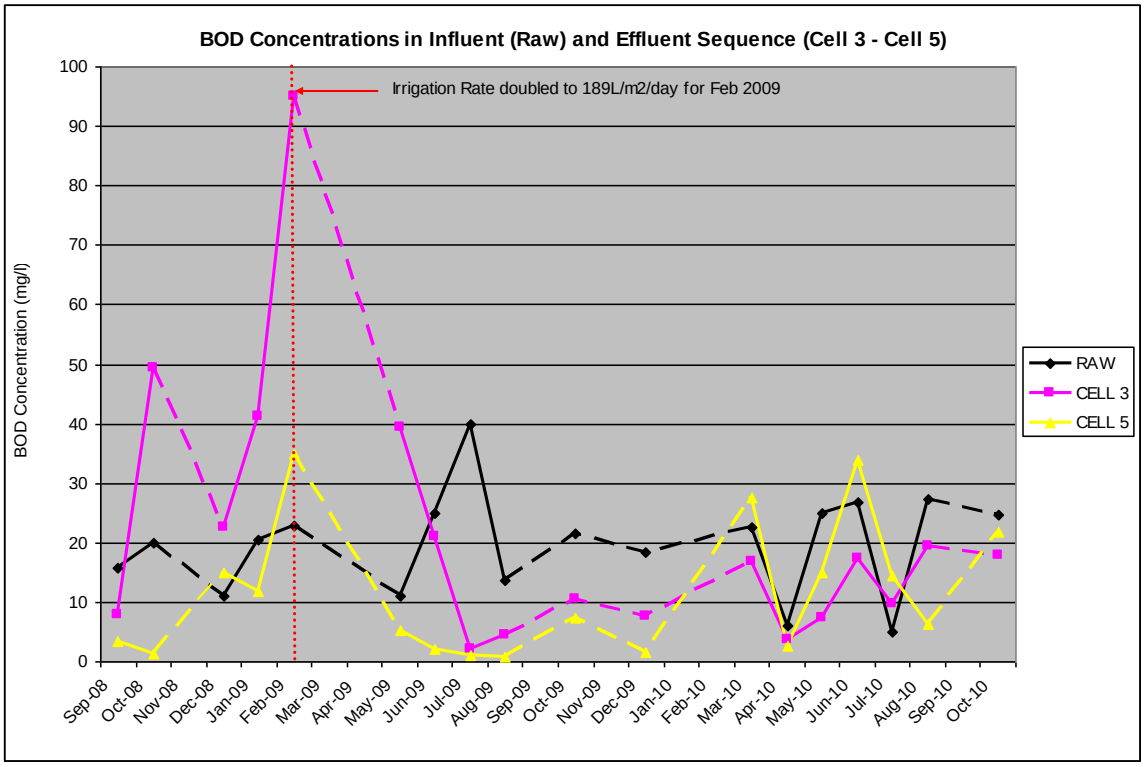


Figure 8.93(a) BOD Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

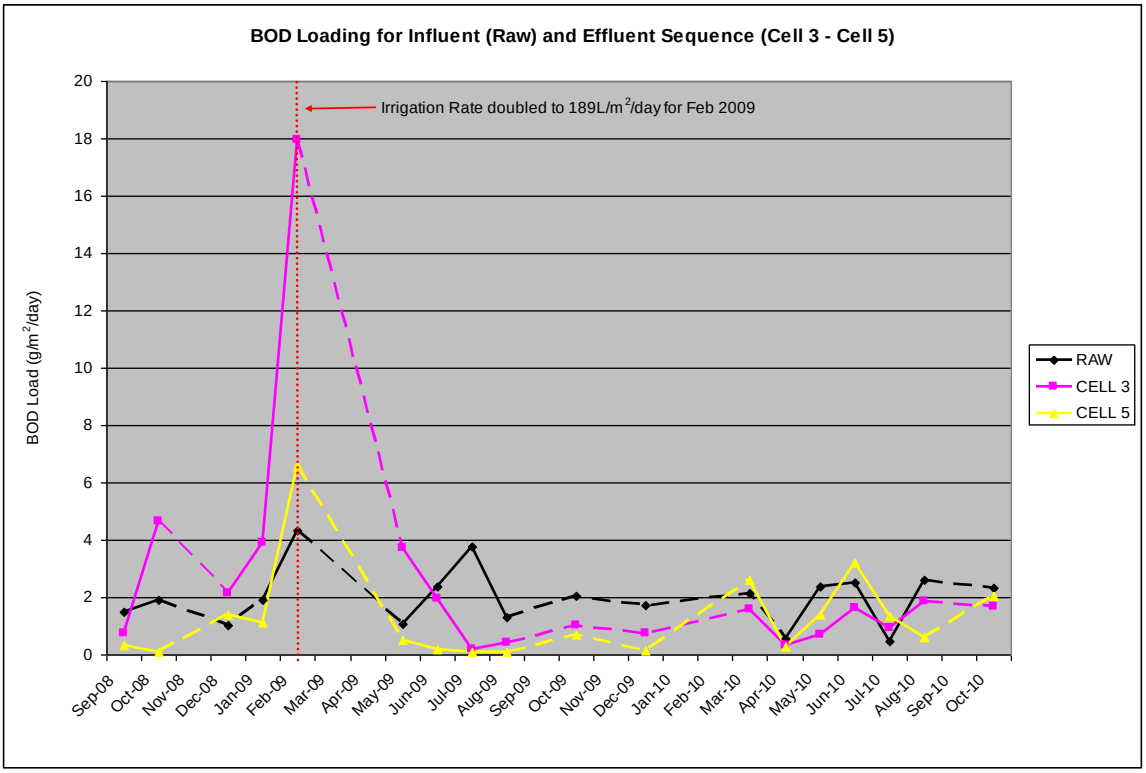


Figure 8.93(b) BOD Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.97(a) Summary of BOD Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

BOD Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
BOD	Influent	18	5 – 40	20 (± 8)
BOD	Effluent Cell 9	18	5 - 40	29 (± 19)
BOD	Effluent Cell 10	18	2 - 83	28 (± 25)
BOD	Effluent VF 1	17	1 - 58	14 (± 16)
BOD	Effluent VF 2	17	1 - 31	6 (± 8)
BOD	Effluent HF 2	4	0.40 - 14	5 (± 6)
BOD	Effluent VP 1	9	0.35 - 19	4 (± 6)
BOD	Effluent VP 2	13	14 - 57	3 (± 3)

Table 8.97(b) Summary of BOD Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

BOD	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	19	27	2.6	1.4	0.5	0.53	0.34
Effluent Load g/m^2/day	27	26	1.4	0.5	0.5	0.34	0.30
Load Removal g/m^2/day	-8	1	1.3	0.9	0.03	0.19	0.04
Cumulative Load Removal g/m^2/day	-8	-8	-6	-5	-5.37	-5.21	-5.17

Table 8.97(c) Summary of BOD Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

BOD	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	47	69	66	34.2	12.9	12.9	8.5
Effluent Load g/unit/day	69	66	34	12.9	12.5	8.5	7.5
Load Removal g/unit/day	-22	2	32	21.3	0.3	4	1
Cumulative Load Removal g/unit/day	-22	-19	13	34	34.56	38.62	39.59
Cumulative Load Removal as % per unit	-46	-41	27	73	73	82	84

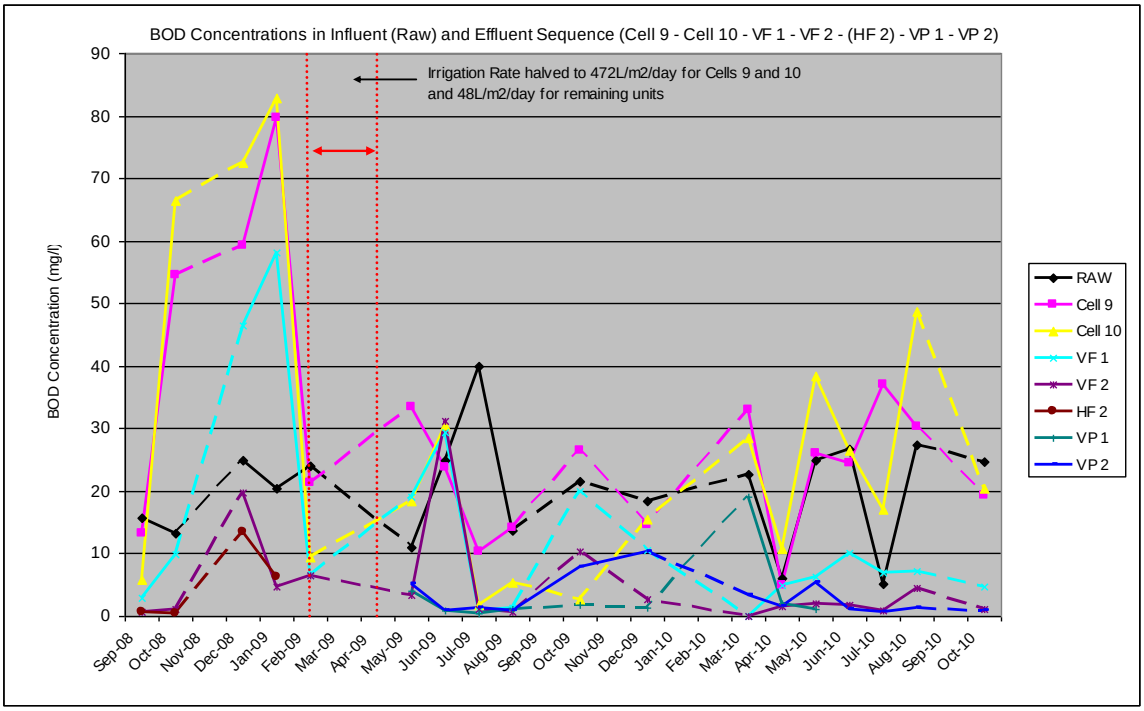


Figure 8.94(a) BOD Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

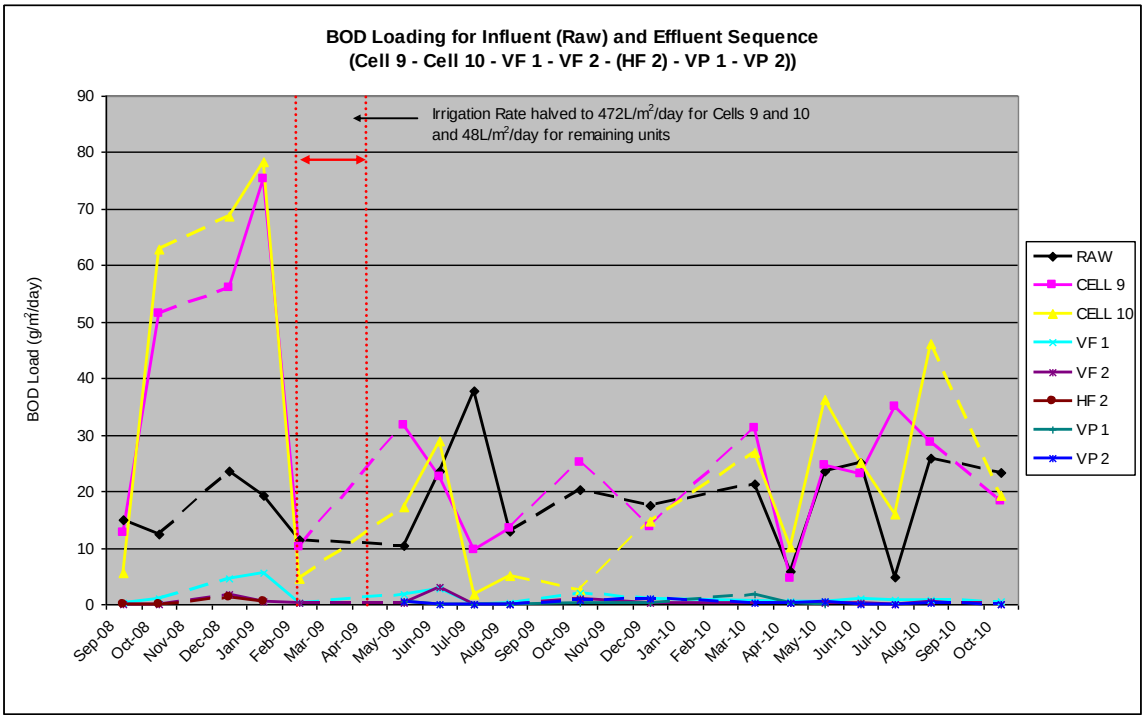


Figure 8.94(b) BOD Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

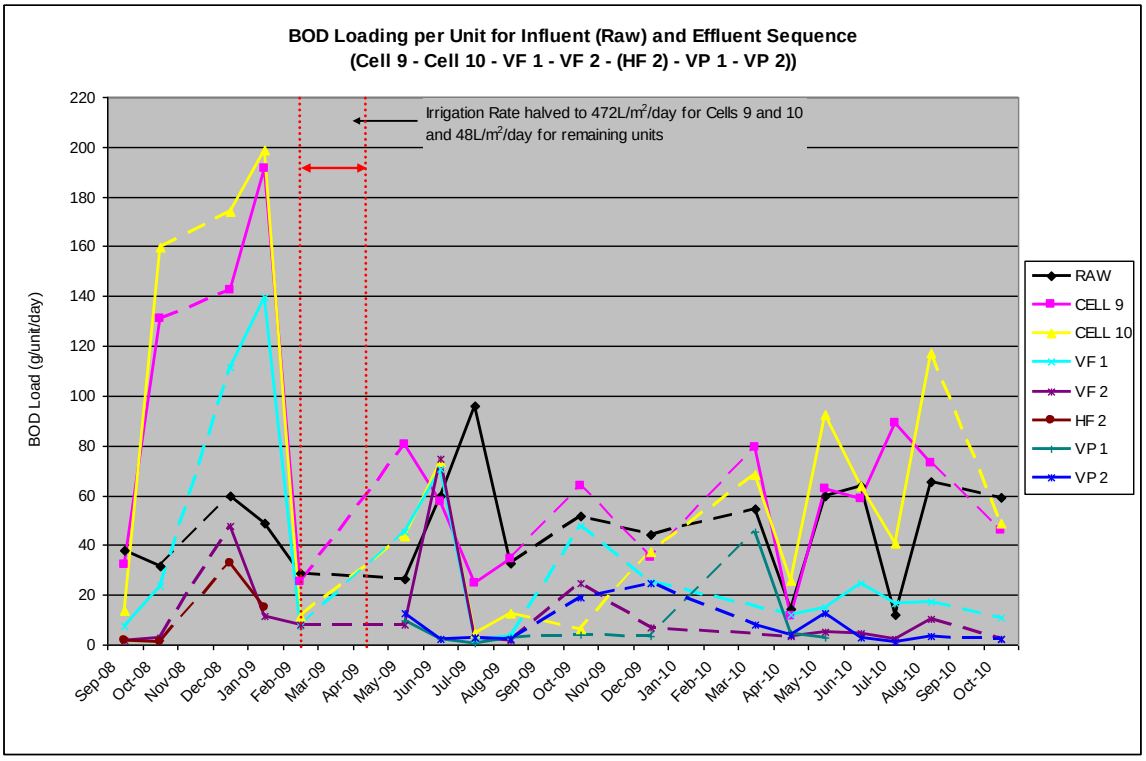


Figure 8.94(c) BOD Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.98(a) Summary of BOD Concentrations for sequence Cell 7 – Cell 8

BOD Concentration (Raw - Cell 7 - Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
BOD	Influent	8	6.0 - 40	22 (± 10)
BOD	Effluent Cell 7	8	7.0 - 50	21 (± 14)
BOD	Effluent Cell 8	8	4.0 - 51	19 (± 17

Table 8.98(b) Summary of BOD Load Removal per m^2 for Cell 7 – Cell 8

BOD	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	20.3	20.3
Effluent Load g/m^2/day	20.3	17.7
Load Removal g/m^2/day	0.0	2.6
Cumulative Load Removal g/m^2/day	0.0	2.6
Cumulative Load Removal as % per m^2	0	13

Table 8.98(c) Summary of BOD Load Removal per unit for Cell 7 – Cell 8

BOD	CELL 7	CELL 8
Influent Load g/unit/day	51.62	51.6
Effluent Load g/unit/day	51.57	44.9
Load Removal g/unit/day	0.05	6.6
Cumulative Load Removal g/unit/day	0.05	6.7
Cumulative Load Removal as % per unit	0.01	13

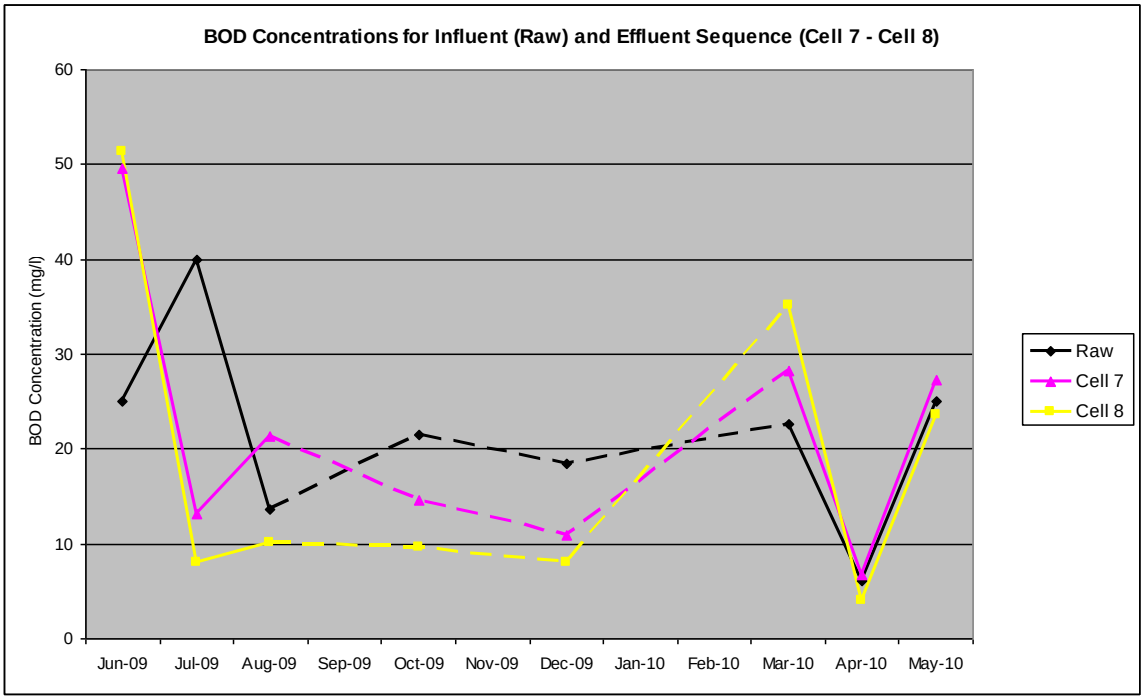


Figure 8.95(a) BOD Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

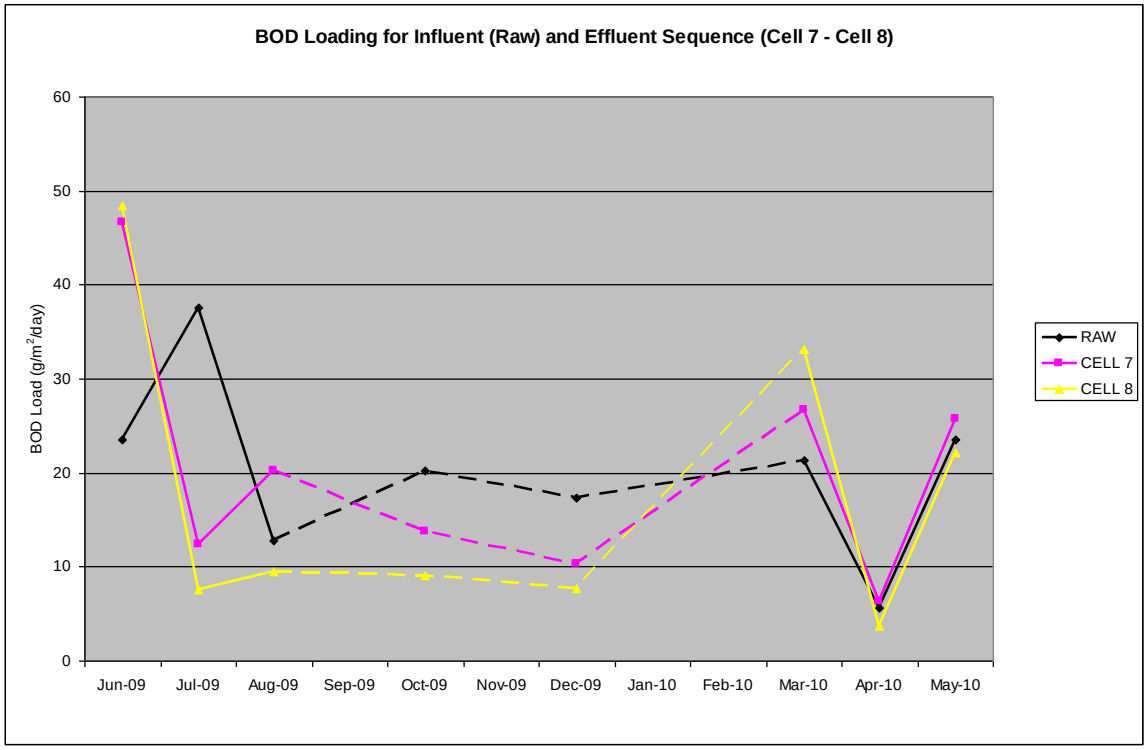


Figure 8.95(b) BOD Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Operational Period: June 2010 – October 2010

Average daily flow = 600L/unit/day

Table 8.98(d) Summary of BOD Concentrations for sequence Cell 7 – Cell 8 – VP 1

BOD Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
BOD	Influent	4	5.0 - 27	21 (± 11)
BOD	Effluent Cell 7	4	9.0 - 30	18 (± 9)
BOD	Effluent Cell 8	4	3.0 - 9	6 (± 3)

Table 8.98(e) Summary of BOD Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

BOD	CELL 7	CELL 8	VP 1
Influent Load g/m^2/day	4.95	4.26	0.14
Effluent Load g/m^2/day	4.26	1.34	0.02
Load Removal g/m^2/day	0.69	2.92	0.11
Cumulative Load Removal g/m^2/day	0.69	3.61	3.73

Table 8.98(f) Summary of BOD Load Removal per unit for Cell 7 – Cell 8 – VP 1

BOD	CELL 7	CELL 8	VP 1
Influent Load g/unit/day	12.58	10.82	3.40
Effluent Load g/unit/day	10.82	3.40	0.56
Load Removal g/unit/day	1.76	7.42	2.84
Cumulative Load Removal g/unit/day	1.76	9.18	12.02
Cumulative Load Removal as % per unit	14	73	96

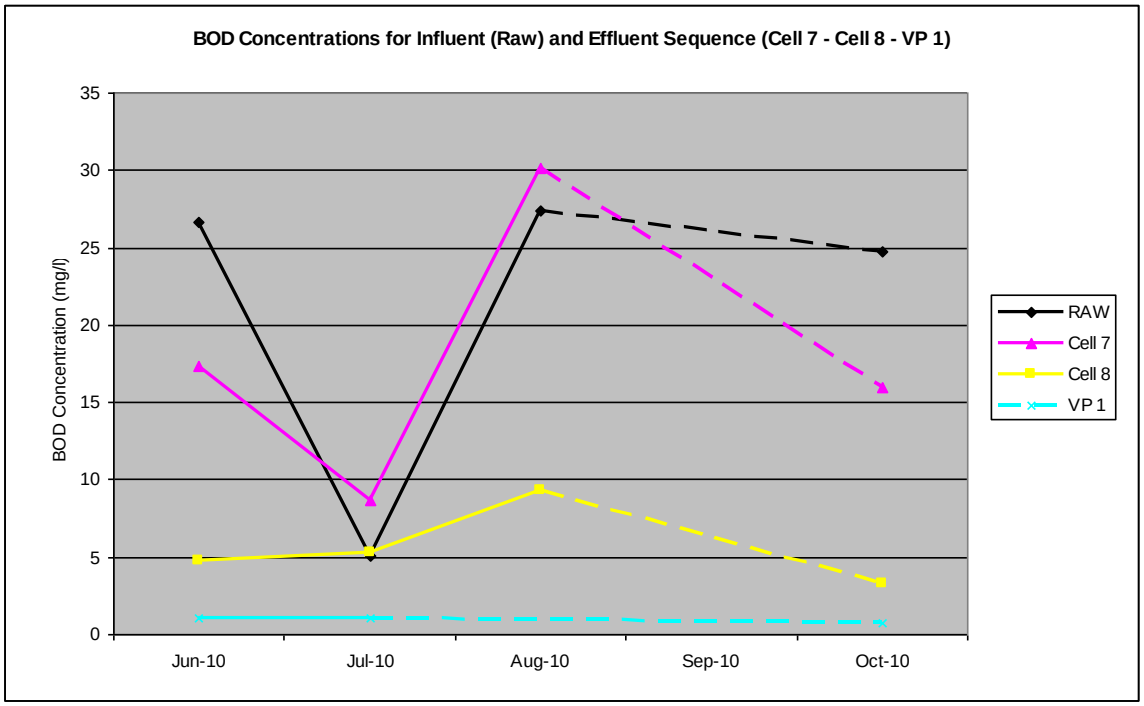


Figure 8.96(a) BOD Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

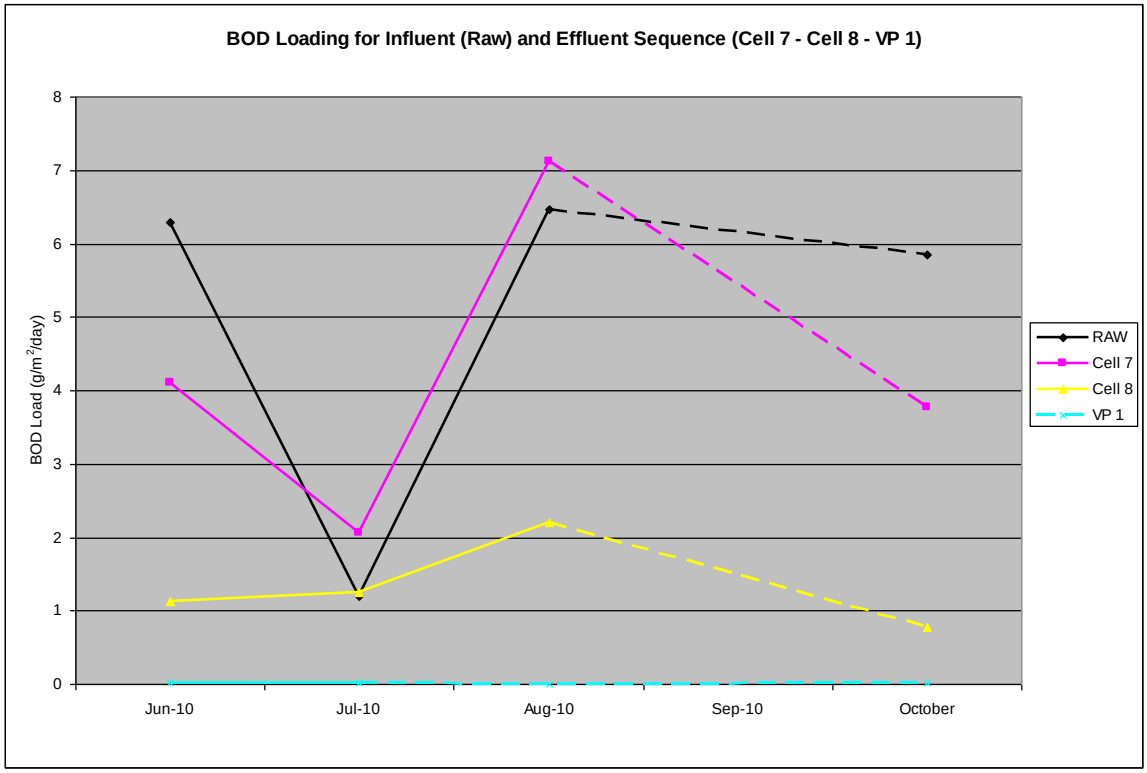


Figure 8.96(b) BOD Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

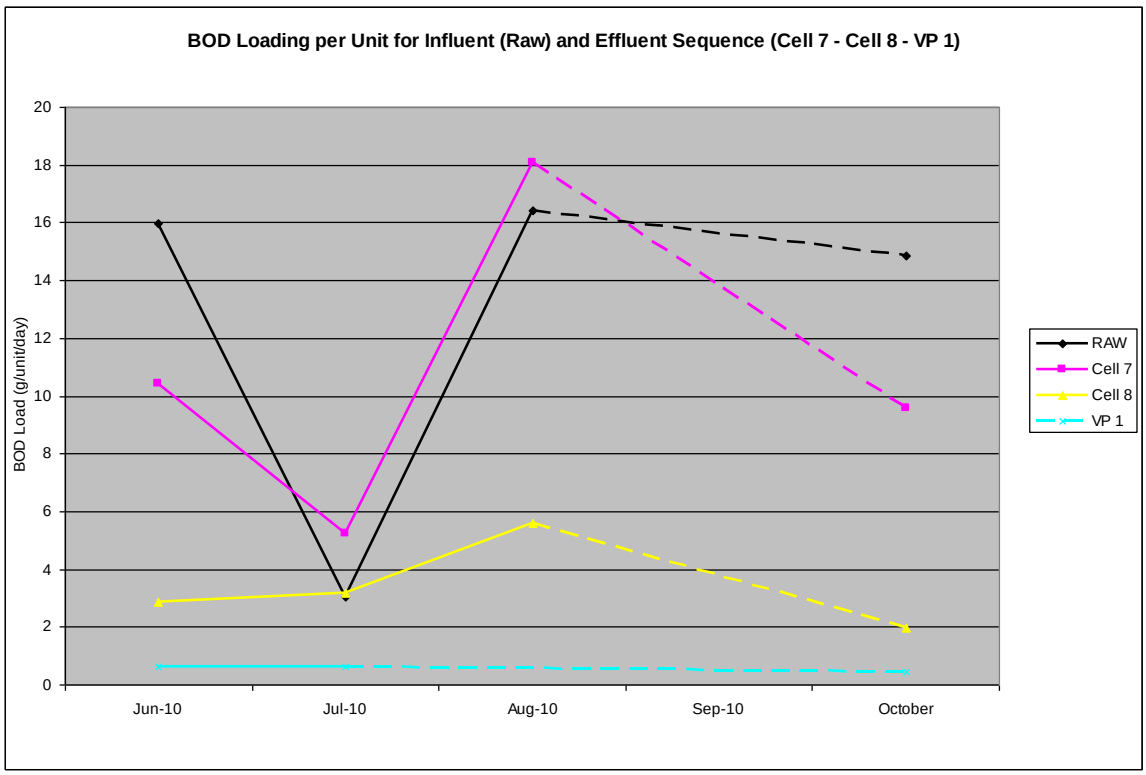


Figure 8.96(c) BOD Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Fresh Leachate (Raw Active)

Monitoring Period: May 2009 - August 2010

Table 8.99 Summary of BOD Concentrations for Fresh Leachate from Active Area

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
BOD	10	9 - 610	127 (± 183)

Tramore River

Monitoring Period: June 2009 - October 2010

Table 8.100 Summary of BOD Concentrations in Tramore River

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
BOD	13	1 - 5	2 (± 1)

COD Removal

COD concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.101(a) to 8.103(f). Concentrations for raw active and the Tramore River are detailed in Tables 8.104 and 8.105.

Charts detailing the range of COD concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented in Figures 8.97(a) to 8.100(c).

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.101(a) Summary of COD Concentrations for sequence Cell 3 – Cell 5

COD Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
COD	Influent	18	177 - 420	282 (± 80)
COD	Effluent Cell 3	18	134 - 360	213 (± 58)
COD	Effluent Cell 5	18	122 - 645	238 (± 133)

Table 8.101(b) Summary of COD Load Removal per m^2 for Cell 3 – Cell 5

COD	CELL 3	CELL 5
Influent Load g/m^2/day	28.46	21.55
Effluent Load g/m^2/day	21.55	23.71
Load Removal g/m^2/day	6.91	-2.16
Cumulative Load Removal g/m^2/day	6.91	4.75
Cumulative Load Removal as % per m^2	24	17

Table 8.101(c) Summary of COD Load Removal per unit for Cell 3 – Cell 5

COD	CELL 3	CELL 5
Influent Load g/unit/day	72.28	54.73
Effluent Load g/unit/day	54.73	60.21
Load Removal g/unit/day	17.55	-5.48
Cumulative Load Removal g/unit/day	17.55	12.07
Cumulative Load Removal as % per unit	24	17

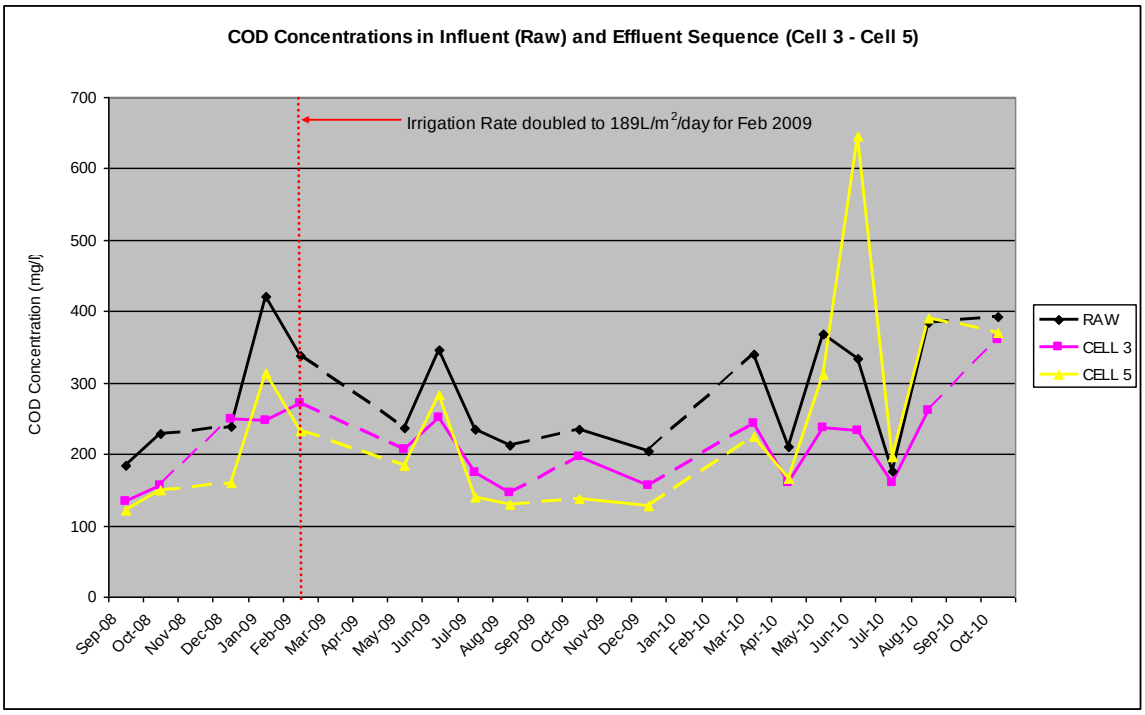


Figure 8.97(a) COD Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

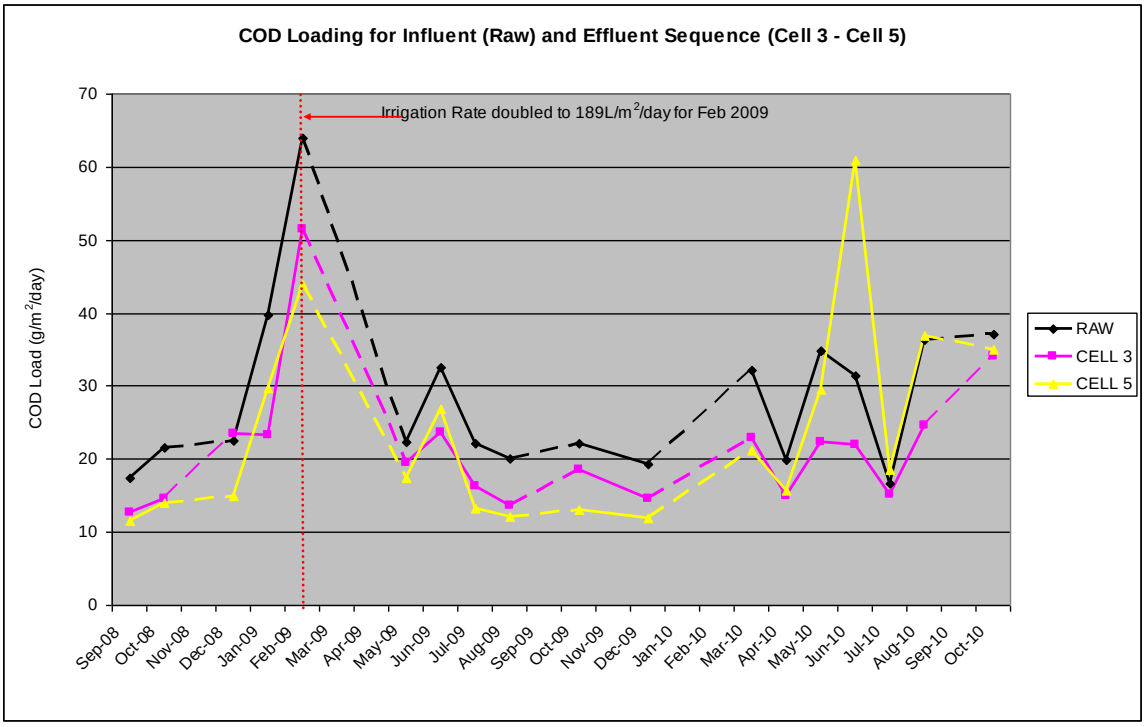


Figure 8.97(b) COD Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.102(a) Summary of COD Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

COD Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
COD	Influent	18	177 - 420	279 (± 80)
COD	Effluent Cell 9	18	136 - 413	268 (± 83)
COD	Effluent Cell 10	18	122 - 392	244 (± 80)
COD	Effluent VF 1	18	110 - 393	212 (± 76)
COD	Effluent VF 2	18	103 - 370	184 (± 81)
COD	Effluent HF 2	4	98 - 230	174 (± 57)
COD	Effluent VP 1	9	72 - 269	134 (± 65
COD	Effluent VP 2	13	68 - 322	145 (± 74)

Table 8.102(b) Summary of COD Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

COD	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	256	247	23	20	17.3	17	13
Effluent Load g/m^2/day	247	225	20	17	16.7	13	14
Load Removal g/m^2/day	9	22	3	3	0.6	4	-1
Cumulative Load Removal g/m^2/day	9	31	34	36	36.9	41	40

Table 8.102(c) Summary of COD Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

COD	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	651	628	573	497	432	432	321
Effluent Load g/unit/day	628	573	497	432	418	321	349
Load Removal g/unit/day	22	56	75	65	14	111	-28
Cumulative Load Removal g/unit/day	22	78	153	219	233	441	302
Cumulative Load Removal as % per unit	3	12	24	34	36	68	46

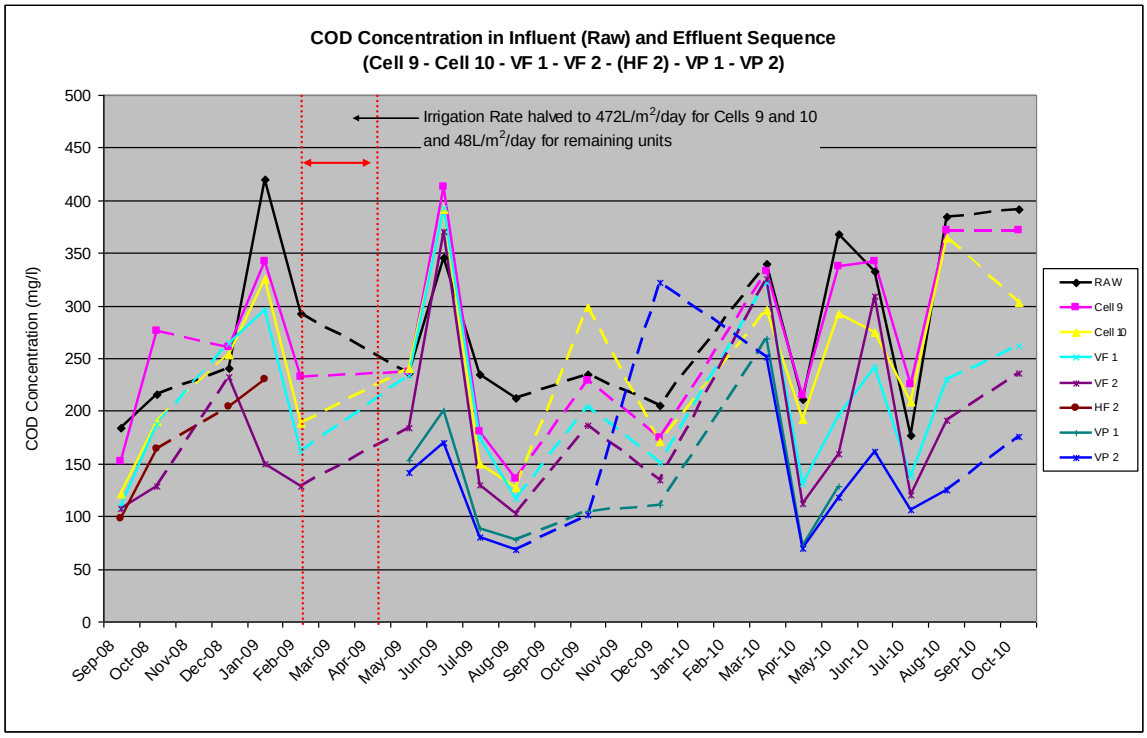


Figure 8.98(a) COD Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

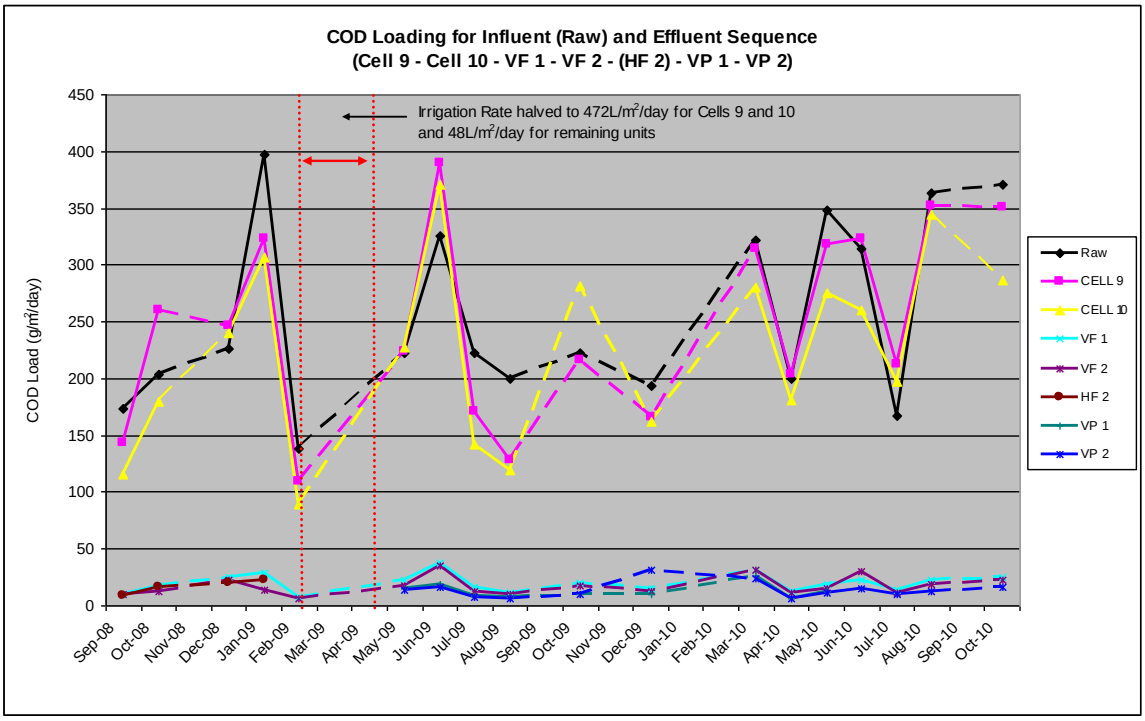


Figure 8.98(b) COD Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

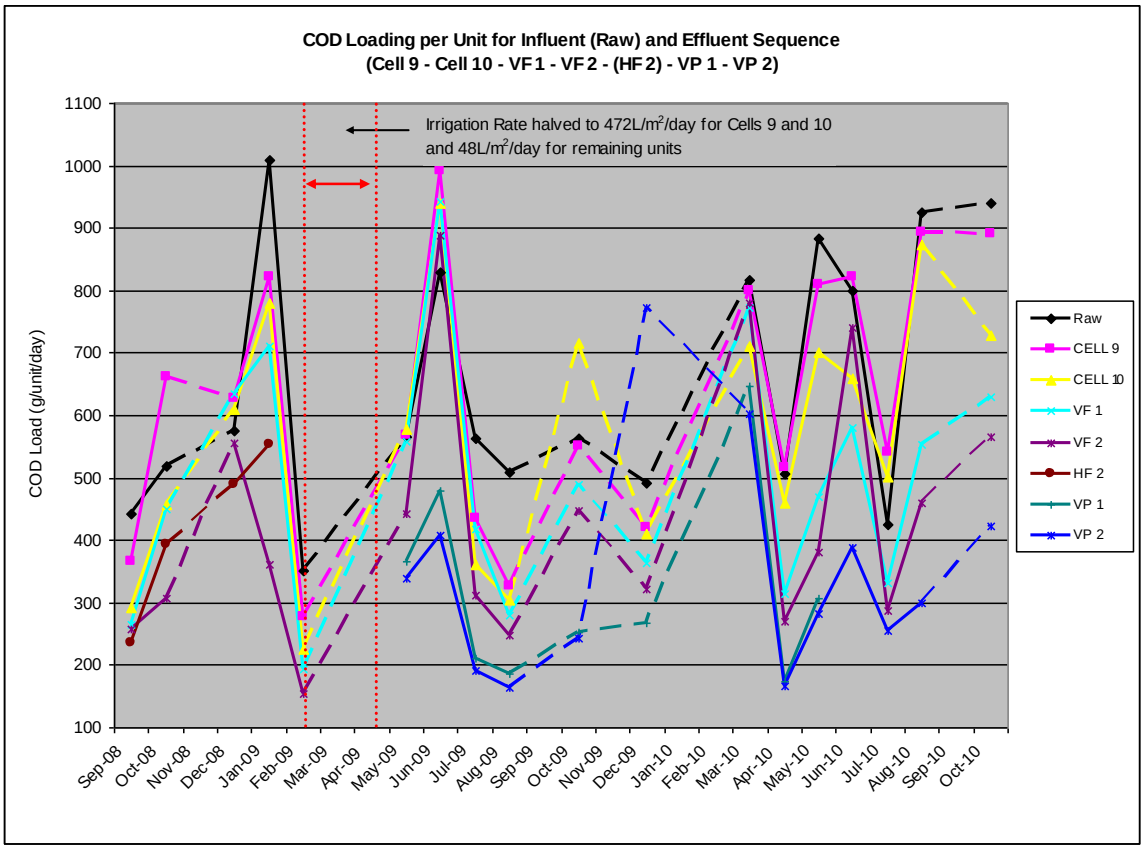


Figure 8.98(c) COD Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

<u>Cell 7 – Cell 8</u>

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.103(a) Summary of COD Concentrations for sequence Cell 7 – Cell 8

COD Concentration (Raw - Cell 7 - Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
COD	Influent	8	205 - 368	269 (± 69)
COD	Effluent Cell 7	8	156 - 377	238 (± 76)
COD	Effluent Cell 8	8	149 - 372	219 (± 74)

Table 8.103(b) Summary of COD Load Removal per m^2 for Cell 7 – Cell 8

COD	CELL 7	CELL 8
Influent Load g/m^2/day	254	225
Effluent Load g/m^2/day	225	207
Load Removal g/m^2/day	29	18
Cumulative Load Removal g/m^2/day	29	47
Cumulative Load Removal as % per m^2	11	19

Table 8.103(c) Summary of COD Load Removal per unit for Cell 7 – Cell 8

COD	CELL 7	CELL 8
Influent Load g/unit/day	645	572
Effluent Load g/unit/day	572	525
Load Removal g/unit/day	74	47
Cumulative Load Removal g/unit/day	74	120
Cumulative Load Removal as % per unit	11	19

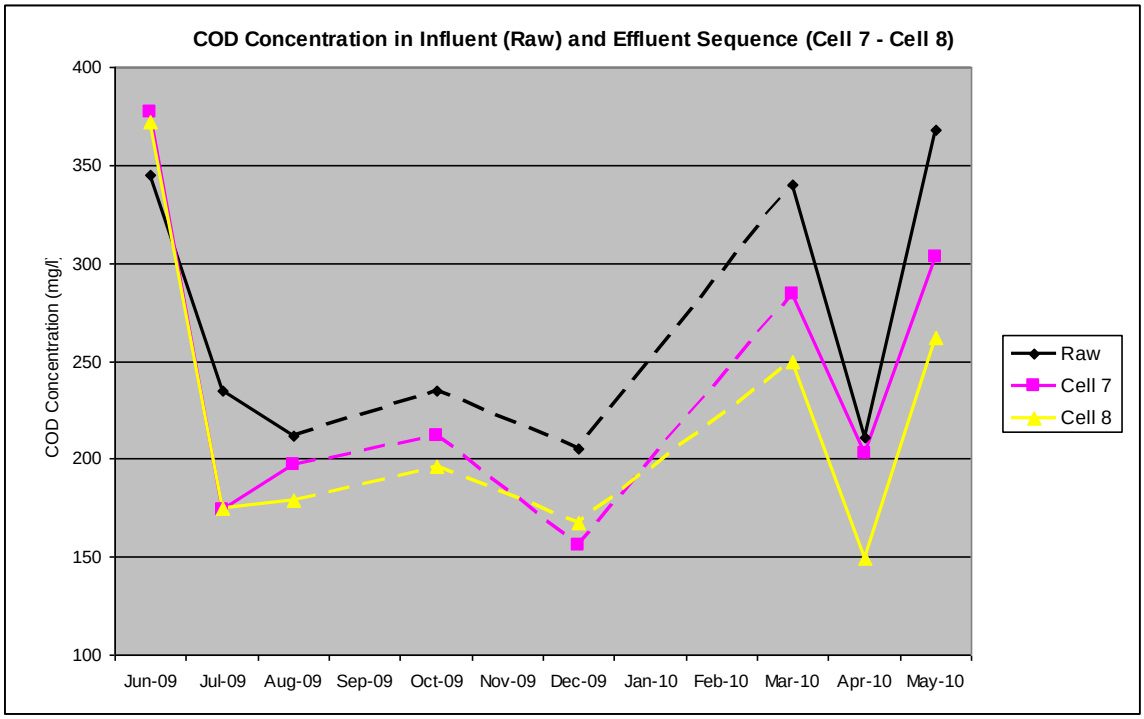


Figure 8.99(a) COD Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

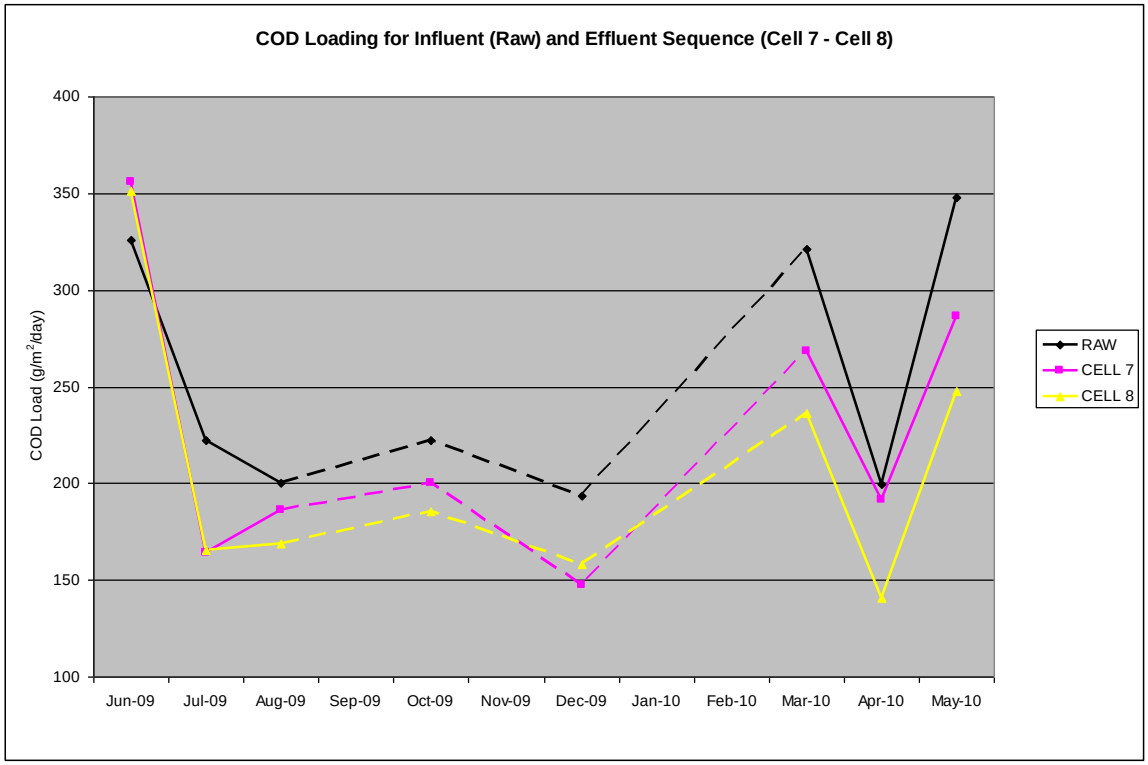


Figure 8.99(b) COD Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Average daily flow = 600L/unit/day

Operational Period: June 2010 – October 2010

Table 8.103(d) Summary of COD Concentrations for sequence Cell 7 – Cell 8 – VP 1

COD Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
COD	Influent	4	117 - 392	322 (± 100)
COD	Effluent Cell 7	4	191 - 281	244 (± 43)
COD	Effluent Cell 8	4	188 - 273	239 (± 37)
COD	Effluent VP 1	4	86 - 137	118 (± 22)

Table 8.103(e) Summary of COD Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

COD	CELL 7	CELL 8	VP 1
Influent Load $g/m^2/day$	76	58	6
Effluent Load $g/m^2/day$	58	56	3
Load Removal $g/m^2/day$	18	1	3
Cumulative Load Removal $g/m^2/day$	18	19	22

Table 8.103(f) Summary of COD Load Removal per unit for Cell 7 – Cell 8 – VP 1

COD	CELL 7	CELL 8	VP 1
Influent Load g/unit/day	193	147	144
Effluent Load g/unit/day	147	144	71
Load Removal g/unit/day	47	3	73
Cumulative Load Removal g/unit/day	47	50	123
Cumulative Load Removal as % per unit	24	26	63

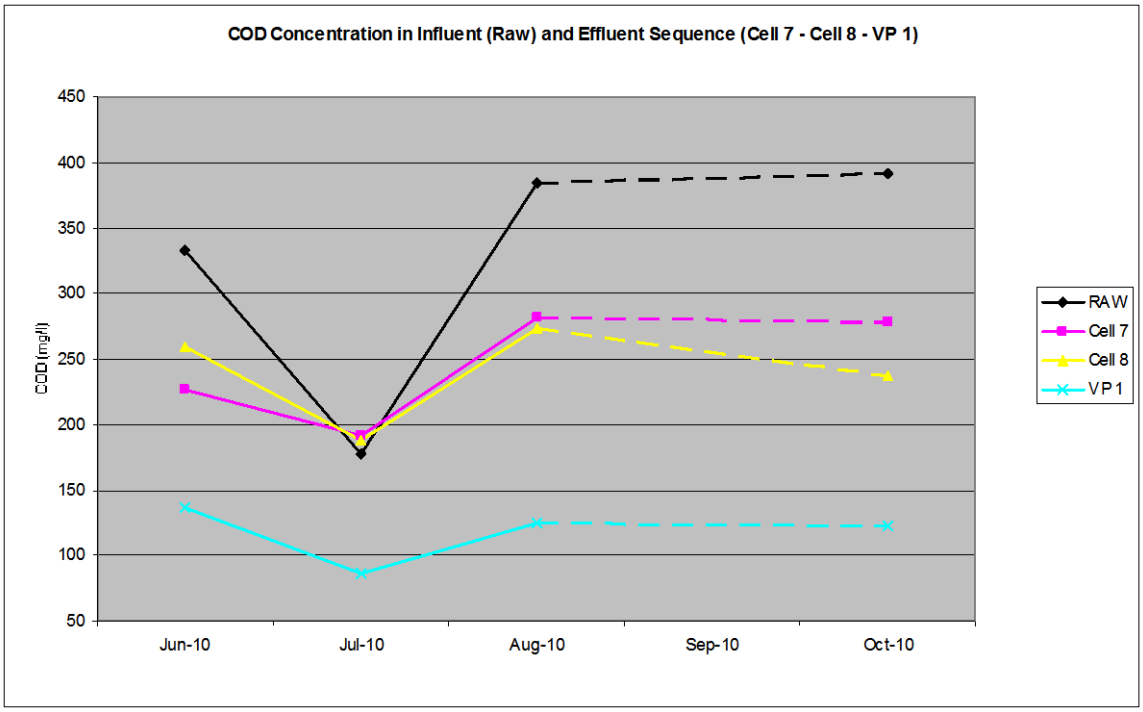


Figure 8.100(a) COD Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

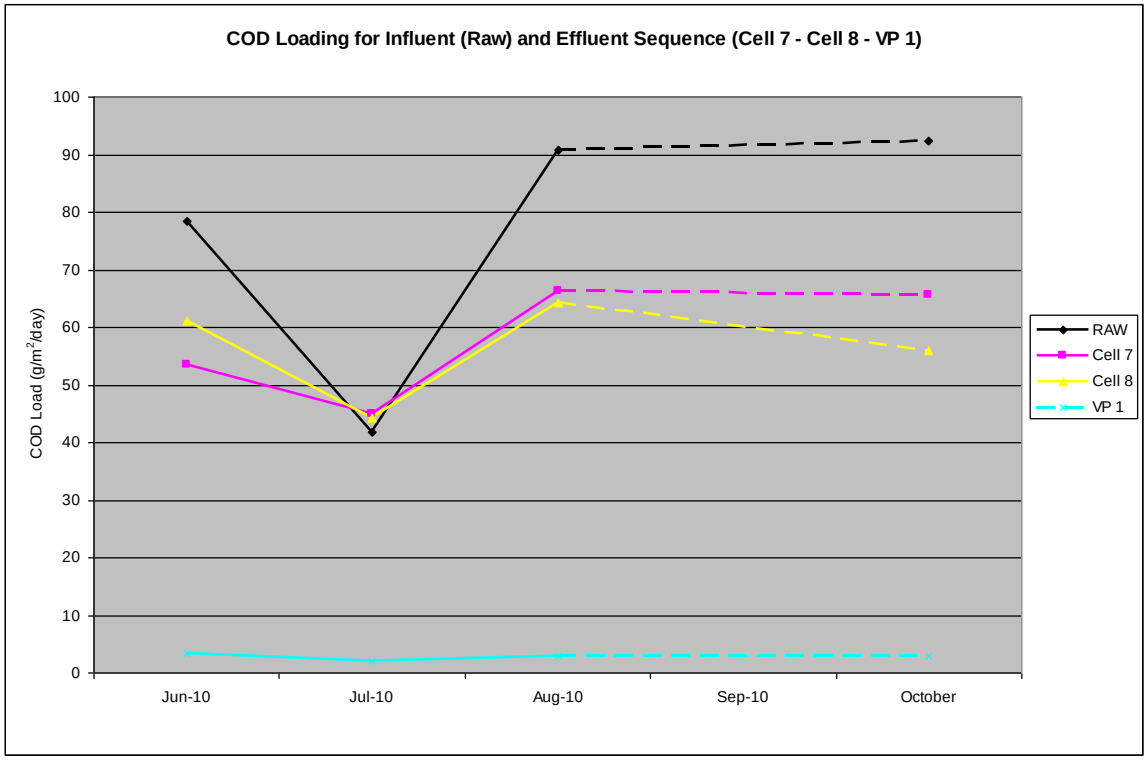


Figure 8.100(b) COD Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

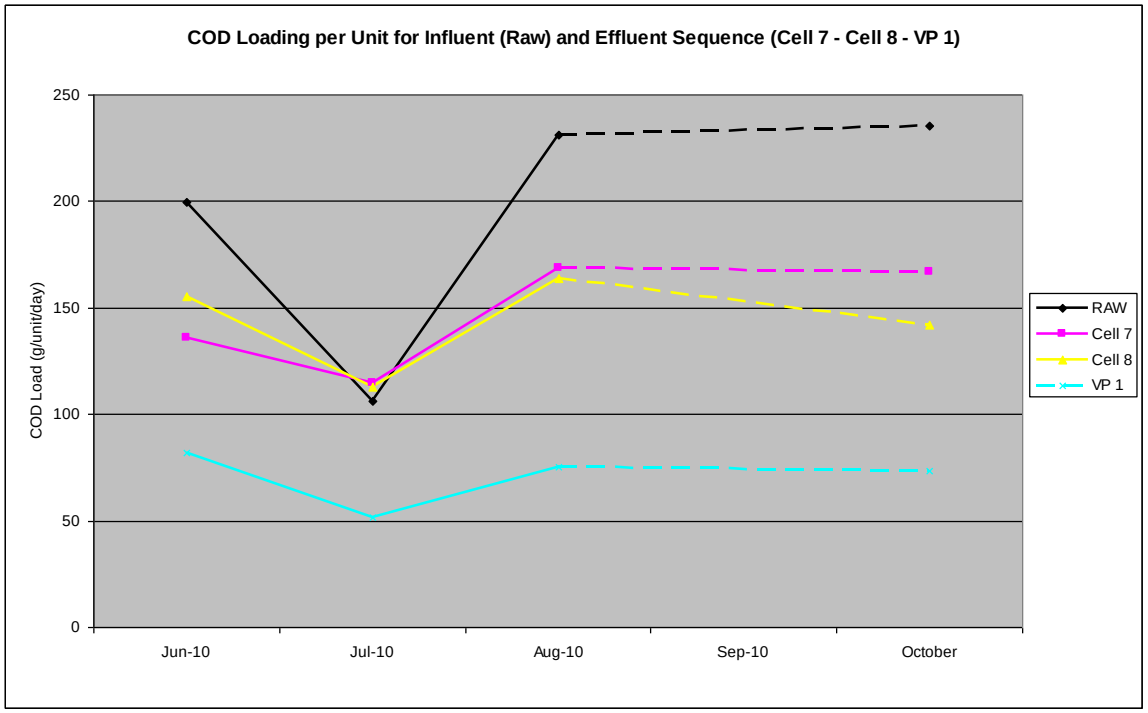


Figure 8.100(c) COD Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Fresh Leachate (Raw Active)

Monitoring Period: May 2009 - August 2010

Table 8.104 Summary of COD Concentrations for Fresh Leachate from Active Area

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
COD	12	71 - 2014	569 (± 622)

Tramore River

Monitoring Period: June 2009 - October 2010

Table 8.105 Summary of COD Concentrations in Tramore River

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
COD	12	0.1 - 55	13 (± 16)

Interpretation of Organics Removal in Treatment Units

Analysis of BOD_5 and COD results for concentrations and load removal rates for treatment units operating in sequence reveals a positive load removal and lower concentrations in the final effluent of each sequence for both parameters.

The cumulative BOD_5 load removal at the final effluent for each of the sequences was as follows; Cell 3 – Cell 5 recorded 0.73g/m^2/day removal (36% removal), Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 recorded 40g/unit/day removal (84% removal); Cell 7 – Cell 8 recorded 2.6g/m^2/day removal (13% removal) and cumulative load removal rates for Cell 7 – Cell 8 – VP 1 were 1.76g/ m^2/day, 9.18g/m^2/day and 12.0g/m^2/day respectively (14%, 73% and 96% removal respectively).

The charts depicting the range of BOD load removal for each of the sequences (Figures 8.93(b) and 8.96(c)) display an erratic pattern of effluent load emanating from the primary and in some cases the secondary treatment unit, which fluctuated above and below the influent load. This variability tended to smoothen out in the third and fourth units in the sequence, specifically sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – VP 1.

The doubling of the irrigation rate to in sequence Cell 3 – Cell 5 to 189L/m^2/day caused a spike in effluent load (and concentration), particularly in cell 3 where the effluent load of 18g/m^2/day was over four times the influent load. These results indicated that the system was extremely overloaded at the increased hydraulic loading rate and it was decided to revert to the original application rate of 94.5L/m^2/day.

The irrigation rate to the sequence Cell 9 → VP 2 was halved to 1200L/unit/day for a three month period (February to April 2009). The effect of the reduction in hydraulic loading rate is difficult to assess due to breaks in the data for BOD sampling between March and April 2009.

In terms of COD, each of the sequences displays positive load removal throughout with a cumulative load removal of 4.75g/m^2/day (17% removal) for sequence Cell 3 – Cell 5, 302g/unit/day (46% removal) for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2; 47g/m^2/day (19% removal) for Cell 7 – Cell 8 and 123g/unit/day (63% removal) for sequence Cell 7 – Cell 8 – VP 1.
End point concentrations for each sequence were lower than influent; with Cell 5 average effluent concentration down by 44mg/l to 238mg/l, VP 2 average effluent concentration down by 134mg/l to 145mg/l; Cell 8 average effluent concentration down by 50mg/l to 219mg/l and concentration at VP 1 effluent down by 204mg/l to 118mg/l.

The charts depicting the range of COD load removal for each of the sequences (Figures 8.97(b) and 8.100(c)) displays considerable variance between each of the trial runs.

Sequence Cell 3 – cell 5 displays a relatively consistent pattern of reduction in effluent load with three exceptions (Figure 8.97(b)). Results for final effluent load for June to August 2010 exceeded the influent load by 29g/m^2/day for June (almost double the influent load), 2g/m^2/day for July and 0.5g/m^2/day for August 2010.

These results were however the exception, with the remainder of the final effluent load results (15 no.) below the influent load.

The doubling of the irrigation rate to sequence Cell 3 – Cell 5 to 189L/m^2/day during February 2009 caused a spike in effluent load (and concentration) from each unit. However, the effluent load from each cell still remained below the initial influent load.

The charts detailing the range of COD concentrations and loadings to sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2; presented in Figures 8.98(a) to 8.98(c); display a high variability in terms of load removal across the trial period with the results

for all treatment units in the sequence tending to follow the peaks and troughs of the influent load at progressively lower loading levels.
There were some notable exceptions to this; October 2008, December 2008, June 2009, October 2009 and July 2009 where results from one or several of the treatment units revealed higher effluent loads. Despite this, there was a general trend of COD load reduction in unit VP 2, with one exception, December 2009 where COD effluent load was 280g/unit/day higher than the influent.
The effect of halving hydraulic loading rate in sequence Cell 9 → VP 2 to 1200L/unit/day between February and April 2009 could not be assessed due to a lack of data for this period.

Charts depicting concentration and load results for sequence Cell 7 - Cell 8 (Figures 8.99(a) – 8.99(b)) reveal positive load removal in the final effluent except for June 2009 at sequence start-up where the final effluent load was 65g/m^2/day higher than the initial influent load.

Results for sequence Cell 7 – Cell 8 – VP 1 reveal a similar pattern, with each unit displaying progressive load removal from the system (Figures 8.100(b) and 8.100(c)). Again, there was one exception to this where effluent load results for cell 7 and cell 8 for July 2010 were 9g/unit/day and 7g/unit/day respectively higher than the initial influent load.

Results for the Tramore River showed an average BOD concentration of 2mg/l with a low range of 1 - 5mg/l. The average COD concentration was 13mg/l and ranged from 0.1mg/l to 55mg/l.

A comparison of the raw active leachate and the filtered leachate stream again shows a much higher strength leachate from the active area, with an average BOD concentration of 127mg/l, as opposed to 20mg/l for the filtered leachate, with corresponding COD concentrations of 569mg/l and 279mg/l respectively.

The average final effluent concentrations for all sequences would meet the EPA emission limit value (ELV) of 20mg/l BOD_5 for discharge to surface water. However, none of the sequences would meet the ELV for COD of 100mg/l. Again caution is warranted in applying these guideline ELVs to applications for consent to discharge to surface water as ELVs are set in line with existing environmental quality standards (EQS) and are very much site specific; i.e. much lower ELVs would be expected for surface water discharge to water bodies within National Heritage Areas (NHA), Special Areas of Conservation (SAC) and any other receiving environment deemed sensitive by the EPA (or other statutory body) and deserving additional protection.

8.3.2.3 Suspended Solids Removal in Treatment Units

Suspended Solids concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.106(a) to 8.108(f). Concentrations for raw active and the Tramore River are detailed in Tables 8.109 and 8.110.

Charts detailing the range of suspended solids concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented in Figures 8.101(a) to 8.104(c).

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.106(a) Summary of SS Concentrations for sequence Cell 3 – Cell 5

Suspended Solids Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Suspended Solids	Influent	18	15 - 47	30 (± 9)
Suspended Solids	Effluent Cell 3	18	2.0 - 26	9 (± 6)
Suspended Solids	Effluent Cell 5	18	1.0 - 90	14 (± 21)

Table 8.106(b) Summary of SS Load Removal per m^2 for Cell 3 – Cell 5

Suspended Solids	**CELL 3**	**CELL 5**
Influent Load $g/m^2/day$	3.1	0.9
Effluent Load $g/m^2/day$	0.9	1.4
Load Removal g/m2/day	2.2	-0.5
Cumulative Load Removal $g/m^{2/day}$	2.2	1.7
Cumulative Load Removal as % per m^2	71	56

Table 8.106(c) Summary of SS Load Removal per unit for Cell 3 – Cell 5

Suspended Solids	**CELL 3**	**CELL 5**
Influent Load g/unit/day	7.8	2.3
Effluent Load g/unit/day	2.3	3.5
Load Removal g/unit/day	5.6	-1.2
Cumulative Load Removal g/unit/day	5.6	4.4
Cumulative Load Removal as % per unit	71	56

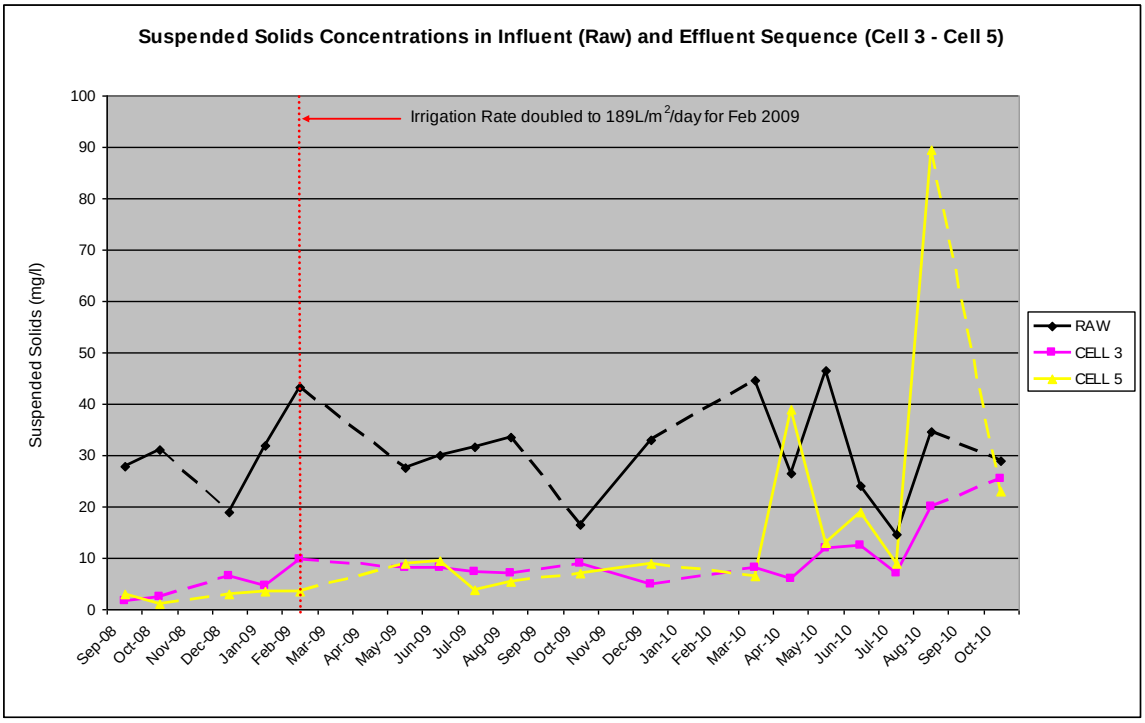


Figure 8.101(a) Suspended Solids Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

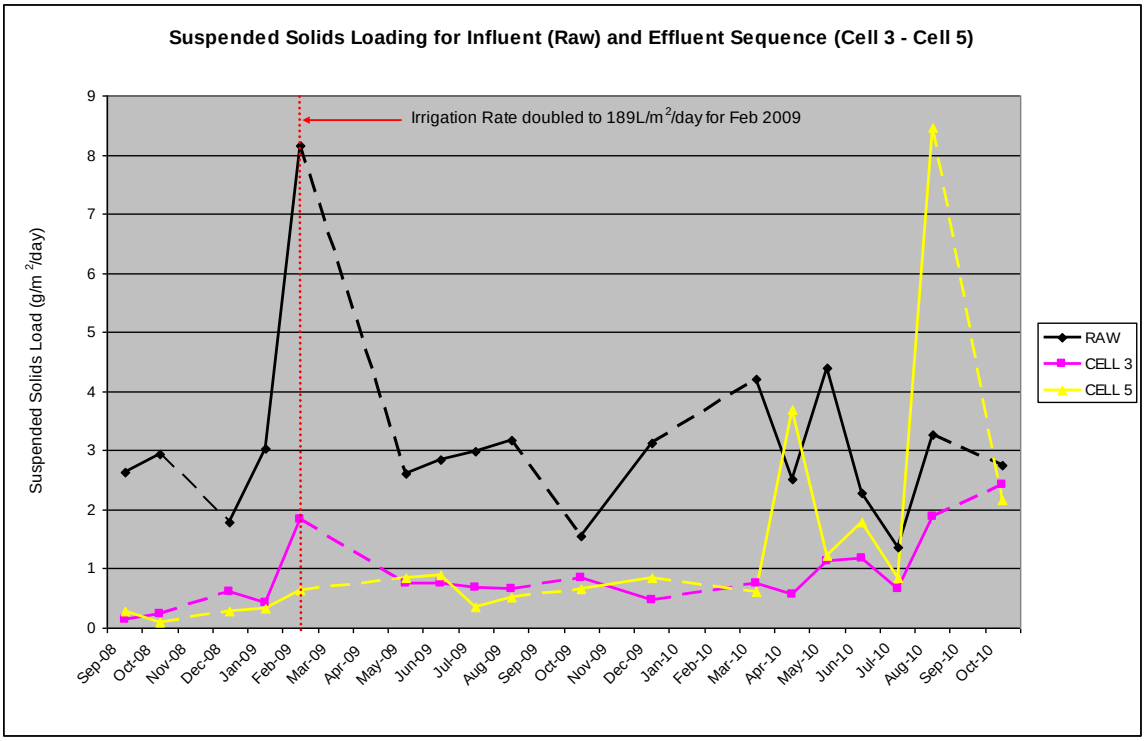


Figure 8.101(b) Suspended Solids Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.107(a) Summary of SS Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

SS Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Suspended Solids	Influent	18	15 - 55	30 (± 10)
Suspended Solids	Effluent Cell 9	18	5 - 115	27 (± 28)
Suspended Solids	Effluent Cell 10	18	2.0 - 73	14 (± 16)
Suspended Solids	Effluent VF 1	18	1.0 - 46	9 (± 10)
Suspended Solids	Effluent VF 2	18	2.0 - 24	8 (± 6)
Suspended Solids	Effluent HF 2	4	4.0 - 14	8 (± 4)
Suspended Solids	Effluent VP 1	9	3.0 - 37	12 (± 12)
Suspended Solids	Effluent VP 2	13	2.0 - 60	11 (± 15)

Table 8.107(b) Summary of SS Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Suspended Solids	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	27.2	25.4	1.4	0.8	0.7	0.7	1.1
Effluent Load g/m^2/day	25.4	13.5	0.8	0.7	0.8	1.1	1.0
Removal g/m^2/day	2	12	0.5	0.1	-0.1	-0.4	0.1
Cumulative Load Removal g/m^2/day	1.8	13.7	14.2	14.3	14.3	14.0	14.0

Table 8.107(c) Summary of SS Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Suspended Solids	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	69.1	64.4	34.3	20.9	18.3	18.3	28.1
Effluent Load g/unit/day	64.4	34.3	20.9	18.3	19.7	28.1	25.7
Load Removal g/unit/day	4.7	30.1	13.4	2.6	-1.3	-9.7	2.3
Cumulative Load Removal g/unit/day	4.7	34.8	48.2	50.8	49.5	41.1	43.4
Cumulative Load Removal as % per unit	7	50	70	73	72	59	63

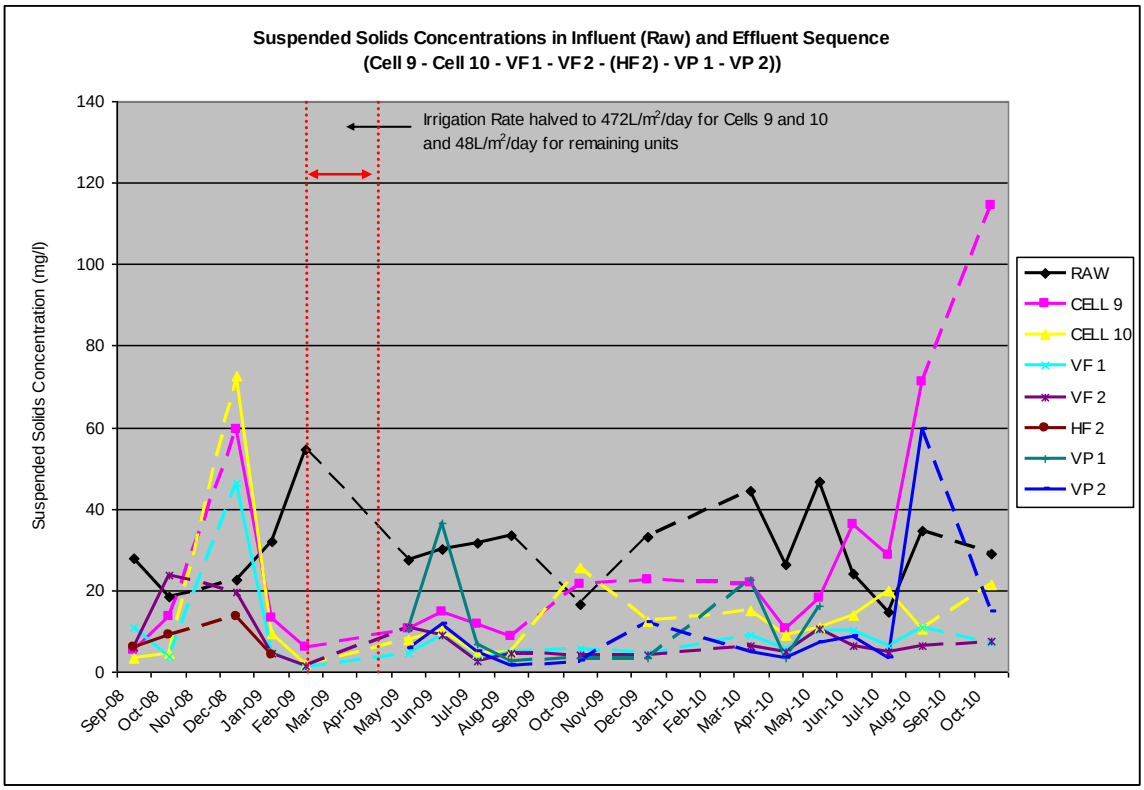


Figure 8.102(a) Suspended Solids Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

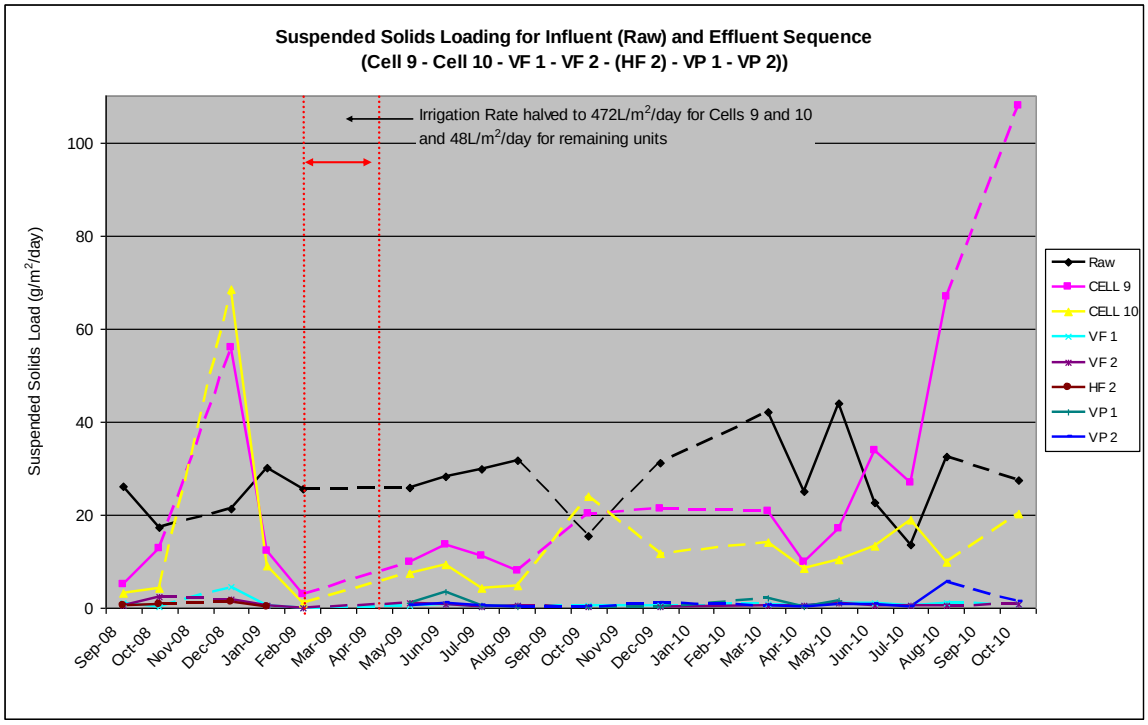


Figure 8.102(b) Suspended Solids Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

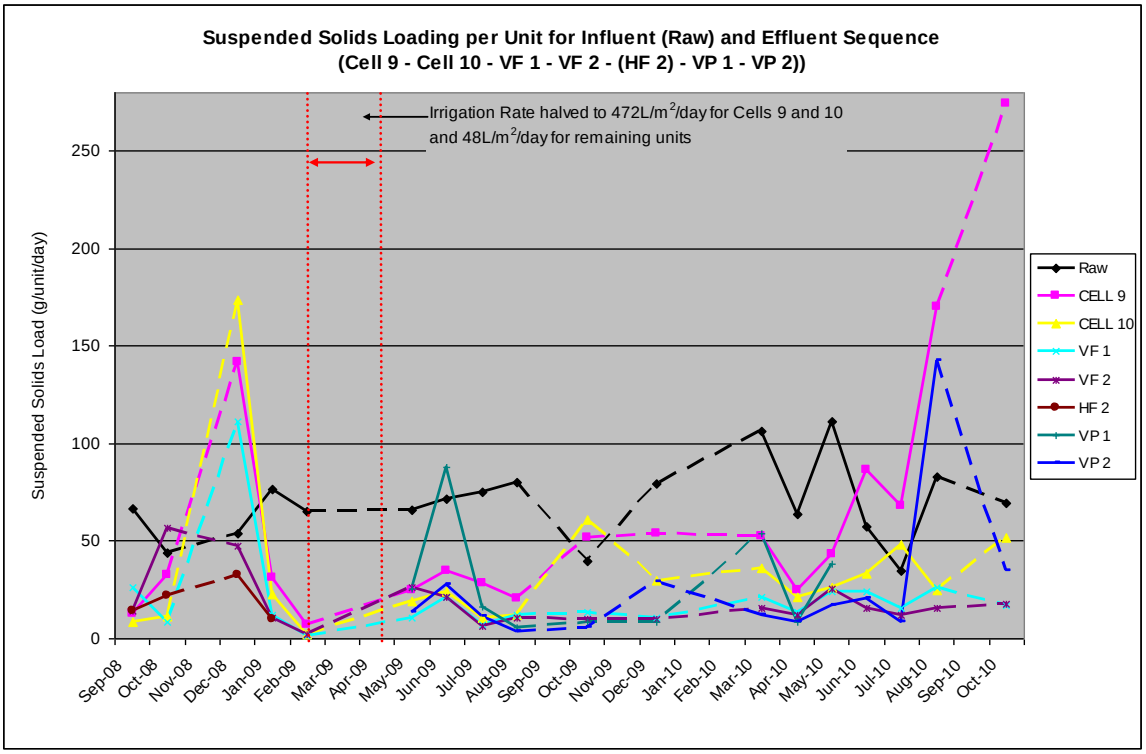


Figure 8.102(c) Suspended Solids Loading per Unit for Influent (Raw) and Effluent Sequence

<u>Cell 7 – Cell 8</u>

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.108(a) Summary of SS Concentrations for sequence Cell 7 – Cell 8

SS Concentration (Raw - Cell 7 - Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Suspended Solids	Influent	8	17 - 47	33 (± 10)
Suspended Solids	Effluent Cell 7	8	8.0 - 20	13 (± 5)
Suspended Solids	Effluent Cell 8	8	4.0 - 13	7 (± 3)

Table 8.108(b) Summary of SS Load Removal per m^2 for Cell 7 – Cell 8

Suspended Solids	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	30.9	12.1
Effluent Load g/m^2/day	12.1	7.1
Load Removal g/m^2/day	18.8	5
Cumulative Load Removal g/m^2/day	18.8	23.8
Cumulative Load Removal as % per m^2	61	77

Table 8.108(c) Summary of SS Load Removal per unit for Cell 7 – Cell 8

Suspended Solids	**CELL 7**	**CELL 8**
Influent Load g/unit/day	78.4	30.7
Effluent Load g/unit/day	30.7	17.9
Load Removal g/unit/day	47.7	12.8
Cumulative Load Removal g/unit/day	47.7	60.5
Cumulative Load Removal as % per unit	61	77

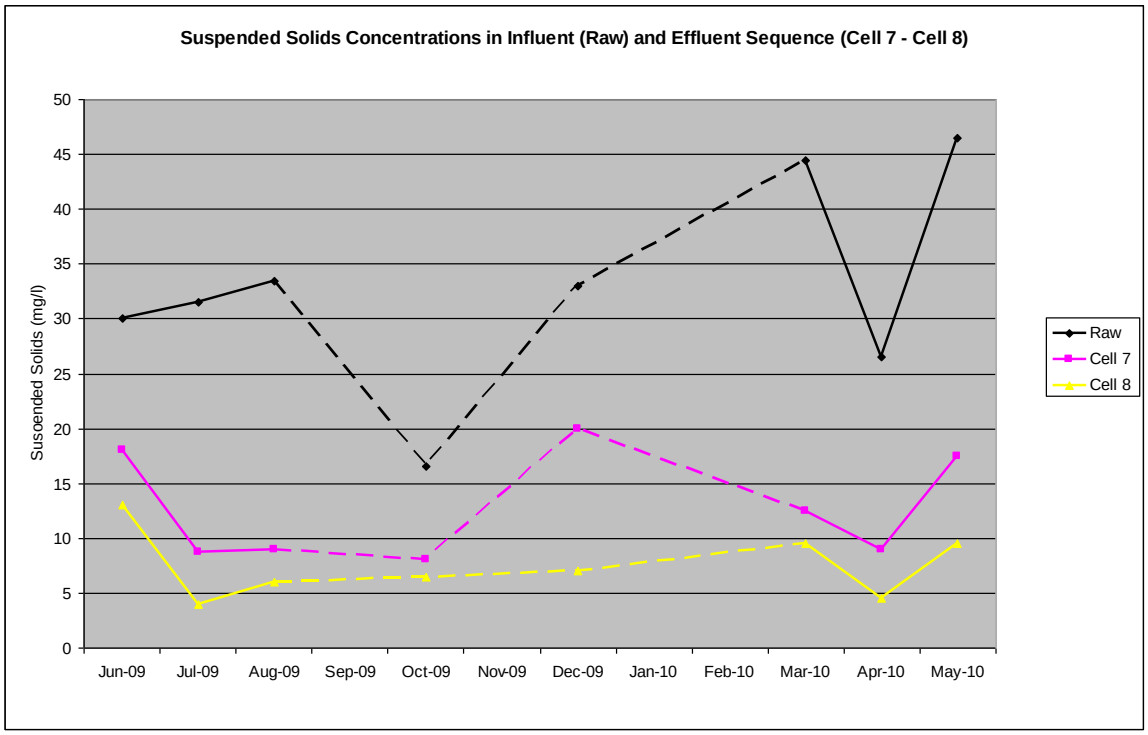


Figure 8.103(a) Suspended Solids Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

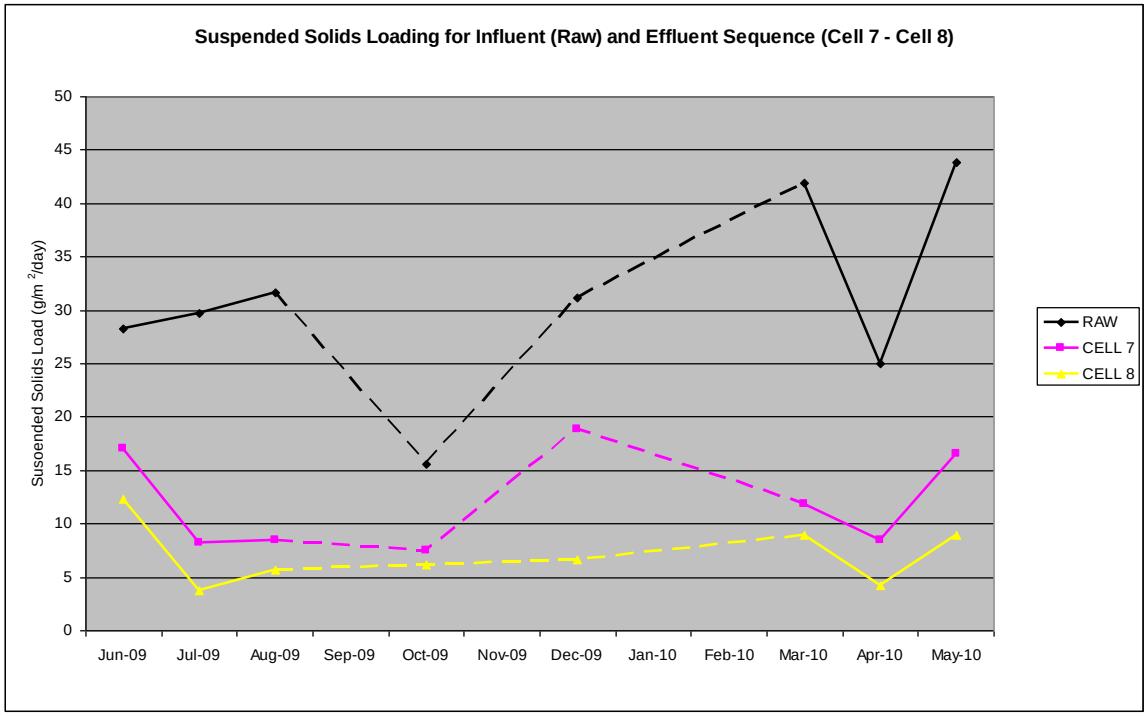


Figure 8.103(b) Suspended Solids Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Operational Period: June 2010 – October 2010

Average daily flow = 600L/unit/day

Table 8.108(d) Summary of SS Concentrations for sequence Cell 7 – Cell 8 – VP 1

SS Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Suspended Solids	Influent	4	15 - 35	26 (± 8)
Suspended Solids	Effluent Cell 7	4	12.0 - 71	40 (± 30)
Suspended Solids	Effluent Cell 8	4	8.0 - 20	13 (± 5)
Suspended Solids	Effluent VP 1	4	4.0 -10	7 (± 3)

Table 8.108(e) Summary of SS Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

Suspended Solids	CELL 7	CELL 8	VP 1
Influent Load g/m^2/day	6.0	9.4	0.3
Effluent Load g/m^2/day	9.4	3.0	0.2
Load Removal g/m^2/day	-3.4	6.4	0.2
Cumulative Load Removal g/m^2/day	-3	3	3

Table 8.108(f) Summary of SS Load Removal per unit for Cell 7 – Cell 8 – VP 1

Suspended Solids	CELL 7	CELL 8	VP 1
Influent Load g/unit/day	15.3	24.0	7.7
Effluent Load g/unit/day	24.0	7.7	3.9
Load Removal g/unit/day	-8.7	16.2	3.8
Cumulative Load Removal g/unit/day	-8.7	7.6	11.4
Cumulative Load Removal as % per unit	-57	50	74

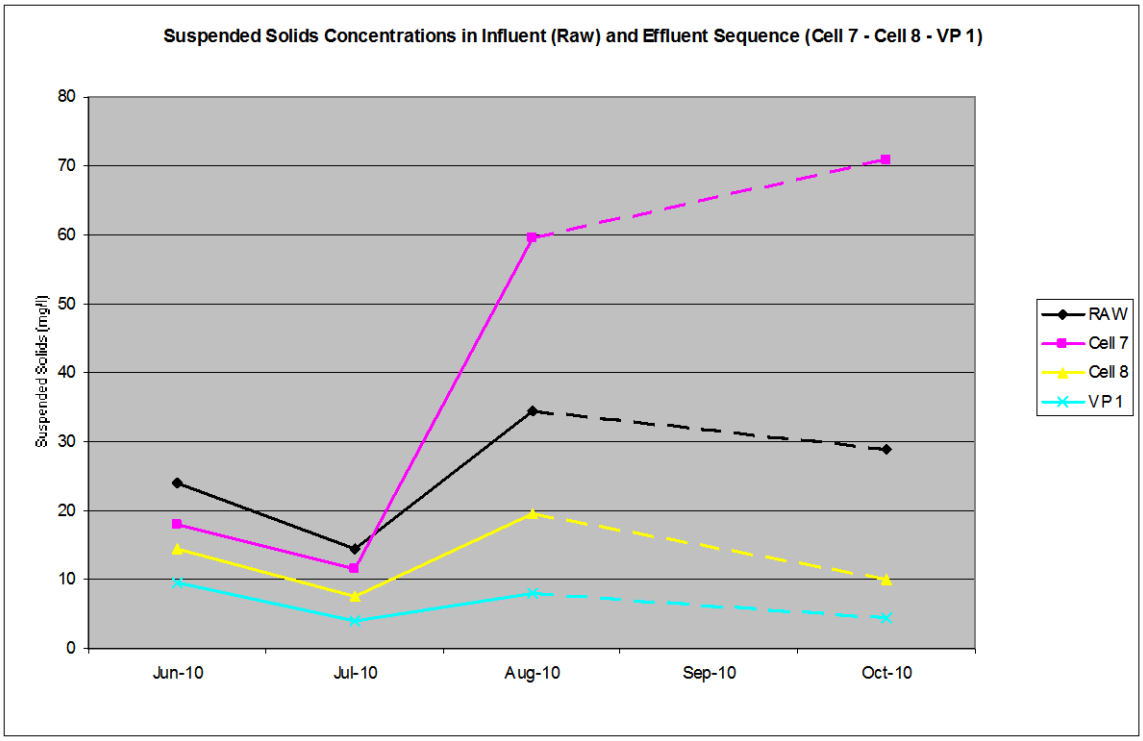


Figure 8.104(a) Suspended Solids Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

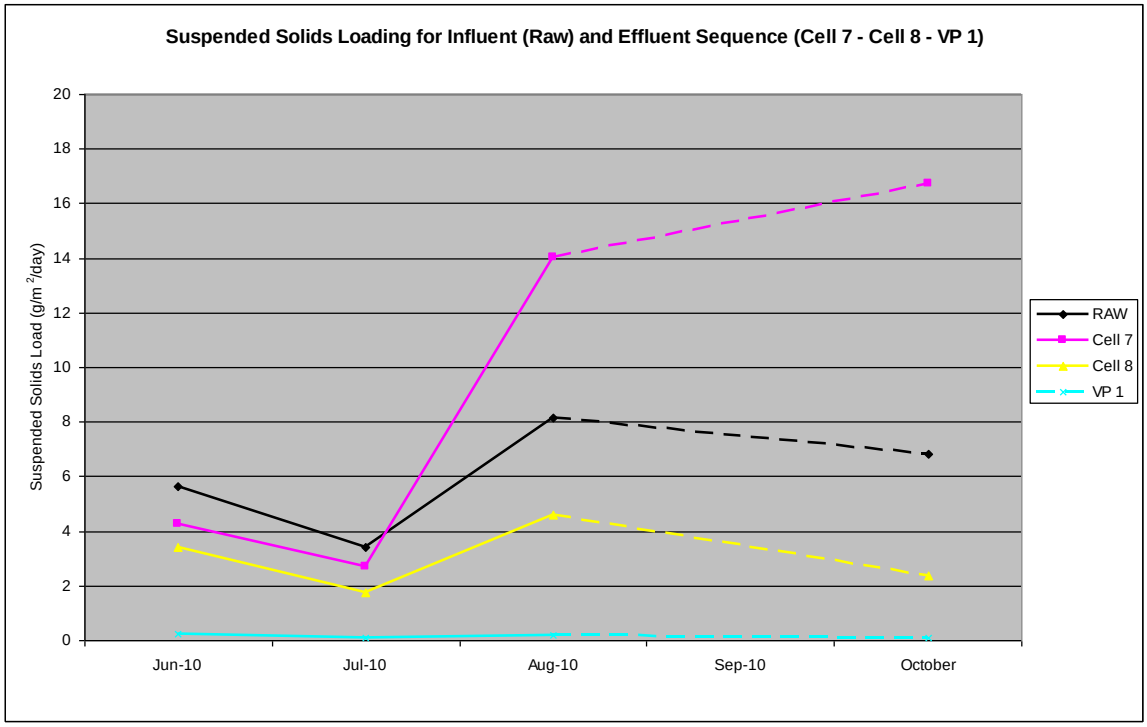


Figure 8.104(b) Suspended Solids Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

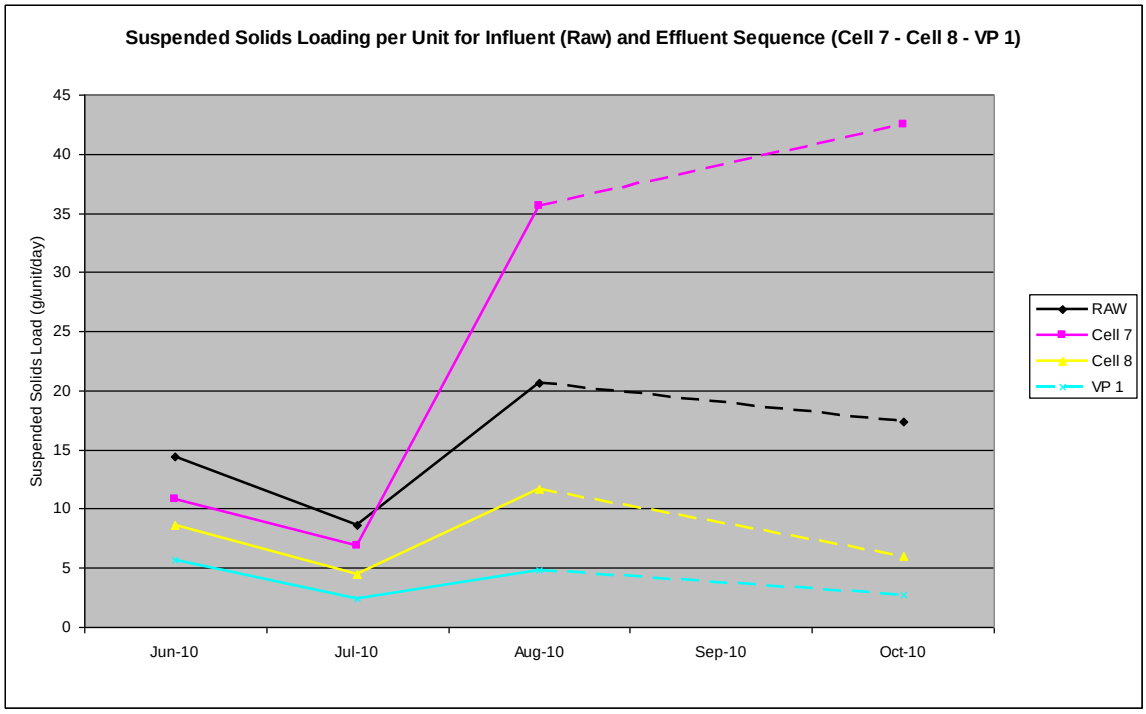


Figure 8.104(c) Suspended Solids Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Fresh Leachate (Raw Active)

Monitoring Period: May 2009 - August 2010

Table 8.109 Summary of SS Concentrations for Fresh Leachate from Active Area

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
SS	12	6 - 1064	175 (± 295)

Tramore River

Monitoring Period: June 2009 - October 2010

Table 8.110 Summary of SS Concentrations in Tramore River

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
SS	12	0.25 – 218	24 (± 62)

Interpretation of Suspended Solids Removal in Treatment Units

Analysis of suspended solids results for concentrations and load removal rates for treatment units operating in sequence reveals very much a mixed set of results.

Cells 3 and 5 display positive average load removal of 2.2g/m^2/day (71% removal) and 1.7g/m^2/day (56% removal) respectively. The averaged results for Cell 5 are distorted by two large negative load removal events in April and August 2010 where the effluent load from the unit was 3g/m^2/day and 13g/m^2/day higher than the influent load. During the course of the trial, the majority of the load removal occurred in cell 3 (timber chip medium), accounting for 71% treatment efficiency (effluent from cell 5 (containing sand, grit and gravel) in many cases returned suspended solids to the wastewater stream).

The doubling of the irrigation rate to sequence Cell 3 – Cell 5 to 189L/m^2/day resulted in a small rise in effluent load (and concentration) for cell 3; however, the effluent from each unit was well below the influent load.

Charts detailing the range of suspended solids concentrations and loadings to sequence Cell 3 – Cell 5 are presented in Figures 8.101(a) and 8.101(b).

Results from sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 were even more diverse in terms of suspended solids load removal. The sequence displayed positive cumulative load removal up to unit VF 2 (51g/unit/day, 73% removal) but this fell back to 41g/unit/day (59% removal) in VP 1 and 43g/unit/day (63% removal) in VP 2 due to negative load removal in these units. The average result for each of the grass plane units

was somewhat distorted by large negative removal rates in June 2009 (VP 1 ~ 16g/unit/day in excess of raw influent load) and August 2010 (VP 2 ~ 60g/unit/day in excess of raw influent load). An element of the negative load removal rates can be attributed to grass cutting within each unit closely followed by effluent sampling in the subsequent week or fortnight. The remainder of the additional suspended solids load in the effluent could be caused by season grass dieback with sediment flushing during wastewater dosing and pulse rainfall events.

Other anomalous results were achieved in December 2008; where effluent loads from cell 9, cell 10 and VF 1 were well in excess of the raw influent load; and during the period June to October 2010; where effluent load results for cell 9 were consistently higher than influent (up to three times the influent load).

The effect of halving hydraulic loading rate in sequence Cell 9 → VP 2 to 1200L/unit/day between February and April 2009 could not be assessed due to a lack of data for this period.

Charts detailing the range of suspended solids concentrations and loadings to sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 are presented in Figures 8.102(a) to 8.102(c).

Cells 7 and 8 produced positive results for suspended solids load removal throughout the system, recording average load removal rates of 48g/m^2/day (61% load removal) and 13g/m^2/day (42% load removal) respectively.

Sequence Cell 7 – Cell 8 - VP 1 revealed suspended solids average load removal rates of -8.7g/unit/day (-57% removal), 16.2g/unit/day (68% removal) and 3.8g/unit/day (49% removal) respectively. Over the 5 months of operation, two high negative results were recorded. In August and October 2010, the effluent load from Cell 7 was considerably higher than the influent (71% and 153% higher respectively). The exact cause is not known but the results do tally with the large negative load removal rates recorded in the effluent from the primary units of the other sequences.

It is interesting to note that the total rainfall on each of the sampling dates was extremely low (0.6mm on 16th August and 0mm on 14th October) and with similarly low total rainfall for the preceding five days.
Charts detailing the range of suspended solids concentrations and loadings to sequences Cell 7 - Cell 8 and Cell 7 – Cell 8 – VP 1 are presented in Figures 8.103(a) to 8.104(c).

Results for the Tramore River showed an average suspended solids concentration of 24mg/l with a high range of 0.25 - 218mg/l. Suspended solids concentrations in rivers are highly responsive to high pulse rainfall events and concentrations will vary according to the timing of sampling.

A comparison of the raw active leachate and the filtered leachate stream again shows a much higher concentration in the leachate from the active area with an average suspended solids concentration of 175mg/l as opposed to 30mg/l for the filtered leachate. The range of values are also particularly divergent with raw active ranging from 6mg/l to 1064mg/l and the filtered leachate ranging from 15mg/l to 55mg/l, again highlighting the degree of straining and entrainment of suspended particles from the leachate during its passage through the waste body.

The average final effluent concentrations for all sequences would meet the EPA emission limit value (ELV) of 25mg/l suspended solids for discharge to surface water with cognisance of the caveats previously mentioned.

8.3.2.4 Chloride Removal in Treatment Units

Chloride concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.111(a) to 8.113(f). Concentrations for raw active and the Tramore River are detailed in Tables 8.114 and 8.115.

Charts detailing the range of chloride concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented in Figures 8.105(a) to 8.108(c).

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Medium: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.111(a) Summary of Chloride Concentrations for sequence Cell 3 – Cell 5

Chloride Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Chloride	Influent	19	241 - 588	407 (± 105)
Chloride	Effluent Cell 3	19	266 - 581	399 (± 91)
Chloride	Effluent Cell 5	19	241 - 574	400 (± 96)

Table 8.111(b) Summary of Chloride Load Removal per m^2 for Cell 3 – Cell 5

Chloride	**CELL 3**	**CELL 5**
Influent Load g/m^2/day	40.9	39.8
Effluent Load g/m^2/day	39.8	40.0
Load Removal g/m2/day	1.2	-0.2
Cumulative Load Removal g/$m^{2/day}$	1.2	1.0
Cumulative Load Removal as % per m^2	3	2

Table 8.111(c) Summary of Chloride Load Removal per unit for Cell 3 – Cell 5

Chloride	**CELL 3**	**CELL 5**
Influent Load g/unit/day	104.0	101.0
Effluent Load g/unit/day	101.0	101.5
Load Removal g/unit/day	3.0	-0.5
Cumulative Load Removal g/unit/day	3.0	2.5
Cumulative Load Removal as % per unit	3	2

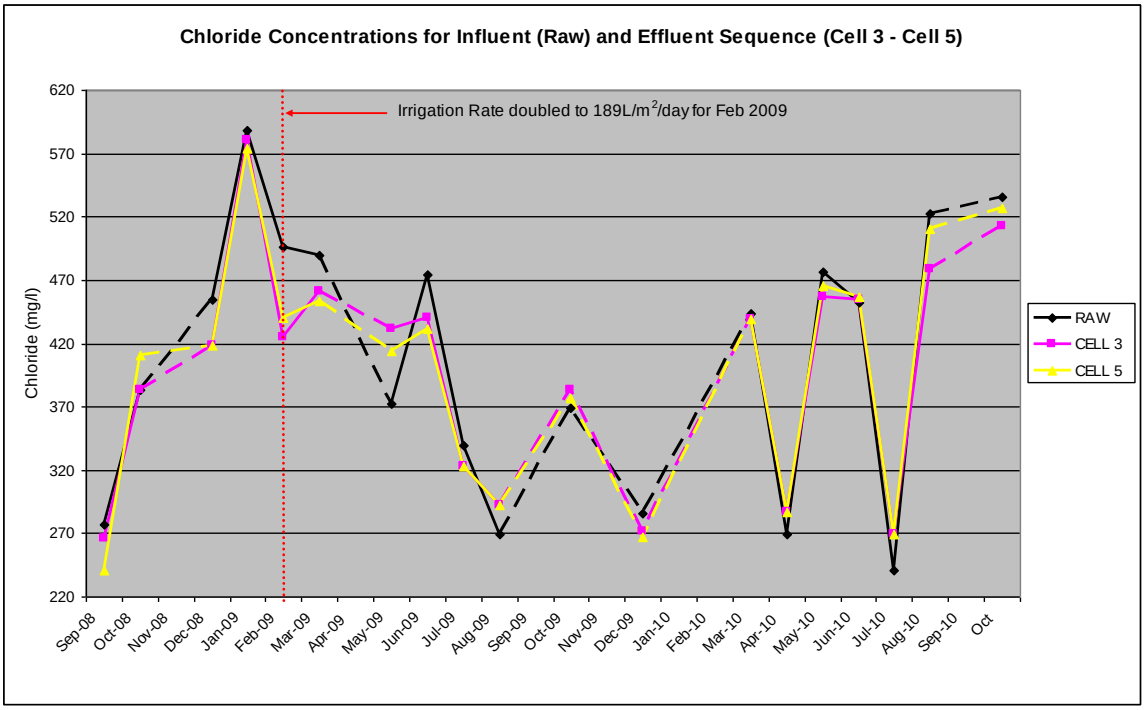


Figure 8.105(a) Chloride Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

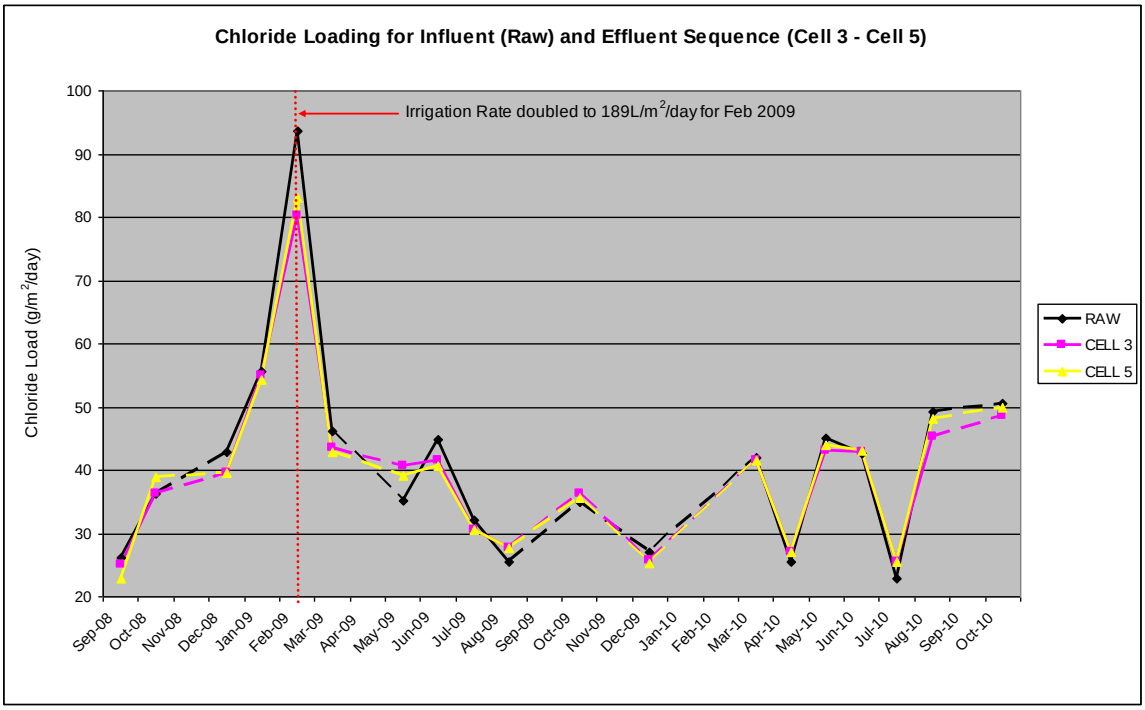


Figure 8.105(b) Chloride Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings*

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix*

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.112(a) Summary of Chloride Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Chloride Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Chloride	Influent	19	241 - 558	404 (± 103)
Chloride	Effluent Cell 9	19	258 - 574	397 (± 90)
Chloride	Effluent Cell 10	19	261 - 588	396 (± 90)
Chloride	Effluent VF 1	19	252 - 574	397 (± 89)
Chloride	Effluent VF 2	19	230 - 525	380 (± 90)
Chloride	Effluent HF 2	4	255 - 475	389 (± 94)
Chloride	Effluent VP 1	9	151 - 445	312 (± 103)
Chloride	Effluent VP 2	13	145 - 519	347 (± 120)

Table 8.112(b) Summary of Chloride Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Chloride	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	359	354	36	36	34	34	30
Effluent Load g/m^2/day	354	353	36	34	37	30	33
Load Removal g/m^2/day	5.4	1.1	-0.1	1.5	-2.87	4.50	-3.37
Cumulative Load Removal g/m^2/day	5.4	6.5	6.4	8	5.02	12.40	9.03

Table 8.112(c) Summary of Chloride Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Chloride	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	912	899	896	899	862	862	749
Effluent Load g/unit/day	899	896	899	862	934	749	833
Removal g/unit/day	14	3	-3	37	-72	113	-84
Cumulative Load Removal g/unit/day	14	17	13	50	-21	276	79
Cumulative Load Removal as % per unit	2	2	1	6	-2	30	9

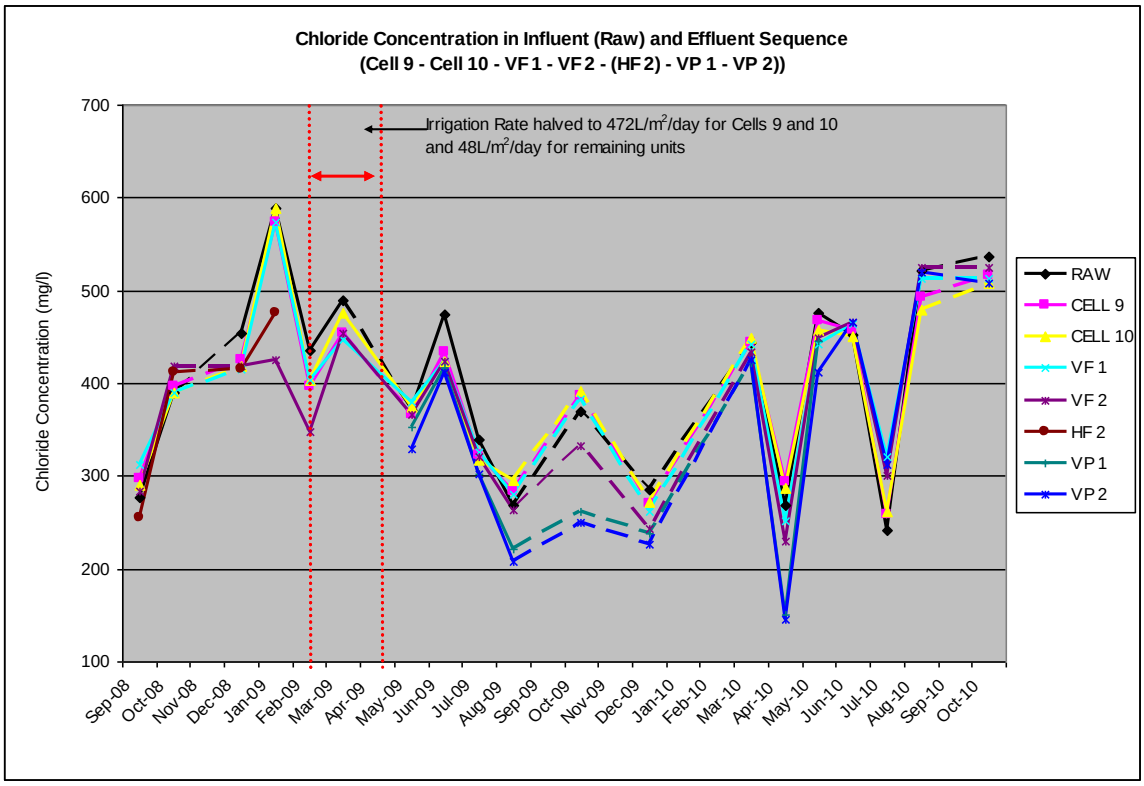


Figure 8.106(a) Chloride Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

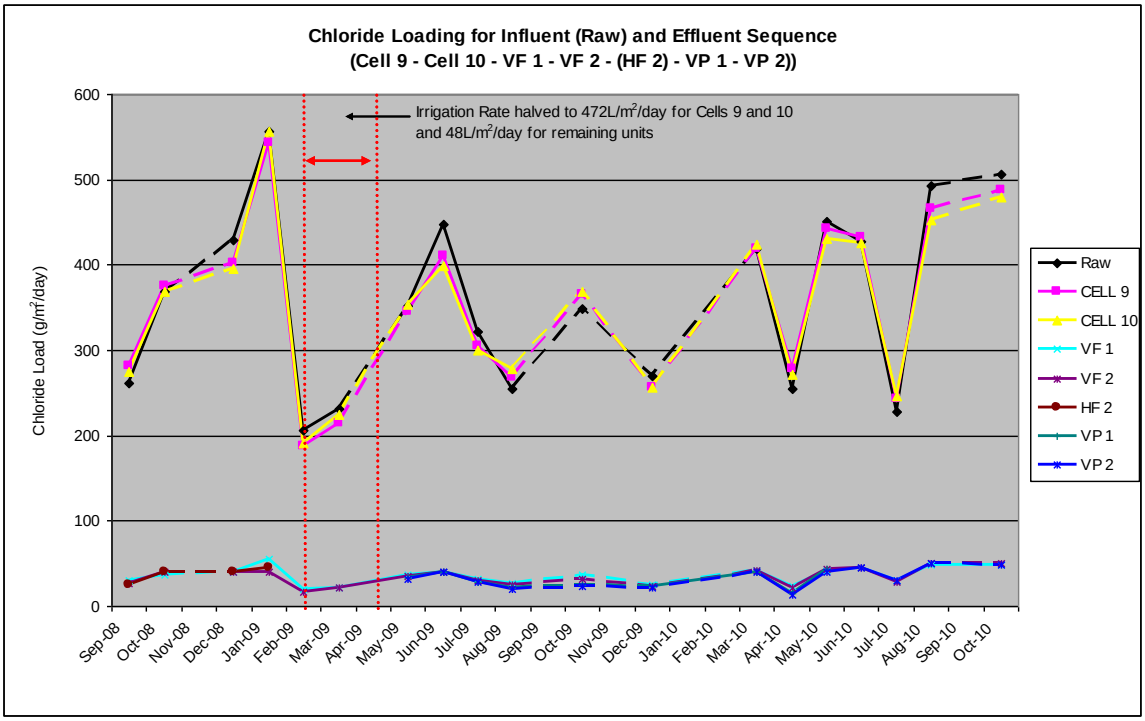


Figure 8.106(b) Chloride Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

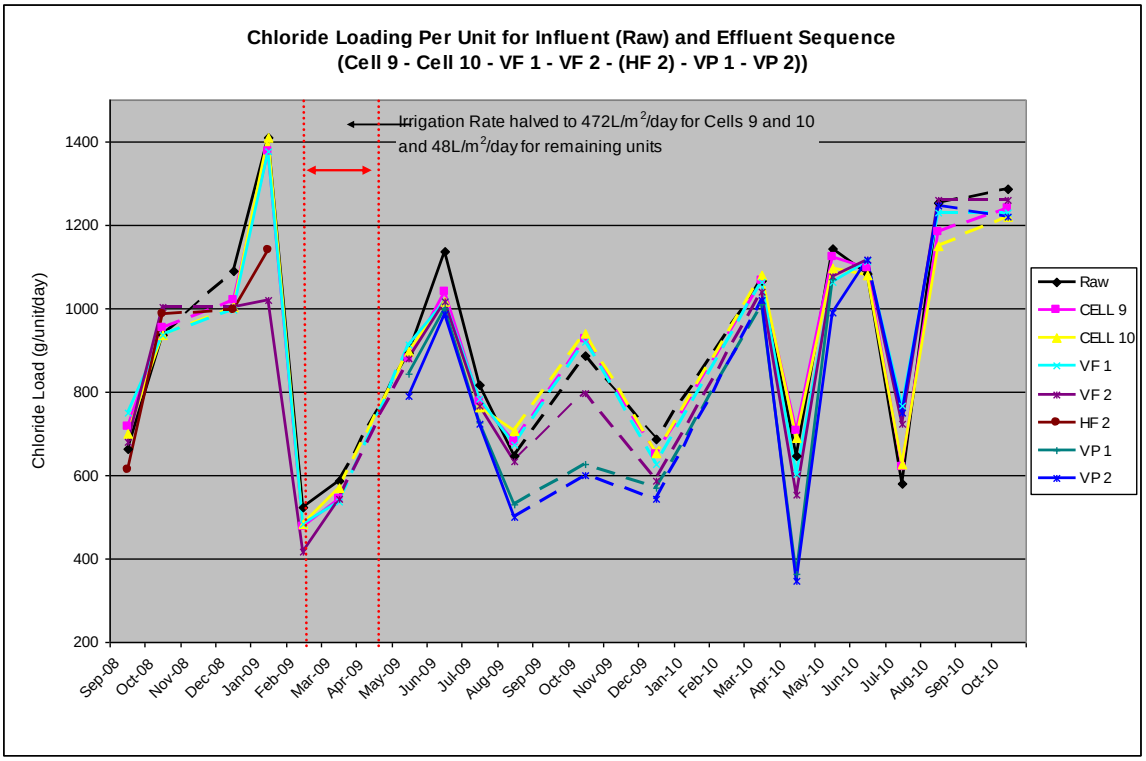


Figure 8.106(c) Chloride Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.113(a) Summary of Chloride Concentrations for sequence Cell 7 – Cell 8

Chloride Concentration (Raw - Cell 7 - Cell 8)				
Chloride	Influent	8	269 - 476	388 (± 83)
Chloride	Effluent Cell 7	8	275 - 464	380 (± 76)
Chloride	Effluent Cell 8	8	267 - 457	379 (± 74

Table 8.113(b) Summary of Chloride Load Removal per m^2 for Cell 7 – Cell 8

Chloride	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	366.4	358.9
Effluent Load g/m^2/day	358.9	357.6
Removal g/m^2/day	7.6	1.2
Cumulative Load Removal g/m^2/day	7.6	8.8
Cumulative Load Removal as % per m^2	2.1	2.4

Table 8.113(c) Summary of Chloride Load Removal per unit for Cell 7 – Cell 8

Chloride	CELL 7	CELL 8
Influent Load g/unit/day	930.7	911.6
Effluent Load g/unit/day	911.6	908.4
Load Removal g/unit/day	19.2	3.1
Cumulative Load Removal g/unit/day	19.2	22.3
Cumulative Load Removal as % per unit	2.1	2.4

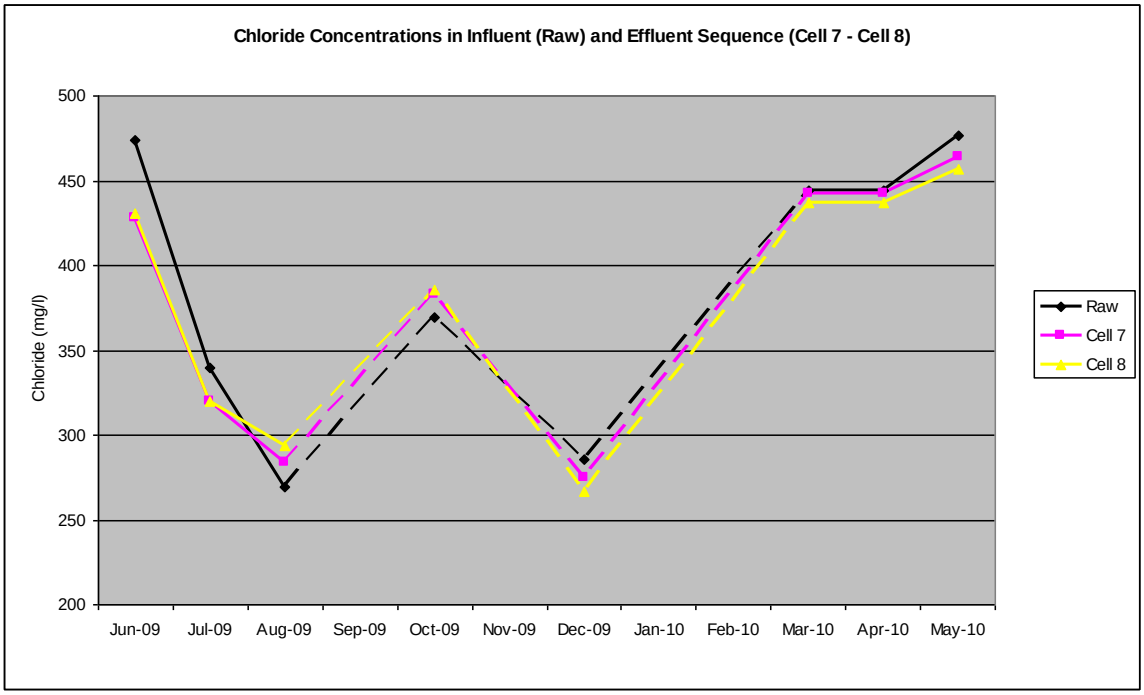


Figure 8.107(a) Chloride Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

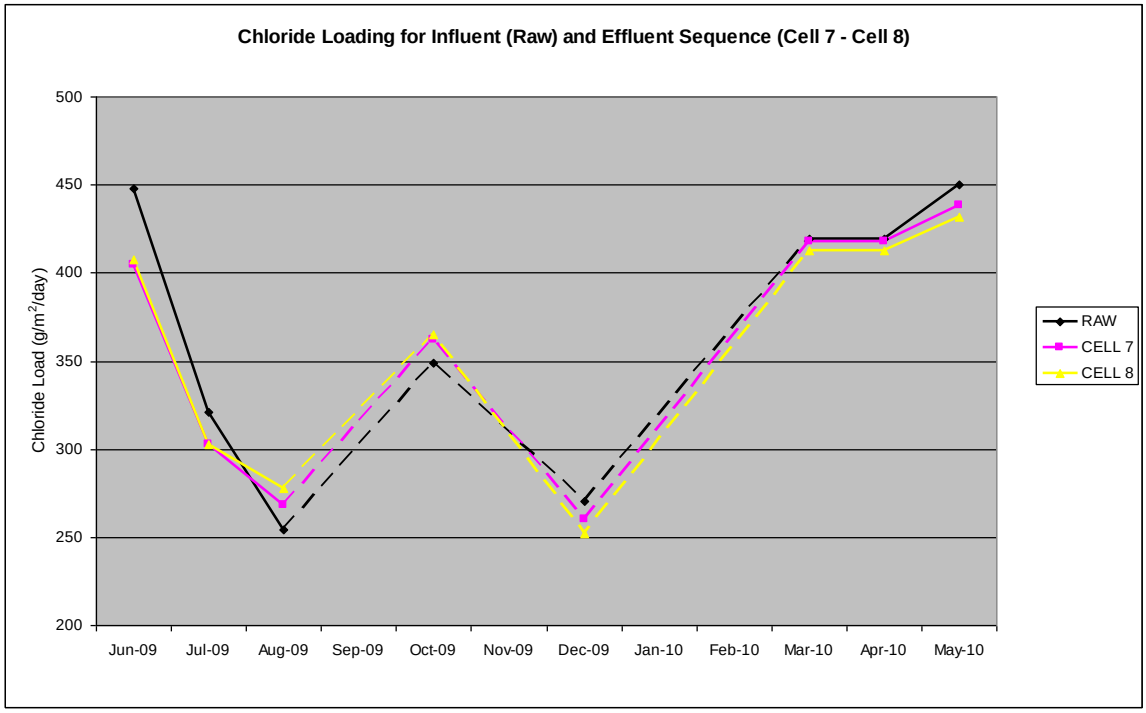


Figure 8.107(b) Chloride Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Operational Period: June 2010 – October 2010

Average daily flow = 600L/unit/day

Table 8.113(d) Summary of Chloride Concentrations for sequence Cell 7 – Cell 8 – VP 1

Chloride Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Chloride	Influent	4	241 - 536	438 (± 136)
Chloride	Effluent Cell 7	4	281 - 508	427 (± 101)
Chloride	Effluent Cell 8	4	312 - 510	433 (± 85)
Chloride	Effluent VP 1	4	315 - 478	416 (± 78)

Table 8.113(e) Summary of Chloride Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

Chloride	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/m^2/day	103.2	100.7	10.4
Effluent Load g/m^2/day	100.7	102.0	10.0
Load Removal g/m^2/day	2.5	-1.2	0.4
Cumulative Load Removal g/m^2/day	2	1	2

Table 8.113(f) Summary of Chloride Load Removal per unit for Cell 7 – Cell 8 – VP 1

Chloride	CELL 7	CELL 8	VP 1
Influent Load g/unit/day	262.1	255.8	259.0
Effluent Load g/unit/day	255.8	259.0	249.5
Load Removal g/unit/day	6.3	-3.1	9.5
Cumulative Load Removal g/unit/day	6.3	3.1	12.7
Cumulative Load Removal as % per unit	2	1	5

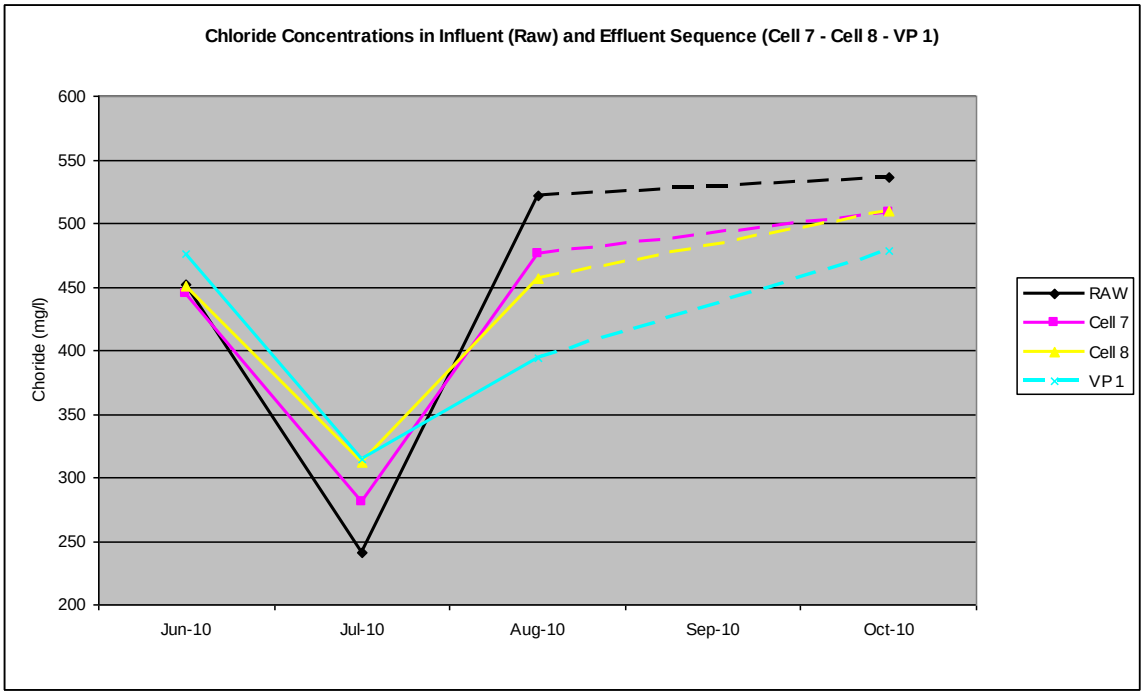


Figure 8.108(a) Chloride Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

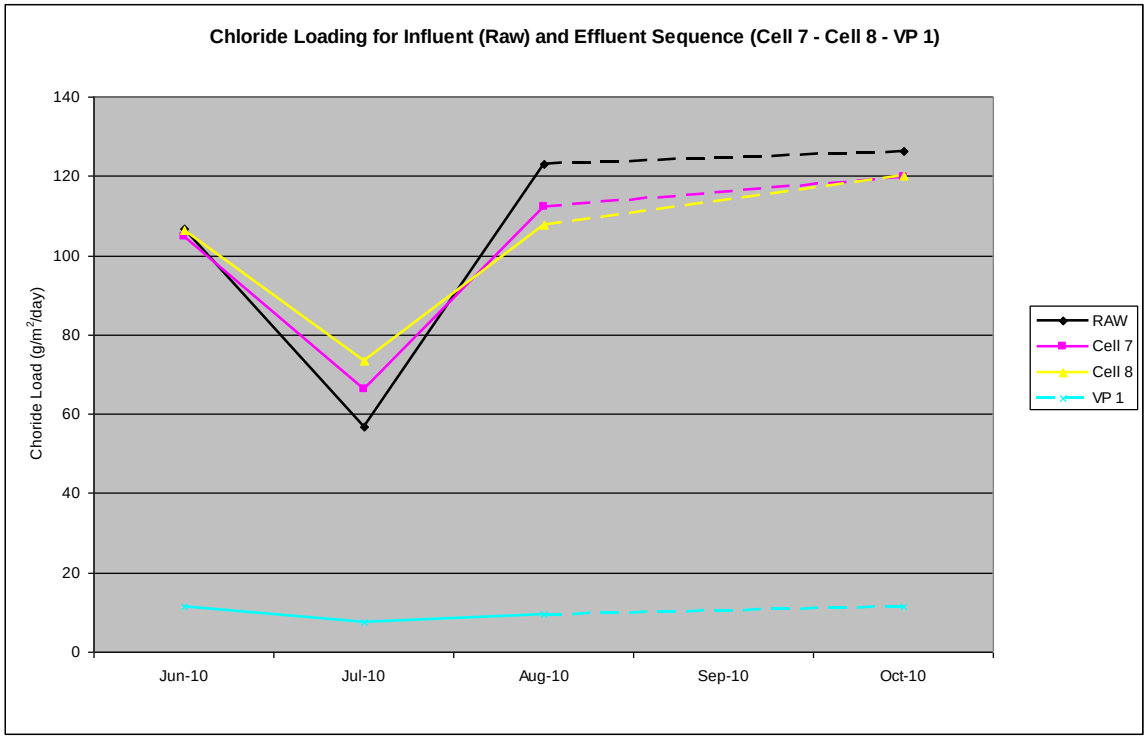


Figure 8.108(b) Chloride Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

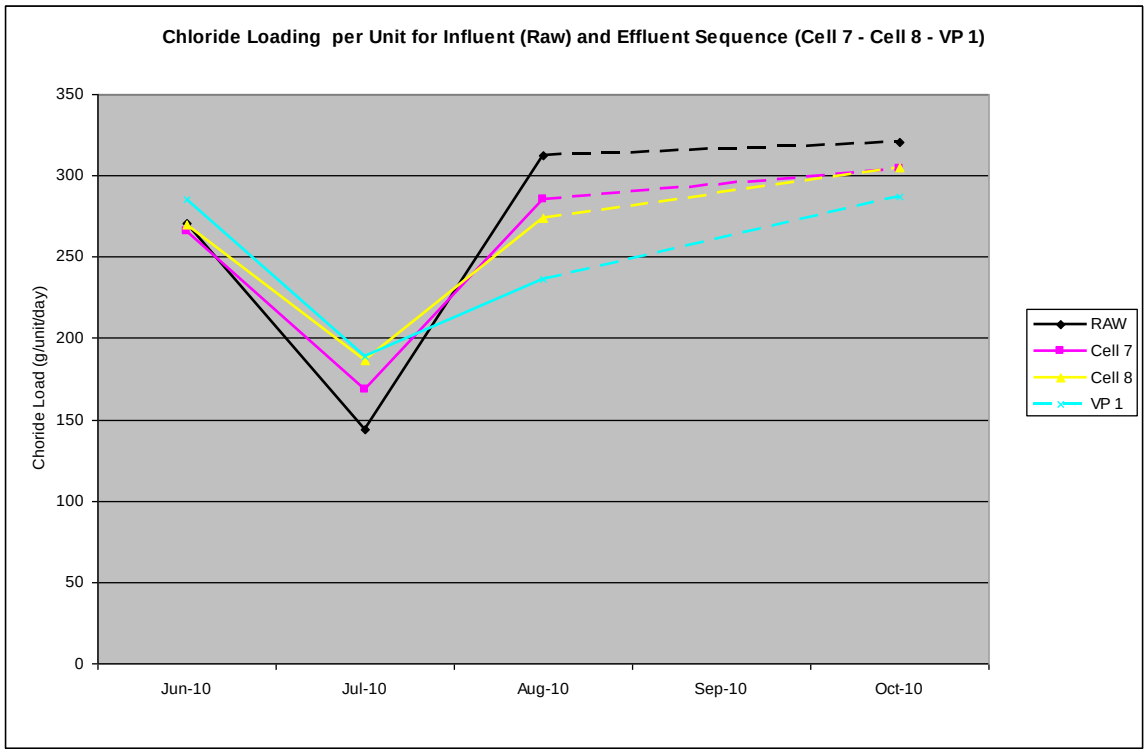


Figure 8.108(c) Chloride Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Fresh Leachate (Raw Active)

Monitoring Period: May 2009 - August 2010

Table 8.114 Summary of Chloride Concentrations for Fresh Leachate from Active Area

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
Chloride	12	18 - 1353	480 (± 461)

Tramore River

Monitoring Period: June 2009 - October 2010

Table 8.115 Summary of Chloride Concentrations in Tramore River

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
Chloride	12	14 – 71	24 (± 18)

Interpretation of Chloride Removal in Treatment Units

Analysis of results for chloride for treatment units operating in sequence reveals a positive load removal in the final effluent for chloride in all four sequences.

Cell 3 and Cell 5 displayed average load removals for chloride of 1.2g/m^2/day (3% removal) and -0.2g/m^2/day respectively. Overall Cl load removal from this sequence was marginal and varied from positive to negative throughout the trial period.

The doubling of the irrigation rate to sequence Cell 3 – Cell 5 to 189L/m^2/day resulted in a sharp rise in effluent load (and concentration) from each cell; however, the resulting effluent load remained below the influent load (Figures 8.103(a) and 8.103(b)).

Sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 displayed an average cumulative load removal at end of sequence of 79g/unit/day (9% removal). Effluent loads from the first four treatment units in the sequence (cell 9, cell 10, VF 1 and VF 2) tended to fluctuate above and below influent load. The effluent from the vegetated plane units (VP 1 and VP 2) was generally below the influent load of the preceding treatment units. Chloride load removal achieved in the VP units was particularly high for the following months: August 2009 (load removal of 103g/unit/day and 31g/unit/day respectively), October 2009 (load removal of 170g/unit/day and 26g/unit/day respectively) and April 2010 (load removal of 190g/unit/day and 14g/unit/day respectively). Since the units were planted with salt tolerant grass, it is likely that biomass uptake coupled with grass cutting

and biomass off-take accounted for the majority of chloride load removal. Further details on grass cutting and biomass off-take are explained in section 8.3.2.7.

This alternating pattern of positive and negative load removal and varying influent and effluent concentrations is displayed in Figures 8.106(a) to 8.106(c).

Halving the hydraulic loading rate in sequence Cell 9 → VP 2 to 1200L/unit/day between February and April 2009 does not seem to have had any major effect in terms of treatment efficiency.

Sequence Cell 7 – Cell 8 showed average load removals for chloride of 7.6g/m^2/day (2.1% removal) and 1.2g/m^2/day (0.33% removal) respectively; whereas Cell 7 – Cell 8 – VP 1 presented an end of sequence average cumulative load removal of 12.7g/unit/day (5% removal). Once again, the influent and effluent from the treatment units of each sequence fluctuated above and below the influent load.

Charts detailing the range of chloride concentrations and loadings to sequences Cell 7 - Cell 8 and Cell 7 – Cell 8 – VP 1 are presented in Figures 8.107(a) to 8.108(c).

Average chloride concentration for the Tramore River was 24mg/l with a range of 14mg/l to 71mg/l.

A comparison of chloride concentrations in the raw active leachate and the filtered leachate stream are similar (average concentration of 404mg/l and 480mg/l respectively). However the range of values differ quite a lot with raw active ranging from 18mg/l to 1353mg/l and the filtered leachate ranging from 241mg/l to 558mg/l.

There are no best available technology (BAT) associated ELVs for chloride emissions to surface water quoted within EPA literature.

8.3.2.5 Iron and Manganese Removal in Treatment Units

The removal of iron and manganese from the system is detailed in this section. A series of tables outlining iron and manganese removal within treatment units operating in sequence are presented below followed by interpretation.

Iron Removal

Iron concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.116(a) to 8.118(f).

Charts detailing the range of iron concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 for phase 3 and phase 4 are presented in Figures 8.109(a) to 8.111(b).

Samples for raw active and the Tramore River were not analysed for iron concentrations.

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Medium: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.116(a) Summary of Iron Concentrations for sequence Cell 3 – Cell 5

Iron Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Iron	Influent	6	4.1 - 12.6	8.2 (± 3)
Iron	Effluent Cell 3	6	0.7 - 1.9	1.4 (± 0.5)
Iron	Effluent Cell 5	6	0.4 - 2.4	1.0 (± 0.8)

Table 8.116(b) Summary of Iron Load Removal per m^2 for Cell 3 – Cell 5

Iron	**CELL 3**	**CELL 5**
Influent Load $g/m^2/day$	0.77	0.14
Effluent Load $g/m^2/day$	0.14	0.09
Load Removal $g/m^2/day$	0.64	0.04
Cumulative Load Removal $g/m^2/day$	0.64	0.68
Cumulative Load Removal as % per m^2	82	88

Table 8.116(c) Summary of Iron Load Removal per unit for Cell 3 – Cell 5

Iron	CELL 3	CELL 5
Influent Load g/unit/day	1.96	0.34
Effluent Load g/unit/day	0.34	0.23
Load Removal g/unit/day	1.62	0.11
Cumulative Load Removal g/unit/day	1.62	1.73
Cumulative Load Removal as % per unit	82	88

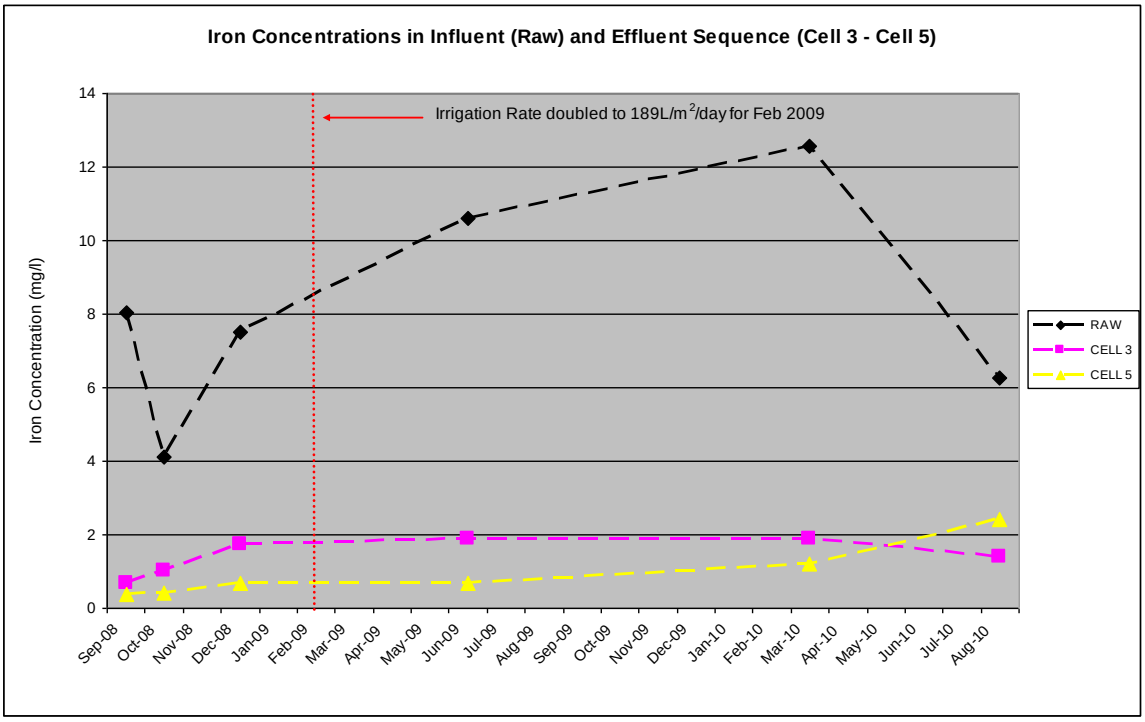


Figure 8.109(a) Iron Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

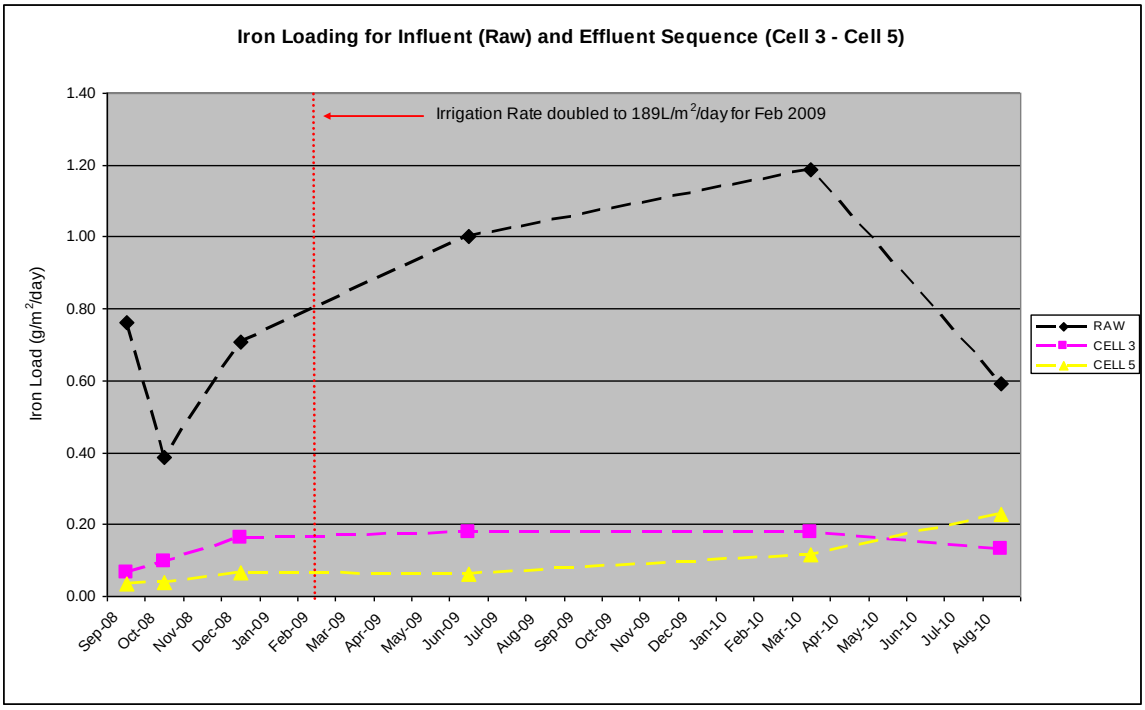


Figure 8.109(b) Iron Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.*) in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.*) in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed **(***Sparganium sp.*) in Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.117(a) Summary of Iron Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Iron Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Iron	Influent	6	4.9 - 12.6	8.3 (± 2.8)
Iron	Effluent Cell 9	5	2.2 - 5.7	4 (± 1.6)
Iron	Effluent Cell 10	6	0.4 - 2.9	1.7 (± 0.9)
Iron	Effluent VF 1	6	0.5 - 1.6	1 (± 0.5)
Iron	Effluent VF 2	6	0.2 - 1.2	0.6 (± 0.4)
Iron	Effluent HF 2	3	0.3 - 0.9	0.5 (± 0.3)
Iron	Effluent VP 1	2	0.3 - 0.4	0.4 (± 0.1)
Iron	Effluent VP 2	3	0.04 - 1.2	0.5 (± 0.6)

Table 8.117(b) Summary of Iron Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Iron	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	7.8	3.8	0.2	0.10	0.05	0.05	0.03
Effluent Load g/m^2/day	3.8	1.6	0.1	0.05	0.05	0.03	0.04
Load Removal g/m^2/day	4.06	2.18	0.07	0.04	0.00	0.02	-0.01
Cumulative Load Removal g/m^2/day	4.1	6.2	6.3	6.4	6.4	6.4	6.4

Table 8.117(c) Summary of Iron Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Iron	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	19.9	9.6	4.1	2.4	1.4	1.4	0.9
Effluent Load g/unit/day	9.6	4.1	2.4	1.4	1.3	0.9	1.1
Load Removal g/unit/day	10.3	5.5	1.6	1.0	0.1	0.5	-0.3
Cumulative Load Removal g/unit/day	10.3	15.9	17.5	18.5	18.7	19.0	18.8
Cumulative Load Removal as % per unit	52	80	88	93	94	96	94

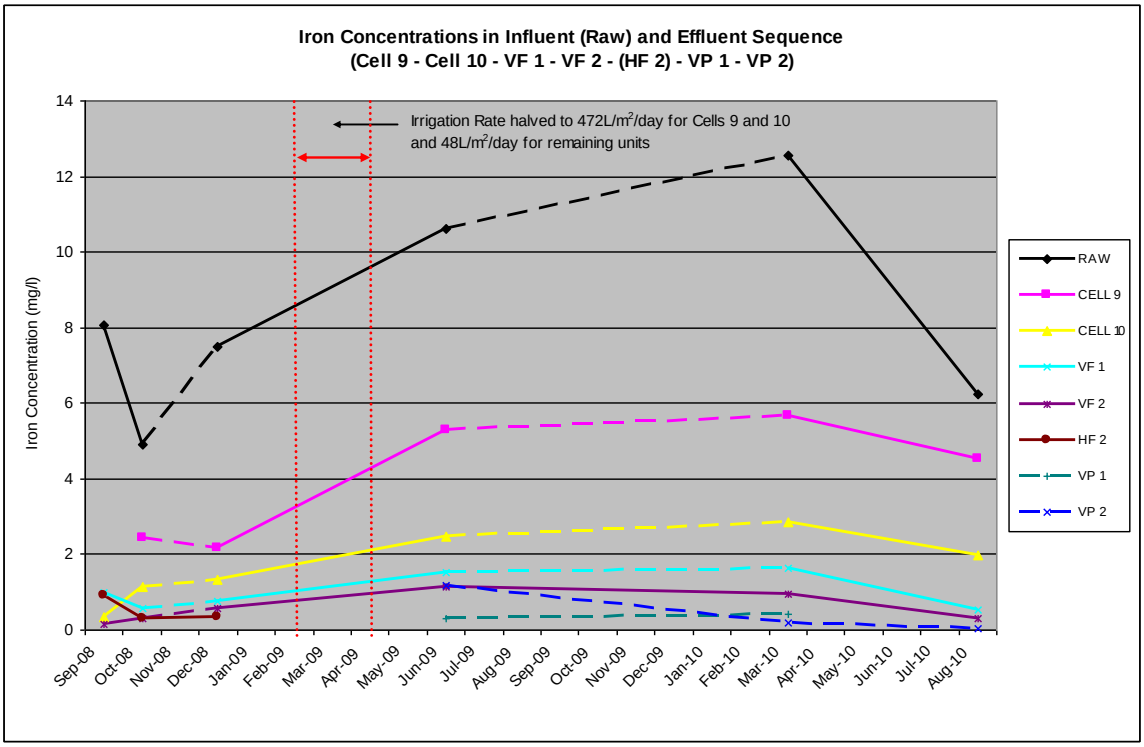


Figure 8.110(a) Iron Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

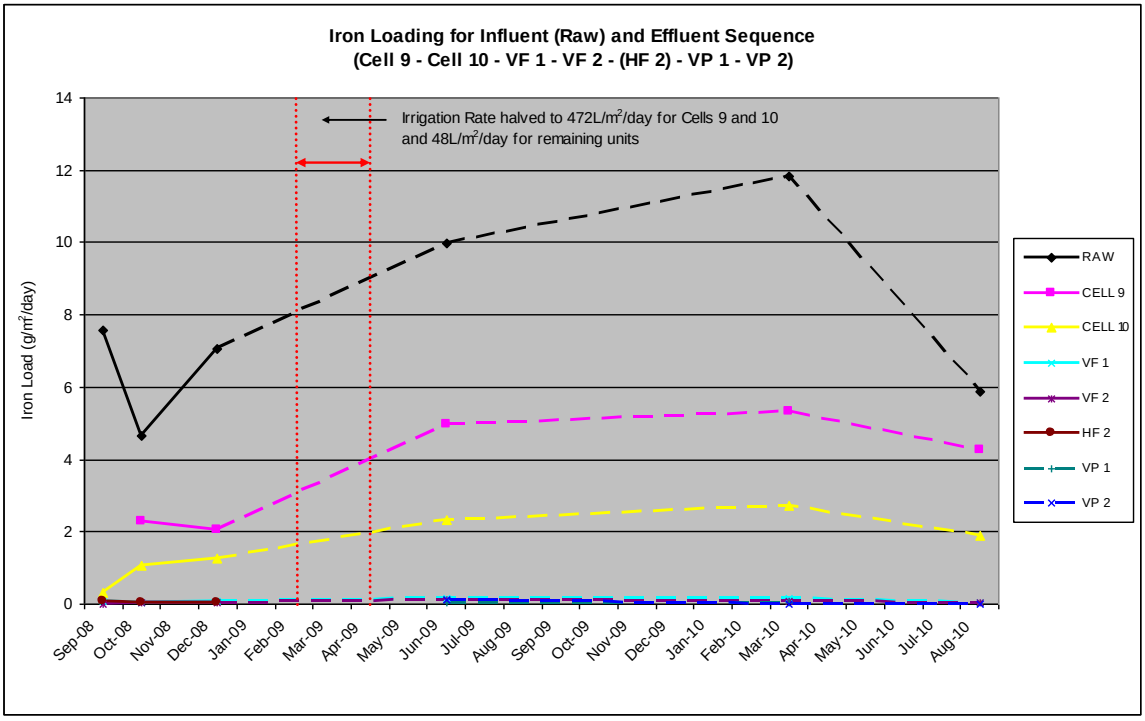


Figure 8.110(b) Iron Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

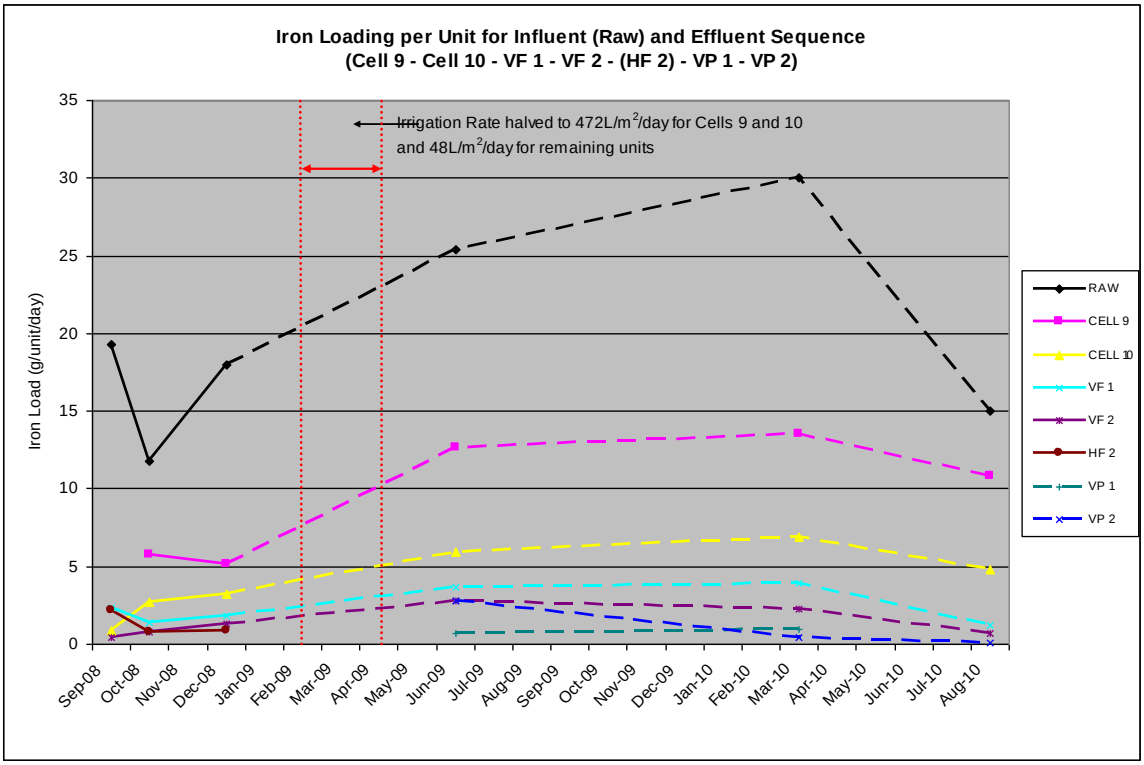


Figure 8.110(c) Iron Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.118(a) Summary of Iron Concentrations for sequence Cell 7 – Cell 8

Iron Concentration (Raw - Cell 7 - Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Iron	Influent	2	10.6 - 12.6	11.6 (± 1.4)
Iron	Effluent Cell 7	2	4.0 - 4.3	4.2 (± 0.2)
Iron	Effluent Cell 8	2	2.1 - 2.2	2.1

Table 8.118(b) Summary of Iron Load Removal per m^2 for Cell 7 – Cell 8

Iron	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	10.94	3.92
Effluent Load g/m^2/day	3.92	2.02
Load Removal g/m^2/day	7.02	1.90
Cumulative Load Removal g/m^2/day	7.02	8.92
Cumulative Load Removal as % per m^2	64	82

Table 8.118(c) Summary of Iron Load Removal per unit for Cell 7 – Cell 8

Iron	CELL 7	CELL 8
Influent Load g/unit/day	27.78	9.96
Effluent Load g/unit/day	9.96	5.12
Load Removal g/unit/day	17.82	4.84
Cumulative Load Removal g/unit/day	17.82	22.66
Cumulative Load Removal as % per unit	64	82

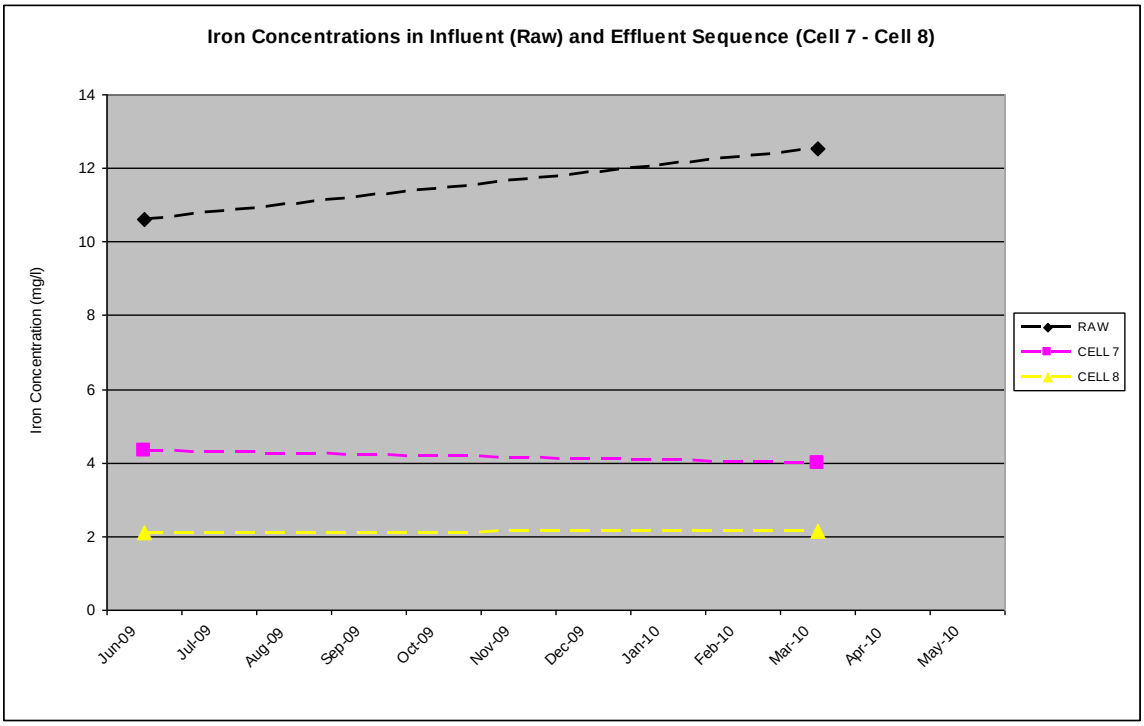


Figure 8.111(a) Iron Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

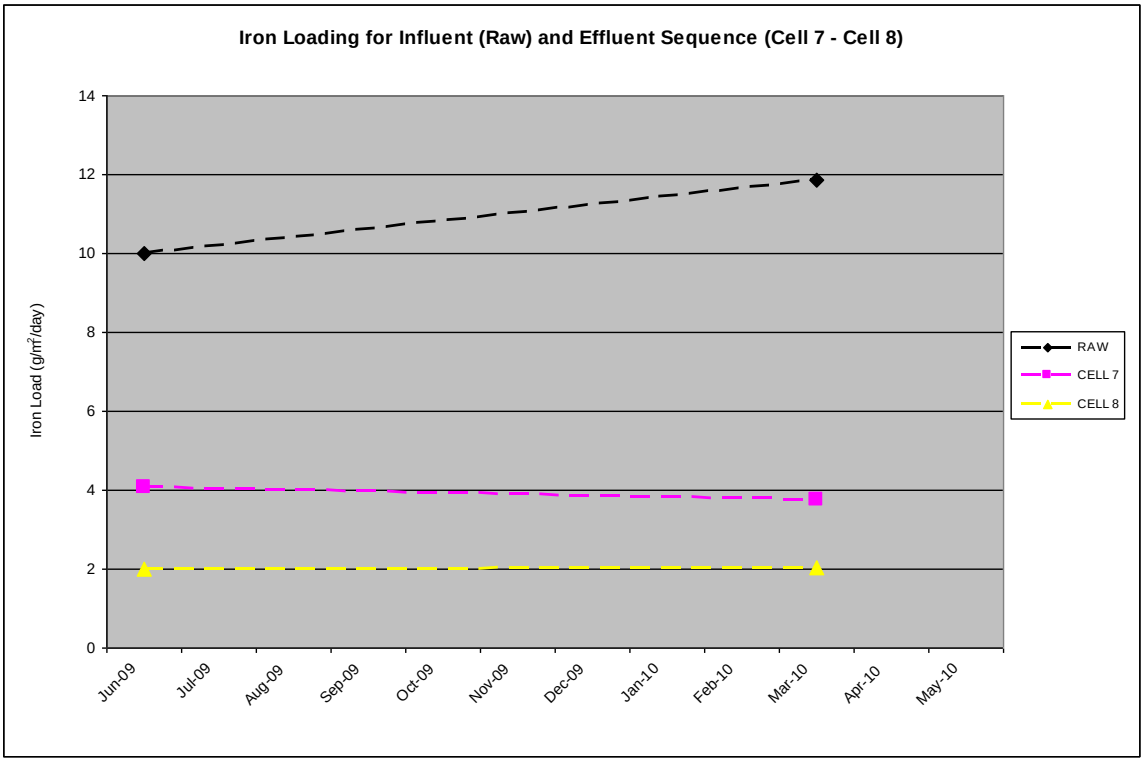


Figure 8.111(b) Iron Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Average daily flow = 600L/unit/day

Operational Period: June 2010 – October 2010

Table 8.118(d) Summary of Iron Concentrations for sequence Cell 7 – Cell 8 – VP 1

Iron Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Iron	Influent	1	6.25	6.25
Iron	Effluent Cell 7	1	3.16	3.16
Iron	Effluent Cell 8	1	1.41	1.41
Iron	Effluent VP 1	1	0.02	0.02

Table 8.118(e) Summary of Iron Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

Iron	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/m^2/day	1.48	0.75	0.03
Effluent Load g/m^2/day	0.75	0.33	0.001
Load Removal g/m^2/day	0.73	0.41	0.03
Cumulative Load Removal g/m^2/day	0.73	1.14	1.18

Table 8.118(f) Summary of Iron Load Removal per unit for Cell 7 – Cell 8 – VP 1

Iron	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/unit/day	3.75	1.90	0.85
Effluent Load g/unit/day	1.90	0.85	0.01
Load Removal g/unit/day	1.85	1.05	0.83
Cumulative Load Removal g/unit/day	1.85	2.90	3.74
Cumulative Load Removal as % per unit	49	77	99.6

Manganese Removal

Manganese (Mn) concentrations and removal efficiencies for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 and Cell 7 – Cell 8 – (VP 1) for phase 3 and phase 4 are presented below in Tables 8.119(a) to 8.121(f). Charts detailing the range of manganese concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP2 and Cell 7 – Cell 8 for phase 3 and phase 4 are presented in Figures 8.112(a) to 8.113(c).

Samples for raw active and the Tramore River were not analysed for manganese concentrations.

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.119(a) Summary of Mn Concentrations for sequence Cell 3 – Cell 5

Mn Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Mn	Influent	6	2.21 - 3.79	2.95 (± 0.51)
Mn	Effluent Cell 3	6	0.35 - 3.11	1.49 (± 1.20)
Mn	Effluent Cell 5	6	0.31 - 1.19	0.79 (± 0.35)

Table 8.119(b) Summary of Mn Load Removal per m^2 for Cell 3 – Cell 5

Mn	**CELL 3**	**CELL 5**
Influent Load g/m^2/day	0.28	0.14
Effluent Load g/m^2/day	0.14	0.07
Load Removal g/m^2/day	0.14	0.07
Cumulative Load Removal g/m^2/day	0.14	0.20
Cumulative Load Removal as % per m^2	50	73

Table 8.119(c) Summary of Mn Load Removal per unit for Cell 3 – Cell 5

Mn	**CELL 3**	**CELL 5**
Influent Load g/unit/day	0.71	0.36
Effluent Load g/unit/day	0.36	0.19
Load Removal g/unit/day	0.35	0.17
Cumulative Load Removal g/unit/day	0.35	0.52
Cumulative Load Removal as % per unit	50	73

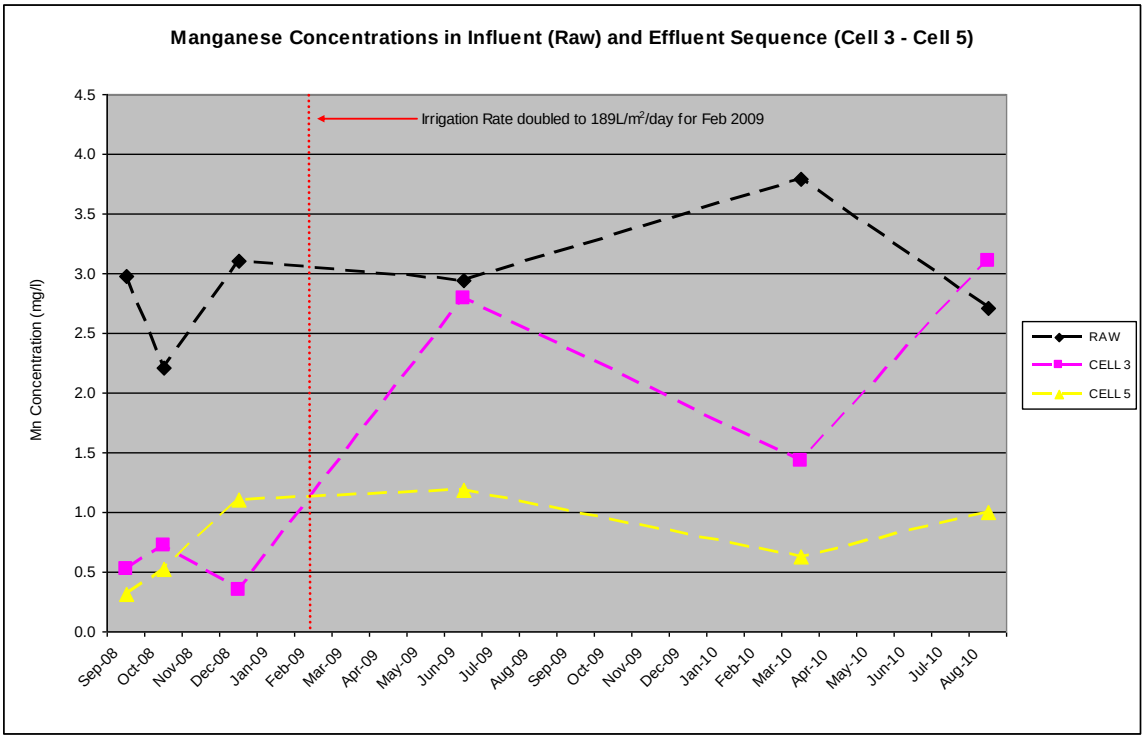


Figure 8.112(a) Mn Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

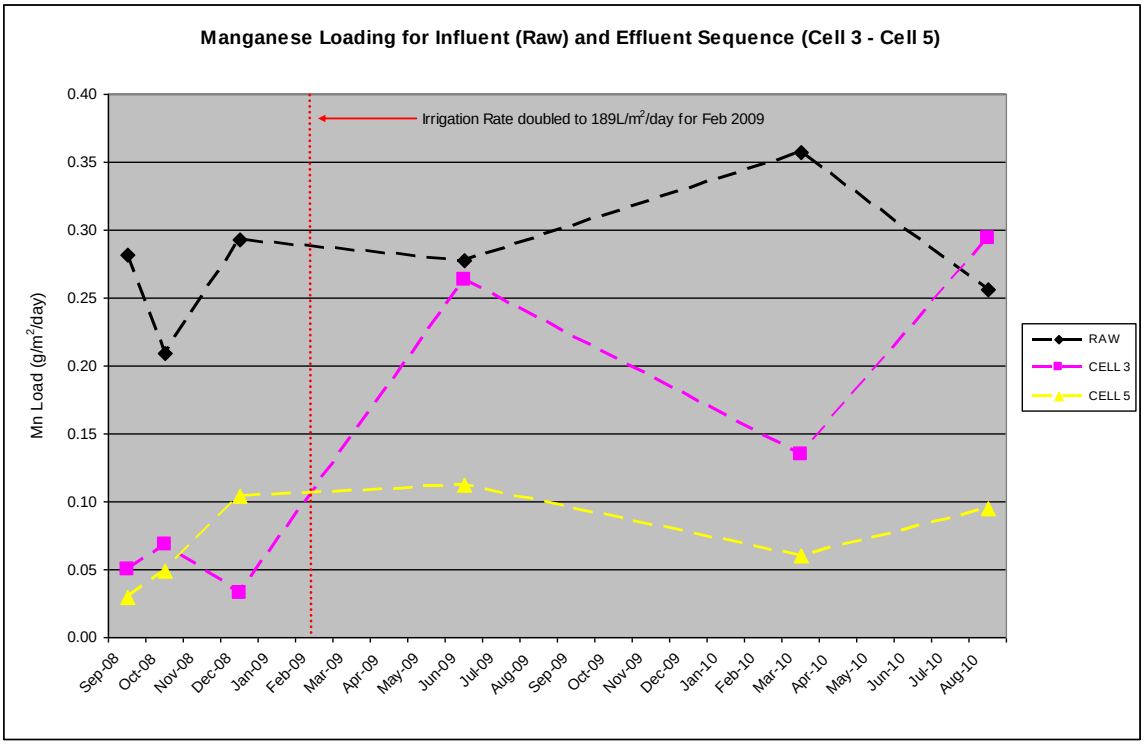


Figure 8.112(b) Mn Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.120(a) Summary of Mn Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Mn Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Mn	Influent	6	2.43 - 3.79	2.99 (± 0.46)
Mn	Effluent Cell 9	5	2.28 - 3.03	2.78 (± 0.29)
Mn	Effluent Cell 10	6	1.42 - 7.81	2.95 (± 2.42)
Mn	Effluent VF 1	6	1.28 - 7.79	2.70 (± 2.51)
Mn	Effluent VF 2	6	0.29 - 6.98	2.36 (± 2.36)
Mn	Effluent HF 2	3	0.27 - 1.11	0.62 (± 0.44)
Mn	Effluent VP 1	2	0.14 - 0.49	0.31 (± 0.25)
Mn	Effluent VP 2	3	0.02 - 0.15	0.06 (± 0.07)

Table 8.120(b) Summary of Mn Load Removal per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Mn	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	2.83	2.62	0.28	0.26	0.23	0.23	0.03
Effluent Load g/m^2/day	2.62	2.78	0.26	0.23	0.06	0.03	0.01
Load Removal g/m^2/day	0.20	-0.16	0.02	0.03	0.17	0.20	0.02
Cumulative Load Removal g/m^2/day	0.20	0.04	0.07	0.10	0.26	0.29	0.32

Table 8.120(c) Summary of Mn Load Removal per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Mn	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	7.18	6.67	7.07	6.48	5.68	5.68	0.75
Effluent Load g/unit/day	6.67	7.07	6.48	5.68	1.49	0.75	0.15
Load Removal g/unit/day	0.51	-0.40	0.59	0.80	4.18	4.93	0.59
Cumulative Load Removal g/unit/day	0.51	0.11	0.70	1.50	5.68	6.43	7.03
Cumulative Load Removal as % per unit	7	1	10	21	9	90	98

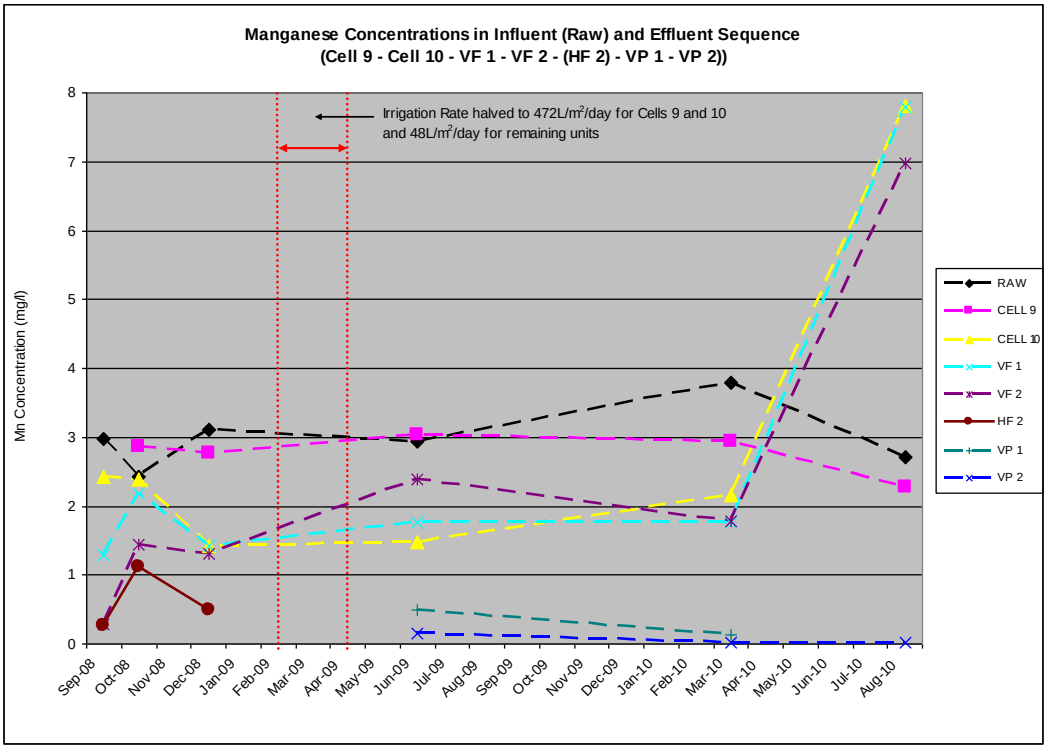


Figure 8.113(a) Mn Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

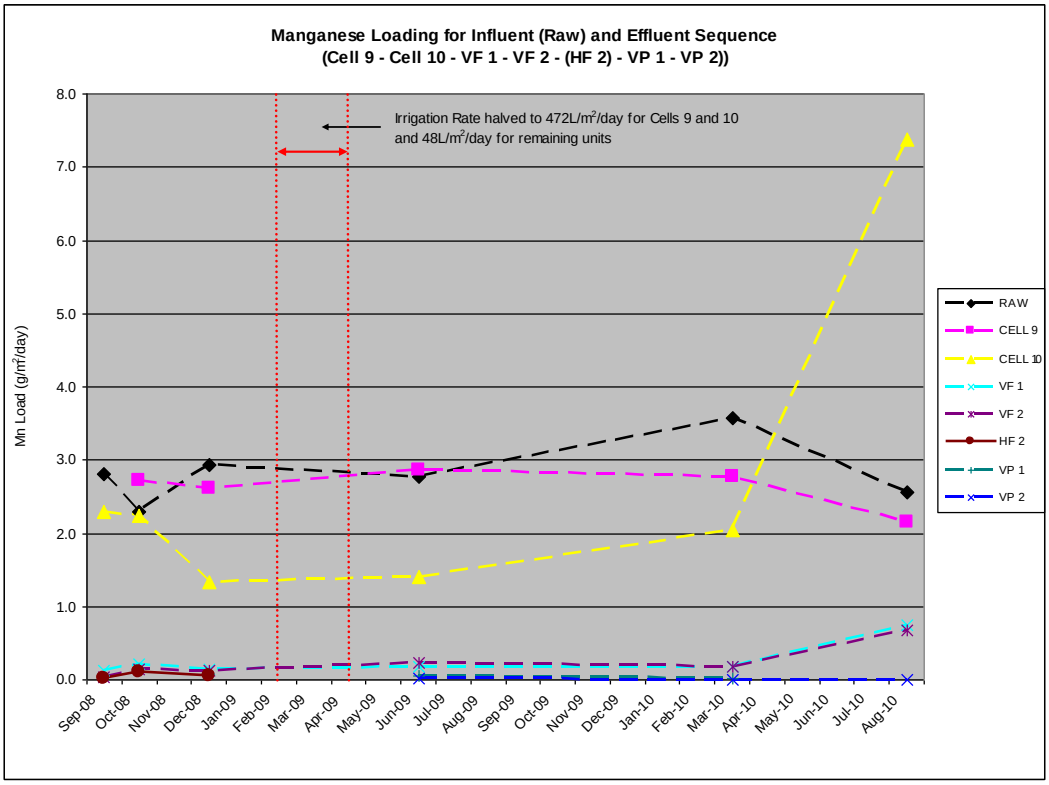


Figure 8.113(b) Mn Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

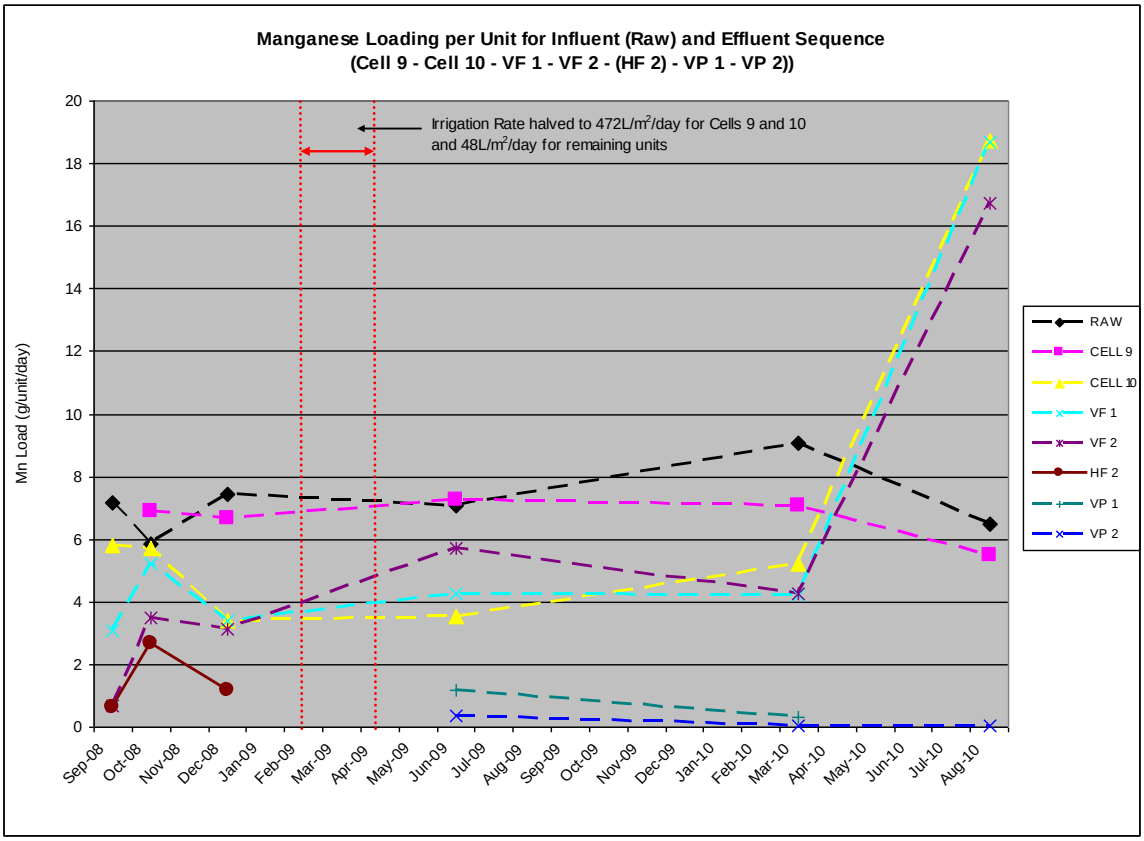


Figure 8.113(c) Mn Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.121(a) Summary of Mn Concentrations for sequence Cell 7 – Cell 8

Mn Concentration (Raw - Cell 7 - Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Mn	Influent	2	2.94 - 3.79	3.36 (± 0.60)
Mn	Effluent Cell 7	2	2.49 - 2.53	2.51 (± 0.03)
Mn	Effluent Cell 8	2	0.89 - 1.69	1.29 (± 0.57)

Table 8.121(b) Summary of Mn Load Removal per m^2 for Cell 7 – Cell 8

Mn	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	3.17	2.37
Effluent Load g/m^2/day	2.37	1.22
Load Removal g/m^2/day	0.80	1.15
Cumulative Load Removal g/m^2/day	0.80	1.95
Cumulative Load Removal as % per m^2	25	62

Table 8.121(c) Summary of Mn Load Removal per unit for Cell 7 – Cell 8

Mn	**CELL 7**	**CELL 8**
Influent Load g/unit/day	8.07	6.02
Effluent Load g/unit/day	6.02	3.09
Load Removal g/unit/day	2.05	2.93
Cumulative Load Removal g/unit/day	2.05	4.98
Cumulative Load Removal as % per unit	25	62

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Operational Period: June 2010 – October 2010

Average daily flow = 600L/unit/day

Table 8.121(d) Summary of Mn Concentrations for sequence Cell 7 – Cell 8 – VP 1

Mn Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
Mn	Influent	1	2.71	2.71
Mn	Effluent Cell 7	1	6.6	6.6
Mn	Effluent Cell 8	1	0.47	0.47
Mn	Effluent VP 1	1	0.01	0.01

Table 8.121(e) Summary of Mn Load Removal per m^2 for Cell 7 – Cell 8 – VP 1

Mn	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/m^2/day	0.64	1.56	0.01
Effluent Load g/m^2/day	1.56	0.11	0.0002
Load Removal g/m^2/day	-0.92	1.45	0.01
Cumulative Load Removal g/m^2/day	-0.92	0.53	0.54

Table 8.121(f) Summary of Mn Load Removal per unit for Cell 7 – Cell 8 – VP 1

Mn	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/unit/day	1.63	3.96	0.28
Effluent Load g/unit/day	3.96	0.28	0.004
Load Removal g/unit/day	-2.33	3.68	0.28
Cumulative Load Removal g/unit/day	-2.33	1.34	1.62
Cumulative Load Removal as % per unit	-144	83	99.7

Interpretation of Iron and Manganese Removal in Treatment Units

A breakdown of results for load removal rates for iron and manganese within treatment units operating in sequence reveals strongly positive removal rates for iron and manganese within each treatment sequence.

The average cumulative load removal for iron at the end of the sequences was as follows:

- Sequence Cell 3 – Cell 5 = 0.68g/m^2/day (88% removal) (Figure 8.109(b))
- Sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 = 18.8g/unit/day (94% removal) (Figures 8.110(b) and 8.110(c))
- Sequence Cell 7 – Cell 8 = 8.92g/m^2/day (82% removal) (Figure 8.111(b))
- Sequence Cell 7 – Cell 8 – VP 1 = 3.74g/unit/day (99.6% removal)

High load removal rates were achieved in the primary treatment units within each sequence; typically removing in excess of 50% of the iron load from the wastewater stream.

The effect of changes to the hydraulic loading rate in sequences Cell 9 → VP 2 (February to April 2009) and Cell 3 – Cell 5 (February 2009) could not be assessed due to a lack of monitoring data of the period in question.

The average cumulative load removal for manganese at the end of the sequences was as follows:

- Sequence Cell 3 – Cell 5 = 0.2g/m^2/day (73% removal) (Figure 8.112(b))
- Sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 = 7.03g/unit/day (98% removal) (Figures 8.113(b) and 8.113(c))
- Sequence Cell 7 – Cell 8 = 1.95g/m^2/day (62% removal)
- Sequence Cell 7 – Cell 8 – VP 1 = 1.62g/unit/day (99.7% removal)

In sequence Cell 3 – Cell 5, each unit achieved an average load removal of 50% (0.14g/m^2/day and 0.07g/m^2/day respectively). However, results for cell 3 displayed a high effluent load on two occasions; June 2009 and August 2010; the exact reason for the high fluctuations is unknown.

In sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 the majority of Mn load removal took place in VP 1 and VP 2 grass plane units, which accounted for over 50% removal. Results for August 2010 revealed anonymously high results for cell 10, VF 1 and VF 2 where effluent load from the units was almost three times that of the raw leachate influent load (6.5g/unit/day).

In sequence Cell 7 – Cell 8 all units contributed equally to Mn load removal although the sampling number was low (n = 2).

In sequence Cell 7 – Cell 8 – VP 1, Mn removal occurred in Cell 8 and VP 1. Cell 7 produced a load removal figure of -144%, adding 2.33gMn/unit/day to the effluent.
However due to the low sampling number (n = 1) no definitive conclusion on Cell 7 Mn removal performance can be made.

Manganese removal within the grass plane units seemed to be very effective (albeit the low sampling number, n = 2). Phytoextraction of Mn has been shown to be successful in field trials for stabilising mine tailings. Makauya *et al*. (2012) described manganese uptake in Bermuda grass (*Cynodon dactylon*) of 689µg/g (61% increase over the control plot) at the New Union abandoned gold mine in Limpopo province, South Africa. Bioaccumulation of Mn from the tailings area resulted in bio-concentration in the grass leaves with lesser concentrations in the rhizosphere and plant stem. Mn is an essential micronutrient in plants, required for effective leaf function and biosynthesis of chlorophyll, and is involved in photosynthesis.
Cynodon dactylon is a salt tolerant creeping grass and shares similar properties to the varieties of halophyte grasses planted in the VP treatment units. It is likely that mowing of the VP units coupled with biomass off-take helped increase the availability of Mn in the growing media in a form suitable for plant uptake (Mn^{2+}) by accelerating decomposition of soil organic matter (Fert Facts, 2003).
The river and raw active samples were not tested for iron or manganese concentrations.

8.3.2.6 Total Oxidised Nitrogen and Total Nitrogen Results for Treatment Units

Results for total oxidised nitrogen (TON) and total nitrogen (N) for the influent and effluent of the four sequences are presented in this section.

TON (nitrate and nitrite) concentrations and loadings for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2, Cell 7 – Cell 8 and Cell 7 – Cell 8 – VP 1; for phase 3 and phase 4 are presented below in Tables 8.122(a - c), 8.123(a – c), 8.124(a – c) and 8.124(f - h). Concentrations for raw active and the Tramore River are detailed in Tables 8.125 and 8.126.

Charts detailing the range of TON concentrations and loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2, Cell 7 – Cell 8 and Cell 7 – Cell 8 – VP 1 for phase 3 and phase 4 are presented in Figures 8.114(a - b), 8.115(a – c), 8.116(a – b) and 8.117(a - c).

Nitrate results are not presented, as of the 22 samples analysed for TON, only 15 were further analysed for nitrate and nitrite.

Total N loadings for influent (Raw) and final effluent for units operating in sequence; Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2, Cell 7 – Cell 8 and Cell 7 – Cell 8 – VP 1 for phase 3 and phase 4 are presented in Tables 8.122(d - e), 8.123(d - e), 8.124(d - e) and 8.124(i - j).

Charts detailing the range of N loadings for sequences Cell 3 – Cell 5; Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2, Cell 7 – Cell 8 and Cell 7 – Cell 8 – VP 1 for phase 3 and phase 4 are presented in Figures 8.114(c), 8.115(d - e), 8.116(c) and 8.117(d - e).

It should be noted that all references to total nitrogen in this project are in fact total inorganic nitrogen (NH_4, NO_2 and NO_3 as N), as the organic fraction was not measured. Although the majority of N is expected to be in the mineralised form due to the nature of the influent (leachate), the omission of organic N from the calculations presents a small, unquantified error.

In addition to the above, a further error enters into the calculation of total N whereby the figure for total oxidised nitrogen (TON) (nitrate and nitrite) is converted to N using the conversion factor for nitrate; i.e. NO_3 x 0.226 $\rightarrow$ N. The actual conversion factor for TON to N is: TON $\rightarrow$ N = (NO_3 x 0.226 $\rightarrow$ N) + (NO_2 x 0.304 $\rightarrow$ N) (www.hach.com/wah).

The actual error has not been quantified; however, the proportion of NO_2 as TON in all samples was quite low, typically ranging from 1% to 5% with an occasional high of 10%. Given that the conversion error is -0.038/0.226 (17%) (NO_2 as a proportion TON ranged from 1% to 5%), the actual error (0.17% - 0.85%) was not deemed significant and was discounted.

Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: August 2008 – October 2010

Average daily flow = 250L/unit/day

Table 8.122(a) Summary of TON Concentrations for sequence Cell 3 – Cell 5

TON Concentration (Raw - Cell 3 - Cell 5)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
TON	Influent	22	0 - 304	83 (± 85)
TON	Effluent Cell 3	22	446 - 1404	874 (± 250)
TON	Effluent Cell 5	21	37 - 1418	927 (± 323)

Table 8.122(b) Summary of TON Loading per m^2 for Cell 3 – Cell 5

TON	**CELL 3**	**CELL 5**
Influent Load g/m^2/day	9	85
Effluent Load g/m^2/day	85	93

Table 8.122(c) Summary of TON Loading per unit for Cell 3 – Cell 5

TON	**CELL 3**	**CELL 5**
Influent Load g/unit/day	23	216
Effluent Load g/unit/day	216	236

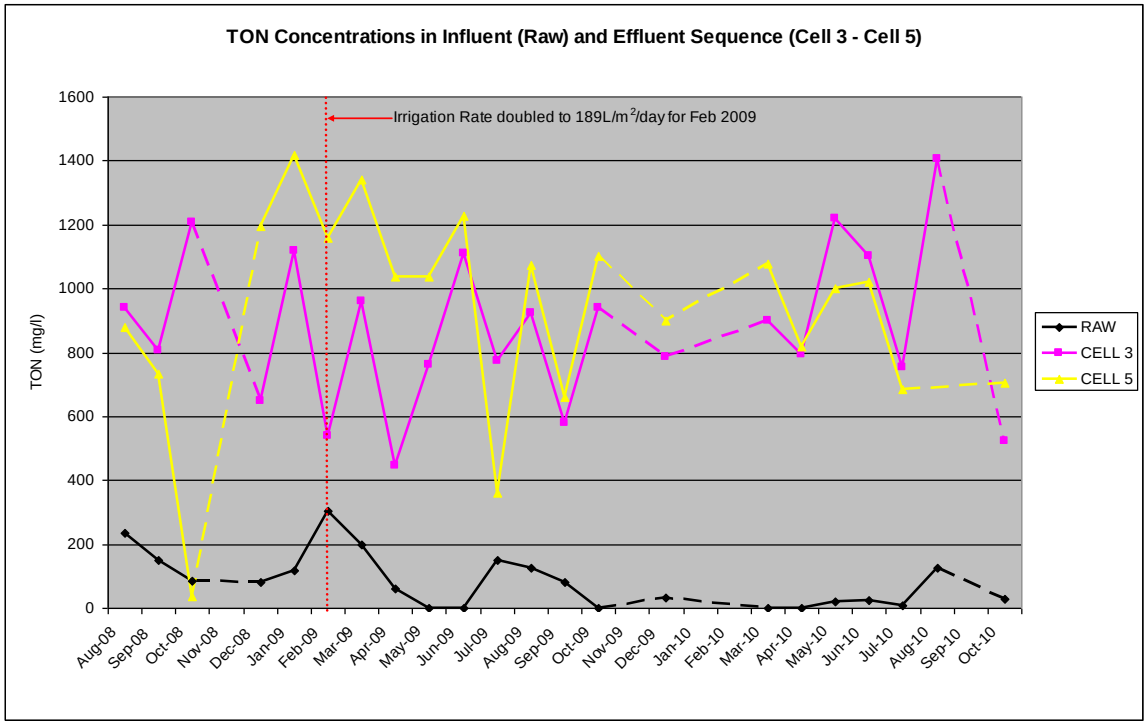


Figure 8.114(a) TON Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

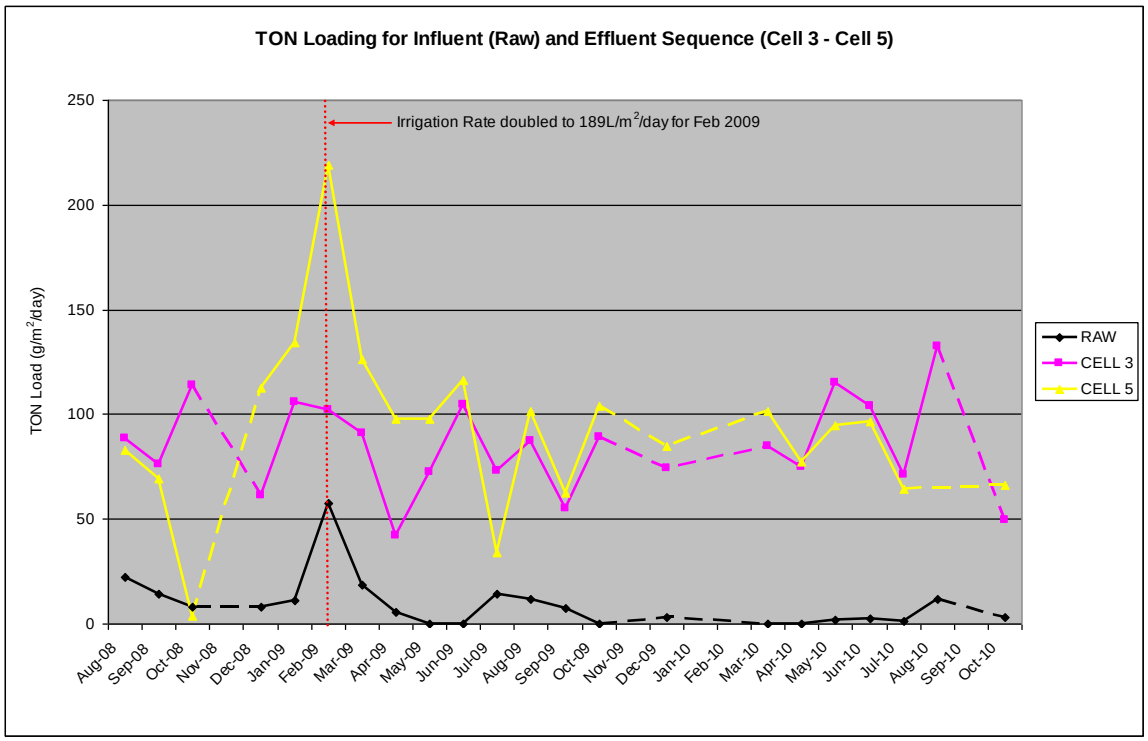


Figure 8.114(b) TON Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Total Nitrogen (N)

Table 8.122(d) Summary of Total Nitrogen (N) Loading per m^2 for Cell 3 – Cell 5

Total Nitrogen (N)	CELL 3	CELL 5
Influent Load g/m^2/day	27	26
Effluent Load g/m^2/day	26	24
Load Removal g/m^2/day	1	3
Cumulative Load Removal g/m^2/day	1	4
Cumulative Load Removal as % per m^2	3	13

Table 8.122(e) Summary of Total Nitrogen (N) Loading per unit or Cell 3 – Cell 5

Total Nitrogen (N)	CELL 3	CELL 5
Influent Load g/unit/day	69	67
Effluent Load g/unit/day	67	60
Load Removal g/unit/day	2	7
Cumulative Load Removal g/unit/day	2	9
Cumulative Load Removal as % per unit	3	13

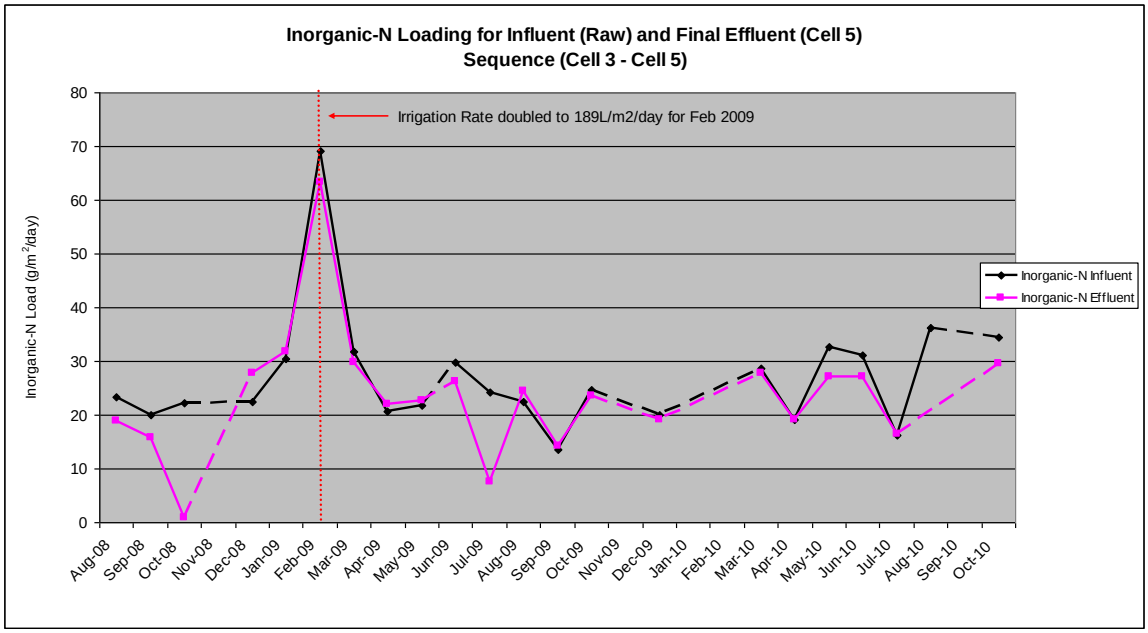


Figure 8.114(c) Total Nitrogen Loading for Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5)

Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost / Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.)* in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.)* in Stratified Sand/Grit/Gravel Matrix

HF 2 – Horizontal Flow Reed Bed (*Sparganium sp.)* in Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: August 2008 – October 2010

Average daily flow = 2243L/unit/day

Table 8.123(a) Summary of TON Concentrations for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

TON Concentration (Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
TON	Influent	22	0 - 304	83 (± 85)
TON	Effluent Cell 9	22	12 - 924	360 (± 317)
TON	Effluent Cell 10	22	124 - 1260	590 (± 297)
TON	Effluent VF 1	22	446 - 1617	917 (± 300)
TON	Effluent VF 2	22	565 - 1632	967 (± 287)
TON	Effluent HF 2	5	531 - 1170	823 (± 283)
TON	Effluent VP 1	10	471 - 1321	807 (± 294)
TON	Effluent VP 2	14	466 - 1508	928 (± 336)

Table 8.123(b) Summary of TON Loading per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

TON	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/m^2/day	66	300	52	82	86	86	77
Effluent Load g/m^2/day	300	512	82	86	79	77	89

Table 8.123(c) Summary of TON Loading per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

TON	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Influent Load g/unit/day	169	762	1300	2040	2148	2148	1936
Effluent Load g/unit/day	762	1300	2040	2148	1976	1936	2228

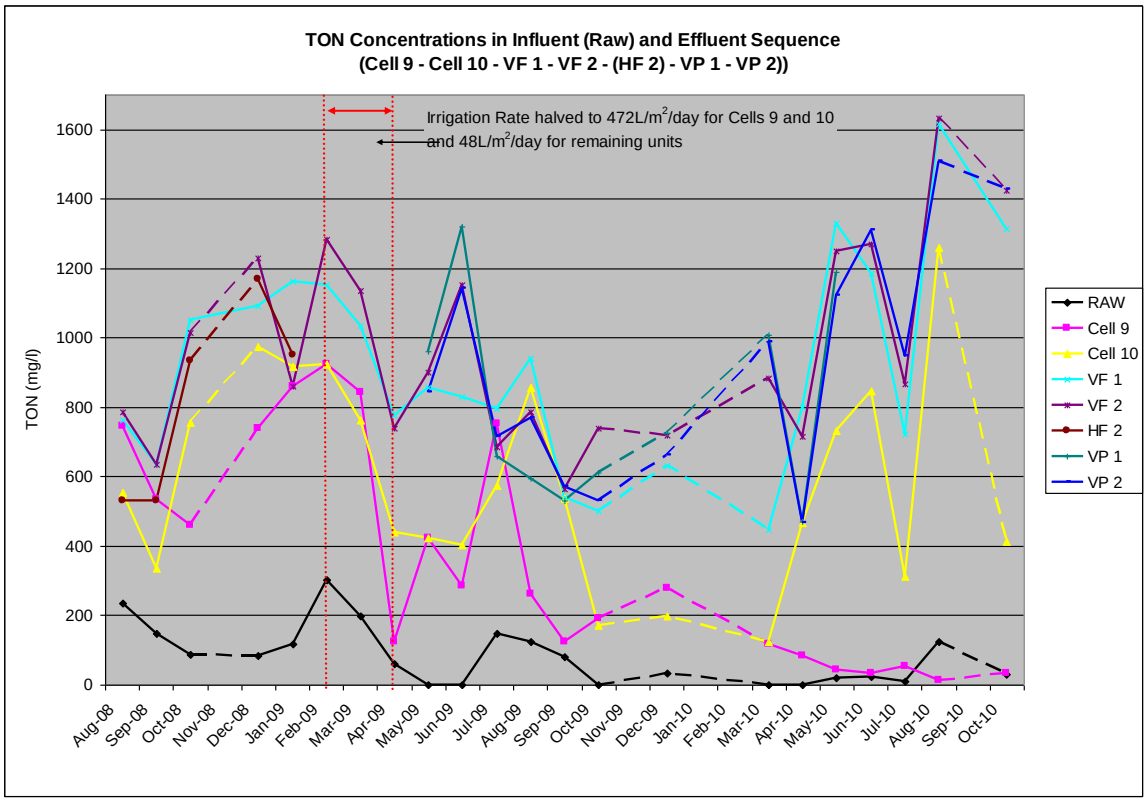


Figure 8.115(a) TON Concentrations in Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

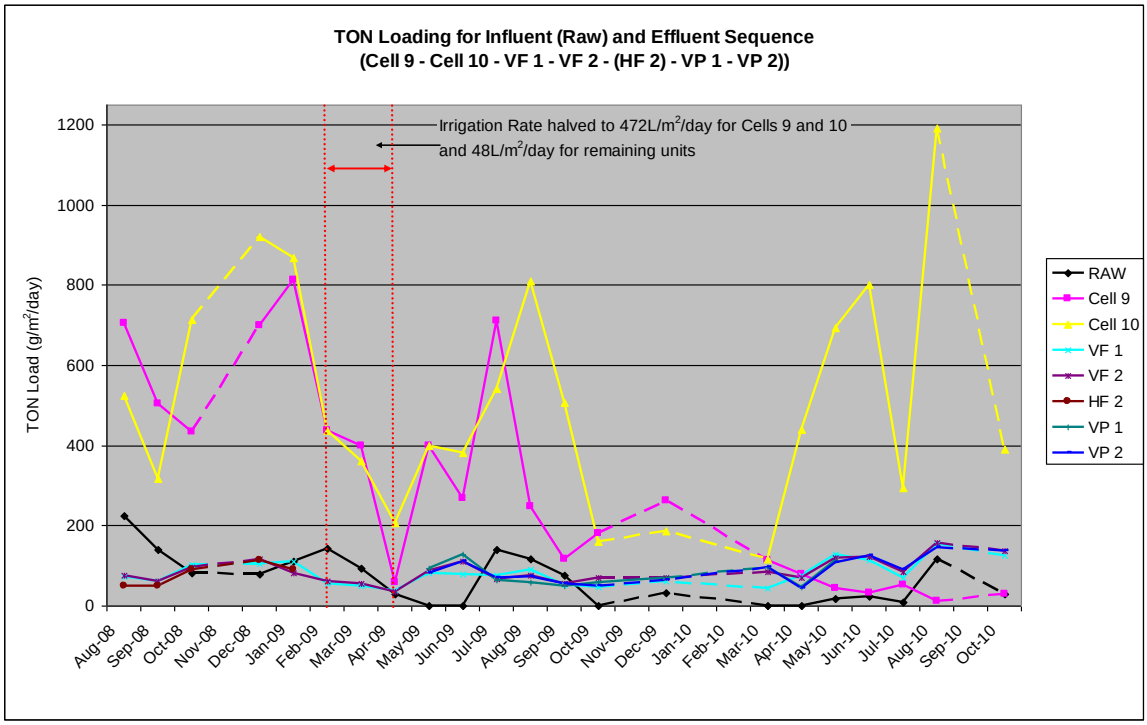


Figure 8.115(b) TON Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

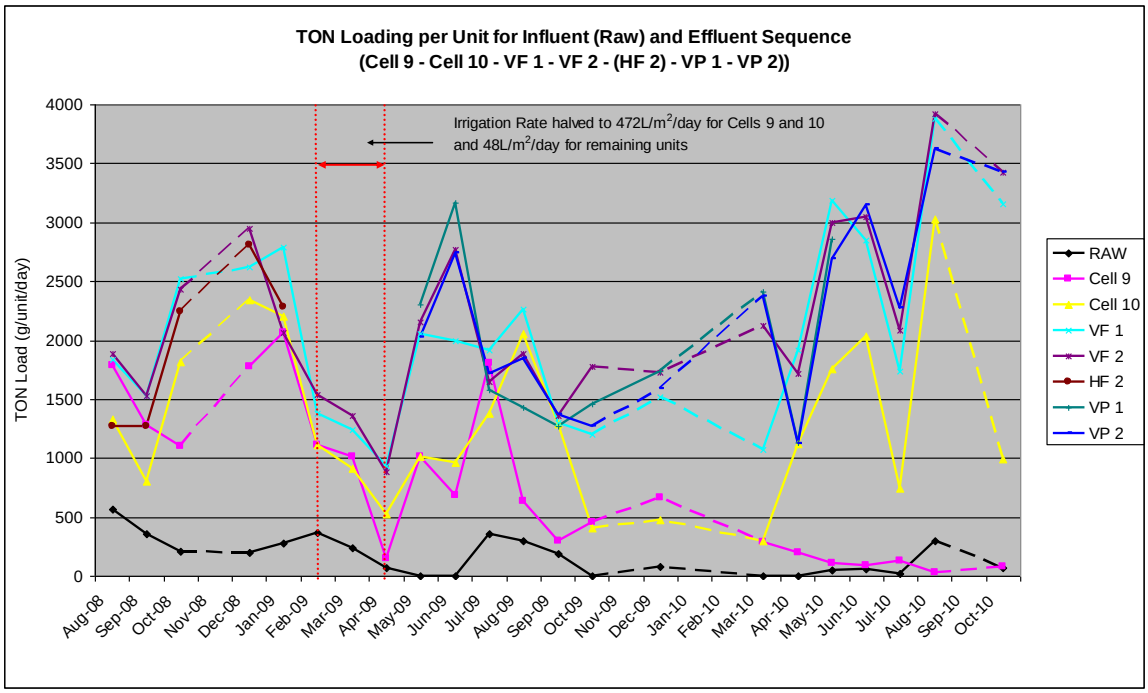


Figure 8.115(c) TON Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Total Nitrogen (N)

Table 8.123(d) Summary of Total Nitrogen (N) Loading per m^2 for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Total Nitrogen (N)	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Influent Load g/m^2/day	235	237	21.1	21.5	20.3	20.3	18.0
Effluent Load g/m^2/day	237	208	21.5	20.3	19.4	18.0	20.4
Load Removal g/m^2/day	-2	29	-0.4	1.2	0.9	2.3	-2.4
Cumulative Load Removal g/m^2/day	-2	28	27	28	29	31	28

Table 8.123(e) Summary of Total Nitrogen Loading per unit for sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2

Total Nitrogen (N)	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Influent Load g/unit/day	597	602	527	538	507	507	450
Effluent Load g/unit/day	602	527	538	507	486	450	509
Load Removal g/unit/day	-4	75	-11	31	21	57	-59
Cumulative Load Removal g/unit/day	-4	70	60	90	112	148	88
Cumulative Load Removal as % per unit	-1	12	10	15	19	25	15

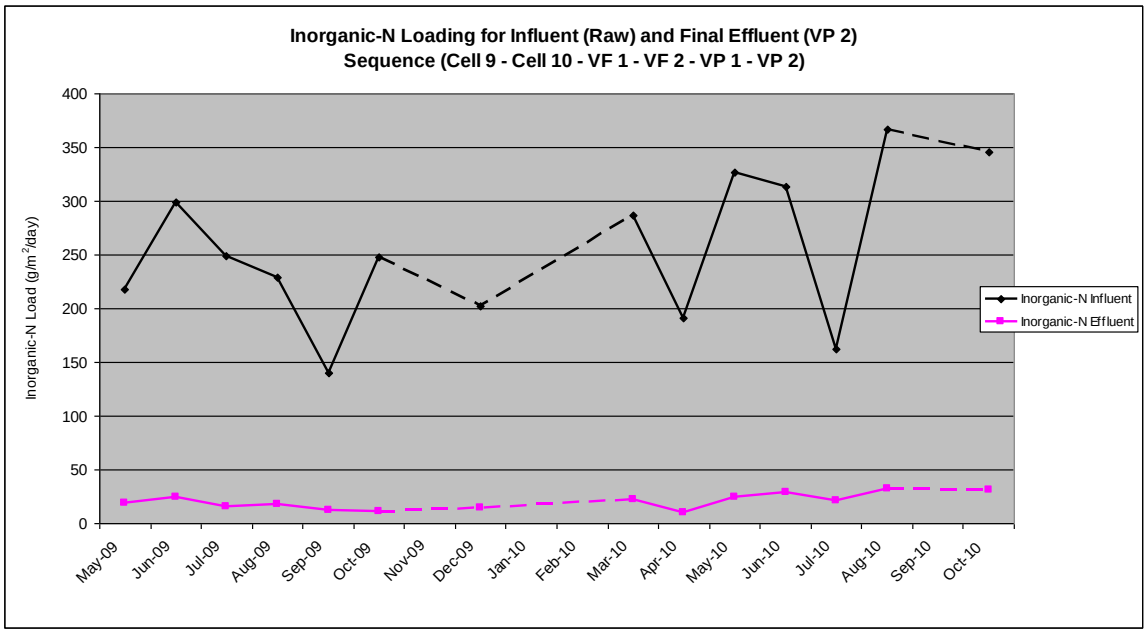


Figure 8.115(d) Total Nitrogen Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

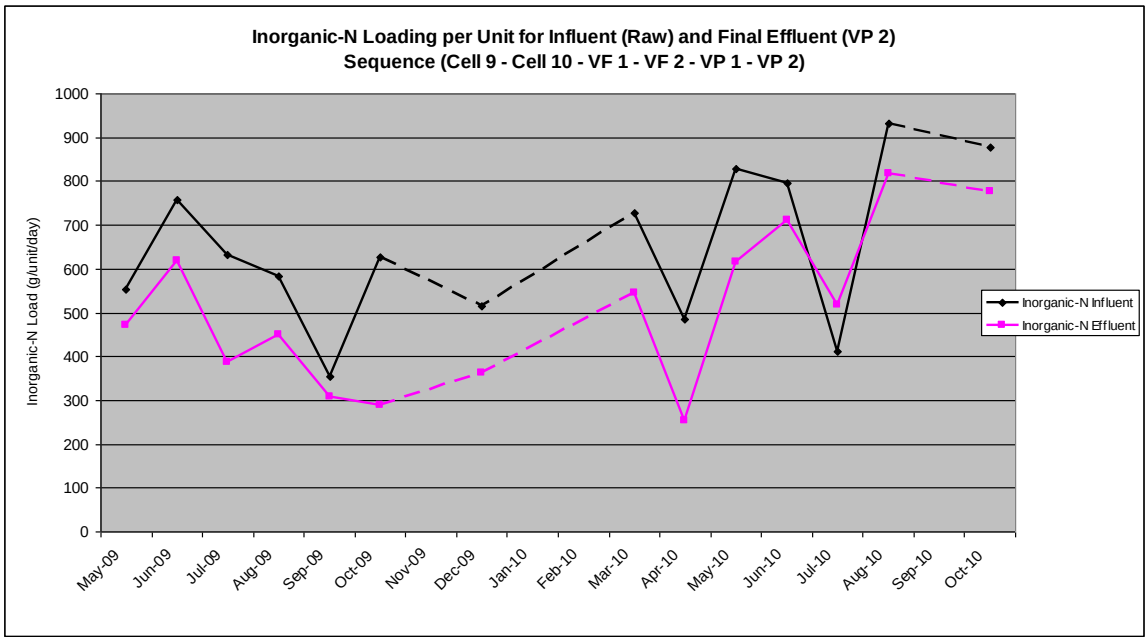


Figure 8.115(e) Total Nitrogen Loading for Influent (Raw) and Effluent Sequence (Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2)

Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: June 2009 – May 2010

Average daily flow = 2400L/unit/day

Table 8.124(a) Summary of TON Concentrations for sequence Cell 7 – Cell 8

TON Concentration (Raw - Cell 7 - Cell 8)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
TON	Influent	9	0 - 148	45 (± 58)
TON	Effluent Cell 7	9	252 - 780	590 (± 168)
TON	Effluent Cell 8	9	206 - 1076	829 (± 288)

Table 8.124(b) Summary of TON Loading per m^2 for Cell 7 – Cell 8

TON	**CELL 7**	**CELL 8**
Influent Load g/m^2/day	43	557
Effluent Load g/m^2/day	557	783

Table 8.124(c) Summary of TON Loading per unit for Cell 7 – Cell 8

TON	**CELL 7**	**CELL 8**
Influent Load g/unit/day	108	1416
Effluent Load g/unit/day	1416	1990

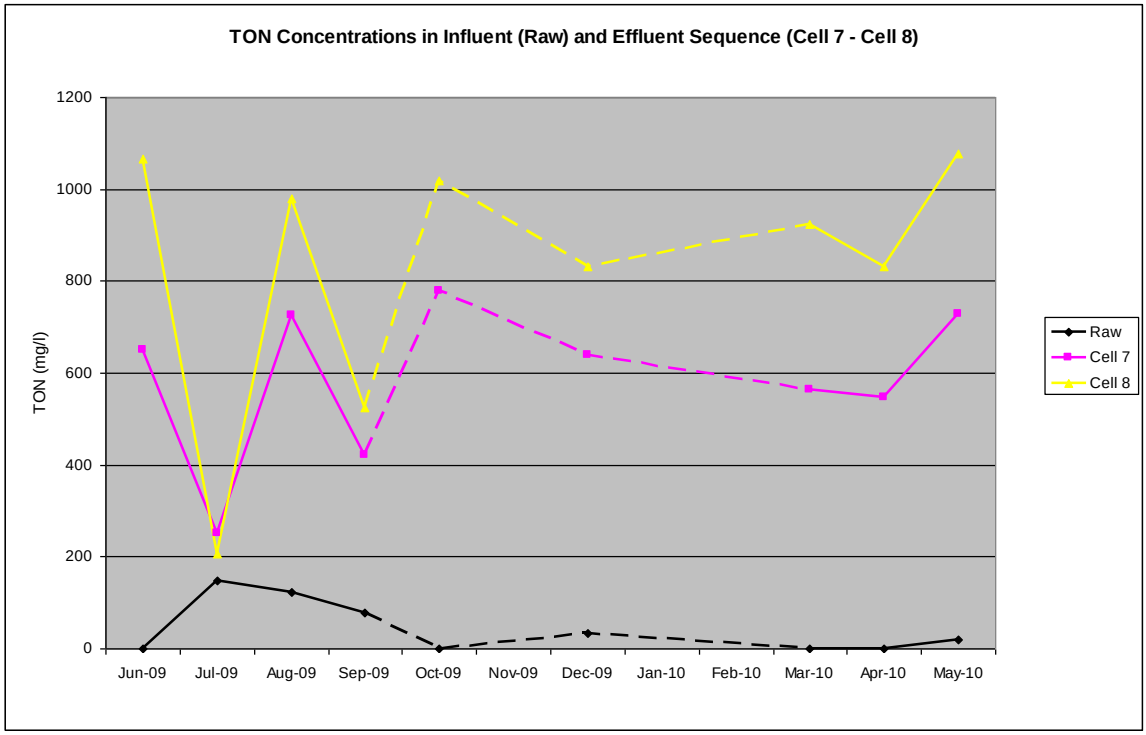


Figure 8.116(a) TON Concentrations in Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

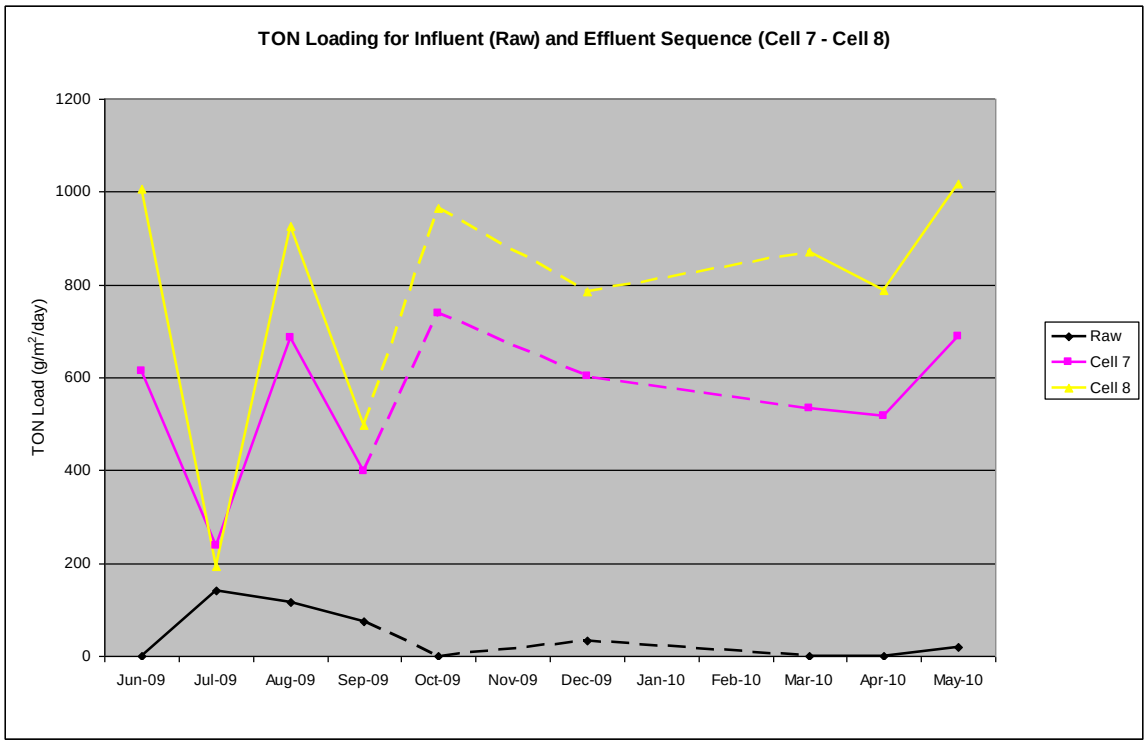


Figure 8.116(b) TON Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Total Nitrogen (N)

Table 8.124(d) Summary of Total Nitrogen (N) Loading per m^2 for Cell 7 – Cell 8

Total Nitrogen (N)	CELL 7	CELL 8
Influent Load g/m^2/day	239	229
Effluent Load g/m^2/day	229	221
Load Removal g/m^2/day	10	8
Cumulative Load Removal g/m^2/day	10	19
Cumulative Load Removal as % per m^2	4	8

Table 8.124(e) Summary of Total Nitrogen (N) Loading per unit for Cell 7 – Cell 8

Total Nitrogen (N)	CELL 7	CELL 8
Influent Load g/unit/day	608	583
Effluent Load g/unit/day	583	560
Load Removal g/unit/day	25	22
Cumulative Load Removal g/unit/day	25	47
Cumulative Load Removal as % per unit	4	8

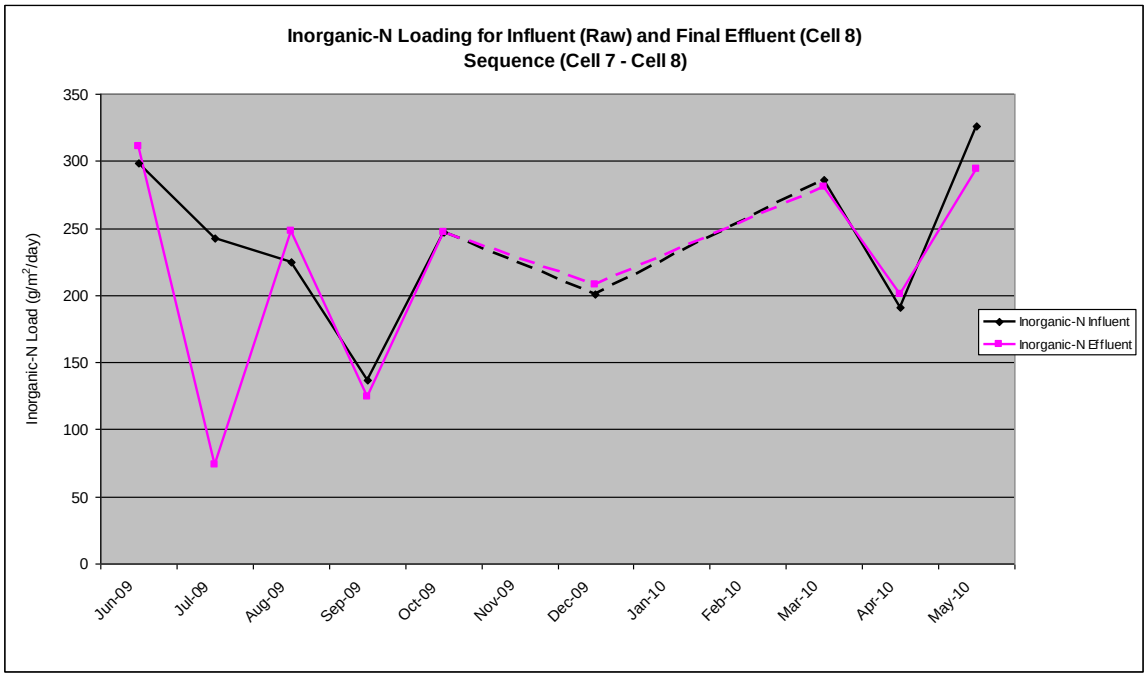


Figure 8.116(c) Total Nitrogen Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8)

Cell 7 – Cell 8 – VP 1

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

VP 1 – Vegetated Grass Plane

Operational Period: June 2010 – October 2010

Average daily flow = 600L/unit/day

Table 8.124(f) Summary of TON Concentrations for sequence Cell 7 – Cell 8 – VP 1

TON Concentration (Raw - Cell 7 - Cell 8 - VP 1)				
Parameter		n	Range (mg/l)	Mean Concentration (± sd)
TON	Influent	4	10 - 124	47 (± 52)
TON	Effluent Cell 7	4	684 - 1295	1073 (± 267)
TON	Effluent Cell 8	4	893 - 1414	1240 (± 238)
TON	Effluent VP 1	4	942 - 1428	1247 (± 218)

Table 8.124(g) Summary of TON Loading per m^2 for Cell 7 – Cell 8 – VP 1

TON	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/m^2/day	11	253	30
Effluent Load g/m^2/day	253	293	30

Table 8.124(h) Summary of TON Loading per unit for Cell 7 – Cell 8 – VP 1

TON	**CELL 7**	**CELL 8**	**VP 1**
Influent Load g/unit/day	28	644	744
Effluent Load g/unit/day	644	744	748

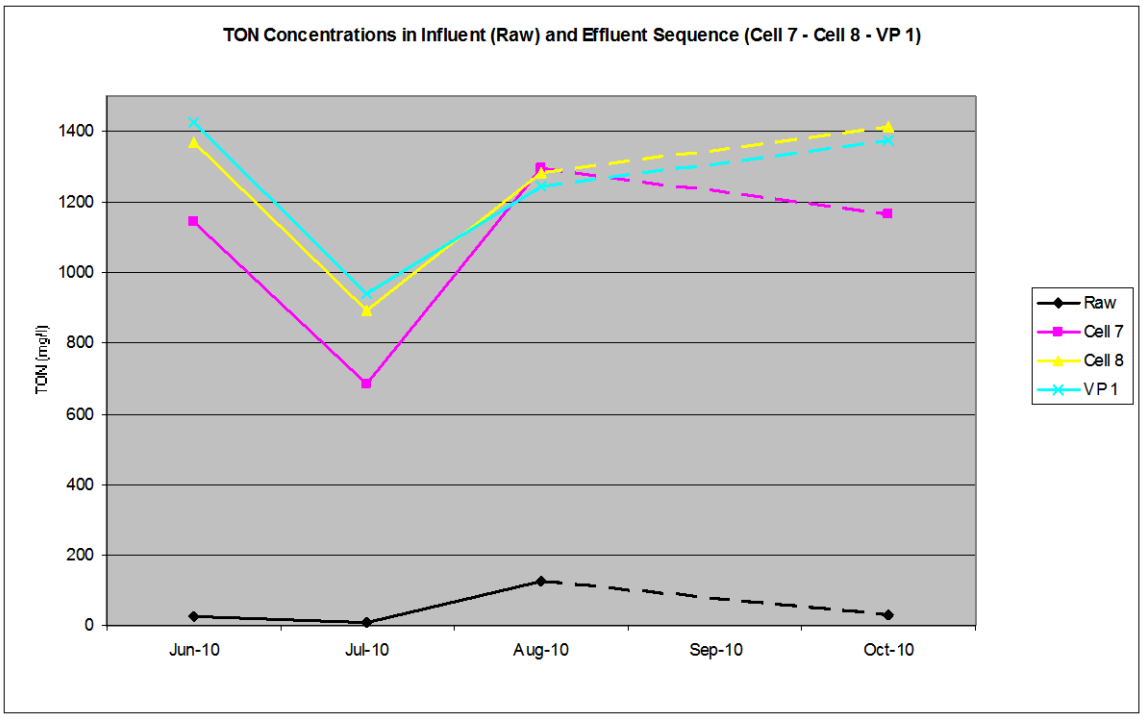


Figure 8.117(a) TON Concentrations in Influent (Raw) and Effluent Sequence (Cell 3 – Cell 5 – VP 1)

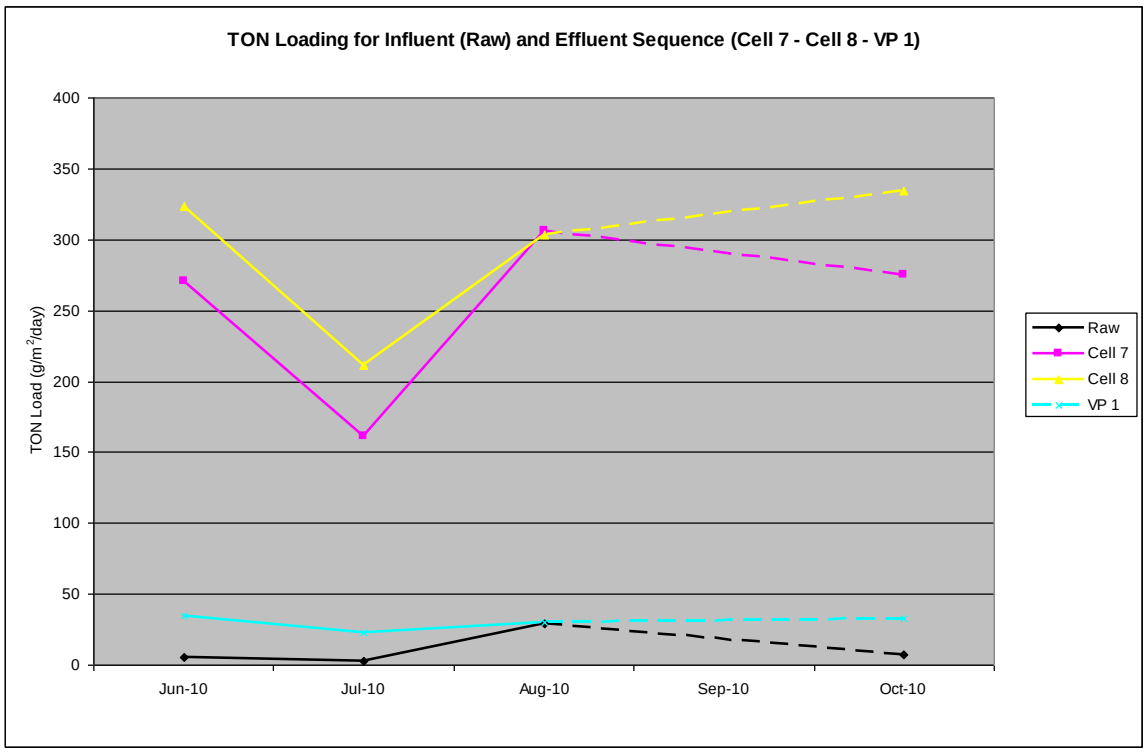


Figure 8.117(b) TON Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

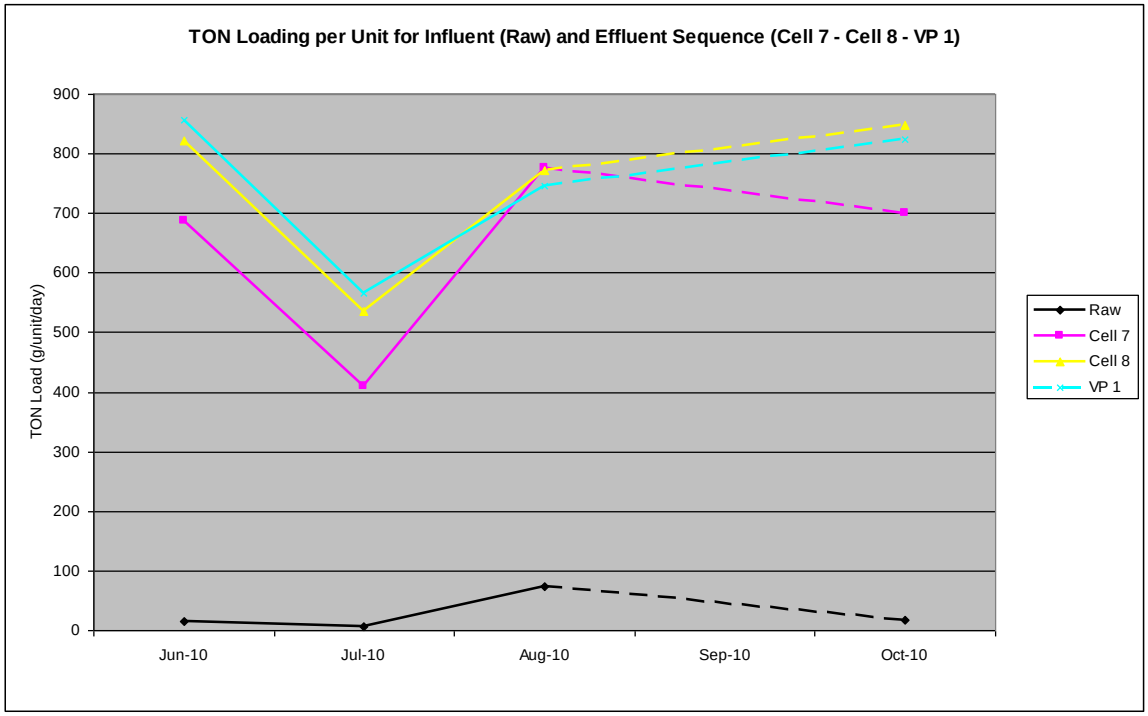


Figure 8.117(c) TON Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Total Nitrogen (N)

Table 8.124(i) Summary of Total Nitrogen (N) Loading per m^2 for Cell 7 – Cell 8 – VP 1

Total Nitrogen (N)	CELL 7	CELL 8	VP 1
Influent Load g/m^2/day	73.8	69.0	6.9
Effluent Load g/m^2/day	69.0	67.7	6.8
Load Removal (g/m2/day)	4.8	1.3	0.1
Cumulative Load Removal g/m^2/day	4.8	6.1	6.2

Table 8.124(j) Summary of Total Nitrogen (N) Loading per unit for Cell 7 – Cell 8 – VP 1

Total Nitrogen (N)	CELL 7	CELL 8	VP 1
Influent Load g/unit/day	188	175	172
Effluent Load g/unit/day	175	172	169
Load Removal g/unit/day	12	3	3
Cumulative Load Removal g/unit/day	12	15	18
Cumulative Load Removal as % per unit	7	8	9.7

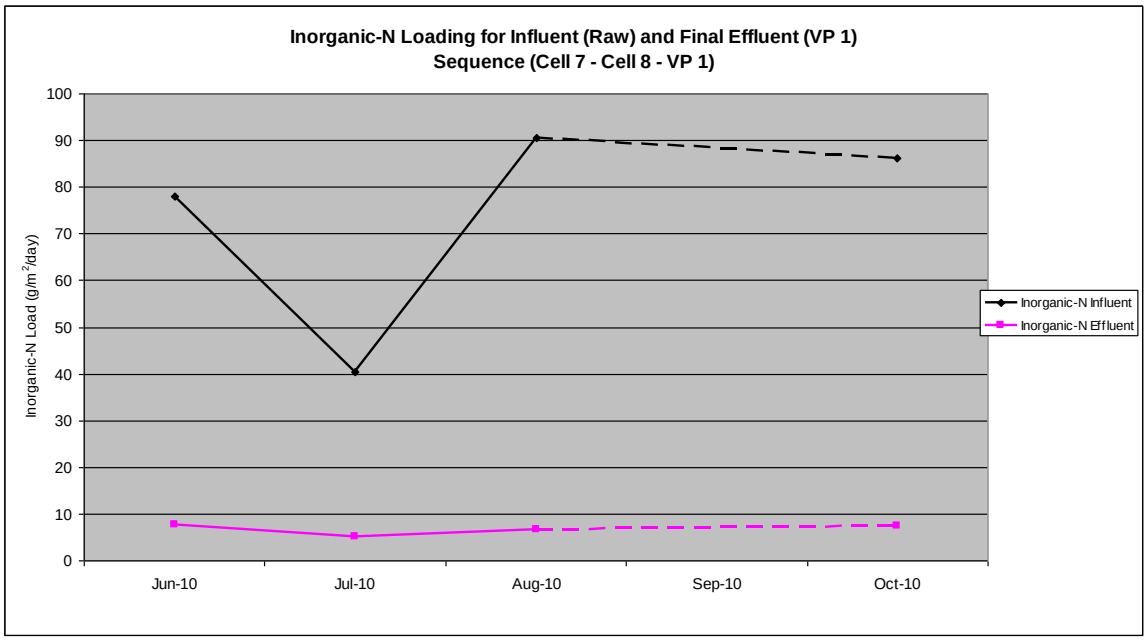


Figure 8.117(d) Total Nitrogen Loading for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

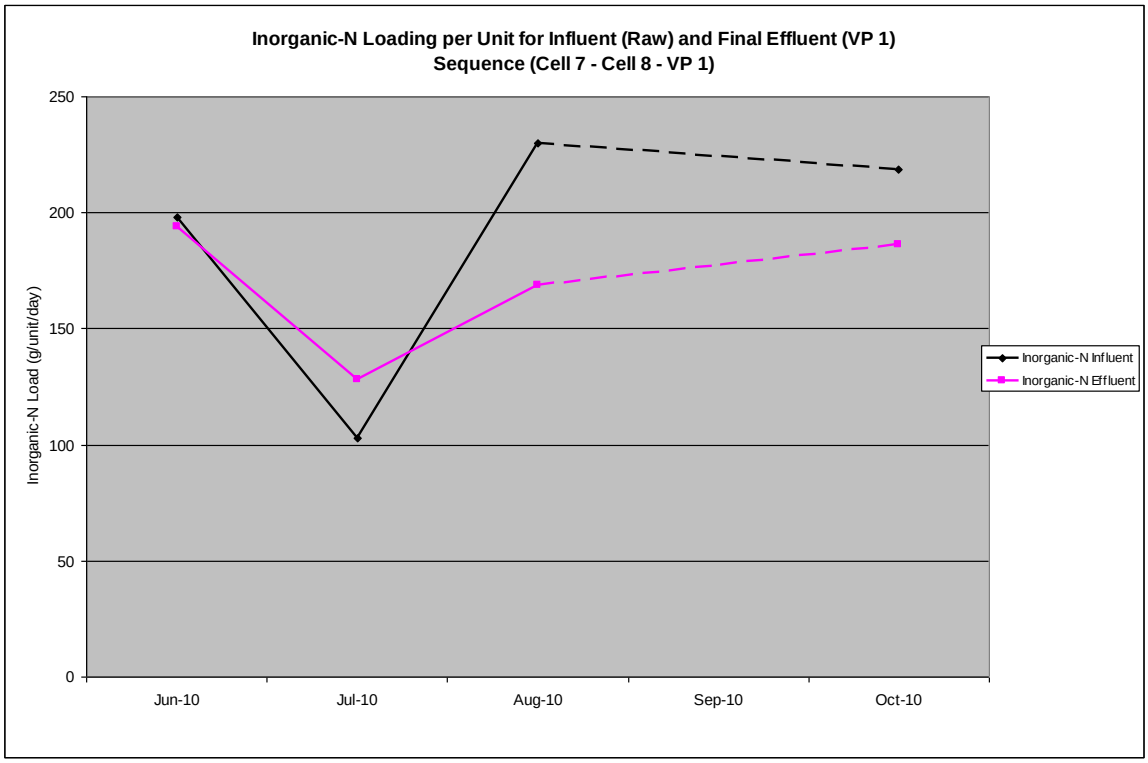


Figure 8.117(e) Total Nitrogen Loading per Unit for Influent (Raw) and Effluent Sequence (Cell 7 – Cell 8 – VP 1)

Fresh Leachate (Raw Active)

Monitoring Period: May 2009 - August 2010

Table 8.125 Summary of TON Concentrations for Fresh Leachate from Active Area

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
TON	12	0 - 665	95 (± 193)

Tramore River

Monitoring Period: June 2009 - October 2010

Table 8.126 Summary of TON Concentrations in Tramore River

Parameter	n	Range (mg/l)	Mean Concentration (± sd)
TON	12	12 – 102	32 (± 23)

Interpretation of TON Results in Treatment Units

TON concentrations and loadings progressively increased throughout each sequence.

The average cumulative TON load increase at the end of the sequences was as follows:

- Sequence Cell 3 – Cell 5 = 84g/m^2/day (213g/unit/day) (Figure 8.114(b))
- Sequence Cell 9 – 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2 = 2059g/unit/day (Figure 8.115(c))
- Sequence Cell 7 – Cell 8 = 740g/m^2/day (1882g/unit/day) (Figure 8.116(b))
- Sequence Cell 7 – Cell 8 – VP 1 = 720g/unit/day (Figure 8.117(c))

The doubling of the irrigation rate to sequence Cell 3 – Cell 5 to 189L/m^2/day resulted in a sharp rise in effluent TON load for cell 5, increasing from 102g/m^2/day to 219g/m2/day.

The effect of halving hydraulic loading rate in sequence Cell 9 → VP 2 to 1200L/unit/day between February and April 2009 produced an obvious drop in TON effluent load in all four units in operation during this period (Cell 9, Cell 10, VF 1 and VF 2).

The increase in nitrate load from influent to effluent is not surprising given the degree of ammonium nitrification, whereby NH_4 was oxidised to NO_3 and NO_2. Average cumulative ammonium removal (through nitrification, volatilization, anammox etc.) for Cell 3 – Cell 5 was 90%; Cell 9 → VP 2 was 99%; Cell 7 – Cell 8 was 81% and for Cell 7 - Cell 8 - VP 1 was 99.9%.

The mass balance calculation for N of the influent and final effluent for each of the sequences reveals that the vast majority of the increase of nitrate (TON) in the effluent load can be attributed to nitrification.

The ratio of N effluent to N influent was as follows:

- Cell 3 – Cell 5 = 89%
- Cell 9 → VP 2 = 85%
- Cell 7 – Cell 8 = 92%
- Cell 7 – Cell 8 - VP 1 = 90%

These results reveal that N removal from the system was limited.

It is interesting to note that despite the overall nitrate increase in end of sequence effluent, there were some minor reductions within a number of the sequences.

Sequence Cell 3 – Cell 5 displayed anonymously low effluent loads for October 2008 and July 2009 where final N load was 1g/m^2/day and 8g/m^2/day representing a 95% and 66% load removal efficiency (Figure 8.114(c)). The reasons for the low effluent N load is not known but the NH_4 and corresponding TON effluent load on each occasion was also low; 0.09gNH_4/m^2/day, 3gTON/m^2/day (October 2008) and 0gNH_4/m^2/day, 34gTON/m^2/day (July 2009) respectively. On each occasion, load reduction occurred in cell 5, with mineralisation of ammonium within the timber chip medium as a possible explanation.

Sequence Cell 9 → VP 2 displayed four significant load reduction episodes throughout the trial.

In August and September 2008, the final effluent load in HF 2 (horizontal flow reed bed, *Sparganium* in gravel medium) was reduced to 340gN/unit/day and 290gN/unit/day respectively, down from an initial influent (raw) load of 592gN/unit/day and 509gN/unit/day (43% load removal on each occasion) (data are not displayed).

Results for October 2009 and April 2010 revealed similar high N load removal from the system with a final effluent load in VP 2 of 287gN/unit/day (54% load reduction) and 255gN/unit/day (47% load reduction) respectively (Figure 8.115(e)).

On each occasion, almost complete reduction of the ammonium load occurred in the absence of a significant increase in TON load.

One result for sequence Cell 7 – Cell 8 revealed a significant reduction in N load throughout the trial period. A cumulative load reduction of 170gN/m^2/day was recorded in the final effluent of cell 8 in July 2009. N was progressively reduced through the sequence from an influent load of 243g/m^2/day (raw leachate) to 135g/m^2/day (cell 7) and 74g/m^2/day (cell 8) respectively.

Two of the four analysed results for sequence Cell 7 – Cell 8 – VP 1 revealed a reduction in N load during the trial period. Cumulative load reductions of 61gN/unit/day (27% reduction) and 33gN/unit/day (15% reduction) were recorded in the final effluent from VP 1 in August and October 2010 respectively. The primary treatment unit (containing timber chippings) accounted for the majority of load removal on each occasion with N load reduction of 26g/unit/day and 20g/unit/day in August and October 2010 respectively.

Neither of the grass plane units operating in sequence Cell 9 → VP 2 and Cell 7 – Cell 8 – VP1 achieved the expected level of N removal from the system. Except for the occasional high removal results previously mentioned, N removal through mowing and biomass uptake was limited. This shall be expanded further below in section 8.3.2.7.

8.3.2.7 Results from Nitrate Uptake Trials

Vegetated Grass Planes (VP 1 and VP 2) were set up in April 2009 replacing HF 1 and HF 2. It was anticipated that dosing the salt tolerant grass mix species with a high nitrate load would produce a lush grass growth, and coupled with regular mowing and removal of the biomass would result in significant nitrate removal rates from the effluent stream.

Dosing to VP 1 and VP 2 began in May 2009 and the timing of the flow sequence was as follows:

- October 2009 – May 2010: Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
- June 2010 – October 2010: Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2
- June 2010 – October 2010: Cell 7 - Cell 8 - VP 1

Tables 8.127 and 8.128 summarises grass mowing events, biomass off-take and equivalent TON, ammonium and total inorganic N loadings for VP 1 and VP 2 influent and effluent. Included within the tables is a comparison of N removal from the grass plane system and the total dry biomass harvested for the same period at an N content ranging from 0.125% to 2.5% (Tables 8.127 and 8.128 column 4 (dry biomass harvested) and column 8 (N load)).

A comparison of grass mowing dates and effluent sampling dates is outlined in Table 8.129.

Table 8.127 Dry Matter (DM) Biomass Off-take and N Loading Comparison for Sequence Cell 9 - Cell 10 - VF 1 - VF 2 - (VP 1) - VP 2

Operation: October 2009 - October 2010								
		DM Grass Removed	Biomass harvested at 1.5%N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (VF 2)	71	4	19.12
VP 1	09-Oct-09	0.25	3.75		Effluent (VP 1)	59	0	13.23
VP 2	09-Oct-09	0.23	3.45		Effluent (VP 2)	51	0	11.50
Total		0.48	7.2		Total N Removal			7.62
		DM Grass Removed	Biomass harvested at 2.5%N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (VF 2)	120	0.4	27.42
VP 1	15-Apr-10	0.06	1.5		Effluent (VP 1)	114	0.4	26.12
VP 2	15-Apr-10	0.05	1.25		Effluent (VP 2)	108	0.4	24.62
Total		0.11	2.75		Total N Removal			2.80
		DM Grass Removed	Biomass harvested and %N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (VF 2)	122	0.8	28.15
VP 1	24-May-10	0.09	NA		Effluent (VP 1)	137	0.1	31.06
VP 2	24-May-10	0.09	NA		Effluent (VP 2)	126	0.1	28.47
Total		0.18	NA		Total N Removal			-0.32
		DM Grass Removed	Biomass harvested and %N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (VF 2)	122	1	28.15
VP 2	15-Jun-10	0.11	NA		Effluent (VP 2)	126	0.1	28.47
Total		0.11	NA		Total N Removal			-0.32
		DM Grass Removed	Biomass harvested at 1.3%N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (VF 2)	157	0	35.41
VP 2	04-Aug-10	0.20	2.6		Effluent (VP 2)	145	0	32.72
Total		0.20	2.6		Total N Removal			2.69
		DM Grass Removed	Biomass harvested and %N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (VF 2)	137	0	30.92
VP 2	24-Sep-10	0.23	NA		Effluent (VP 2)	137	0.1	31.06
Total		0.23	NA		Total N Removal			-0.14

Table 8.128 Dry Matter (DM) Biomass Off-take and N Loading Comparison for Sequence Cell 7 – Cell 8 – VP 1

Sequence: Cell 7 – Cell 8 – VP 1 Operation: June 2010 - October 2010								
		DM Grass Removed	Biomass harvested and %N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (Cell 8)	33	0.2	7.59
VP 1	15-Jun-10	0.13	NA		Effluent (VP 1)	34	0.0	7.76
Total		0.13	NA		Total N Removal			-0.17
		DM Grass Removed	Biomass harvested at 0.125%N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (Cell 8)	31	0.1	7.04
VP 1	04-Aug-10	0.24	0.3		Effluent (VP 1)	30	0	6.75
Total		0.24	0.3		Total N Removal			0.29
		DM Grass Removed	Biomass harvested at 0.35%N DM content			TON Load ($g/m^2/day$)	NH_4 Load ($g/m^2/day$)	N load ($g/m^2/day$)
Unit	Date	Kg / m^2	g/m^2		Influent (Cell 8)	33	0.4	7.97
VP 1	24-Sep-10	0.14	0.49		Effluent (VP 1)	34	0	7.45
Total		0.14	0.49		Total N Removal			0.52

Table 8.129 Comparison of Mowing Dates and Sampling Dates

Mowing Date	**Nitrate Sampling Date**
9th October 2009	23rd October 2009
15th April 2010	6th May 2010
24-May 2010	17th June 2010
15th June 2010	17th June and 22nd July 2010
4th August 2010	16th August 2010
24th September 2010	14th October 2010

Interpretation of Nitrate Uptake Trials

Analysis of the grass mowing in VP 1 and VP 2 units reveals a wide range of results in terms of dry matter (DM) removal from the system. For sequence Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2, biomass off-take ranged from 2.89kg/unit (110g/m^2) to 12.07kg/unit (480g/m^2) (total for VP 1 and VP 2) and from 2.82kg/unit (110g/m^2) to 5.84kg/unit (230g/m^2) for VP 2 only.

Biomass off-take for sequence Cell 7 - Cell 8 - VP 1 ranged from 3.16kg/unit (130g/m^2) to 6.06kg/unit (240g/m^2).

The disparity between the biomass off-take during mowing events is due to increased biomass production as the growing season progressed and can also be attributed to a lack of consistency in the mowing programme, whereby a number of planned mowing events were missed due to other work commitments.

The nitrate (TON), ammonium and total (inorganic) N loadings and concentrations are included in the tables merely for comparison purposes and a reduction in nitrate (TON) load (and inorganic N load) in any one unit cannot necessarily be attributed to previous biomass harvesting. Unfortunately due to an error in the sampling regime, nitrate (TON) samples in the influent and effluent stream were not taken prior to mowing, therefore statistical analysis of the data regarding biomass harvesting and N load reduction is a probable best fit only.

It is possible that a portion of the NO_3 was bound up with organic material that later became available for plant uptake through mineralisation in the soil profile.

Despite the shortcomings described above, the following can be definitively stated:

- A reduction in nitrate (TON) loading in sequence Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 did occur from influent to end system effluent in 3 of the 6 samples analysed (28%, 10% and 7.6% load reduction respectively)
- A reduction in nitrate (TON) loading in sequence Cell 7 - Cell 8 - VP 1 occurred from influent to end system effluent in 2 of the 3 samples analysed (3% and 2.9% respectively)

- A calculated mass balance for N load removal from the applied influent/effluent and total dry biomass harvested for the same period revealed a low level of plant uptake of N ranging from:
    - 1.3% to 2.5% N dry matter content (of harvested biomass) for VP 1 and VP 2 (sequence Cell 9 → VP 2)
    - 0.125% to 0.35% N dry matter content (of harvested biomass) for VP 1 (sequence Cell 7 – Cell 8 – VP 1)

Based on these results, plant growth and associated biomass off-take was not a significant route for N removal from the system under the operating conditions described.

In order to directly attribute biomass off-take with a reduction in N load in grass plane (VP units) effluent, the following conditions would be required:

- Addition of a control plot with similar plant species and media material
- Control plot would not be irrigated but would be mown at the same frequency as the test plot(s)
- Biomass off-take material would be subject to chemical analysis for N, P, K and metals (Cd, Ni, Zn, Fe, Mn etc.) whereby dry matter would be dissolved in an acid solution and the sample solution analysed
- Soil N would have to be measured throughout the trial
- A mass balance for total N would be required to track N processes (nitrification, denitrification, plant uptake etc.)
- A more defined monitoring regime with an increased frequency of sample analysis would be required (at least weekly) in order to attain influent and effluent N values and assist in building up an understanding of how nutrient concentrations fluctuate seasonally
- Regular mowing of the grass crop during the growing season (every two weeks)
- All of the above points would assist in calculating the overall contribution of wastewater application to the overall nutrient and water requirements of the grass crop.

8.3.2.8 Results from De-nitrification Trials

Denitrification phase II trials were in operation from September 2009 to October 2010. The denitrification units consisted of four $1m^3$ reactors set in sequence, connected to VP 2.

The sequence of treatment units was as follows:

Cell 9 - Cell 10 - VF 1 - VF 2 – (VP 1) - VP 2 – N1 – N2 – N3 – N4.

Reactor N1 was dosed with a carbon source (Sorbitol®) at a rate of 520 ml/hour (12.48 litres day, 121.5g/l COD concentration in feedstock tank) to achieve a COD concentration of 632mg/l in the vessel (excluding influent COD in treated leachate). The addition of a readily biodegradable carbon source served to lower the dissolved oxygen levels in the denitrification units. At a later stage in the trial, P was added to the system (dosed to N1) and a steady state concentration of 5 mg/l (P) was achieved in the vessel. The denitrification system was not inoculated or pre-seeded with denitrifying bacteria, however, corrugated land drain pipes were placed in three of the units (N1, N2 and N3) to provide surface area ($121m^2$ in total) for denitrifying bacteria to attach and assist in retention of biomass .

The results for nitrate (as TON) concentrations, loadings and removal efficiencies for the denitrification units are presented below in Tables 8.130 and 8.131(a).

Charts detailing the range of nitrate (TON) concentrations and loadings for the denitrification units are presented in Figures 8.118(a) – (c).

A nitrogen balance (inorganic N) for loading and removal rates in the denitrification units N1 – N4 is presented in Table 8.131(b) with charts detailing the range of N loading for the sampling period outlined Figures 8.118(d) and 8.118(e).

Interpretation of denitrification results is detailed in the subsequent section.

Operational Period: September 2009 – October 2010

Average daily flow = 2400L/unit/day

Table 8.130 Summary of TON Concentrations for Denitrification Units N1 – N4

TON - Denitrification Units				
Parameter	TON	n	Range (mg/l)	Mean Concentration (± sd)
Nitrate (TON)	Influent	10	466 - 1508	953 (± 385)
Nitrate (TON)	Effluent N1	6	600 - 1021	767 (± 160)
Nitrate (TON)	Effluent N2	5	600 - 1085	759 (± 198)
Nitrate (TON)	Effluent N3	5	541 - 938	699 (± 164)
Nitrate (TON)	Effluent N4	8	560 - 893	725 (± 118)

Table 8.131(a) Summary of TON Loading and Removal Rates for Denitrification Units N1 – N4

TON - Denitrification Units	**N1**	**N2**	**N3**	**N4**
Influent Load g/unit/day	2287	1842	1822	1678
Effluent Load g/unit/day	1842	1822	1678	1739
Load Removal g/unit/day	445	20	144	-61
Cumulative Load Removal g/unit/day	445	465	609	548
Cumulative Load Removal as % per unit	19	20	27	24

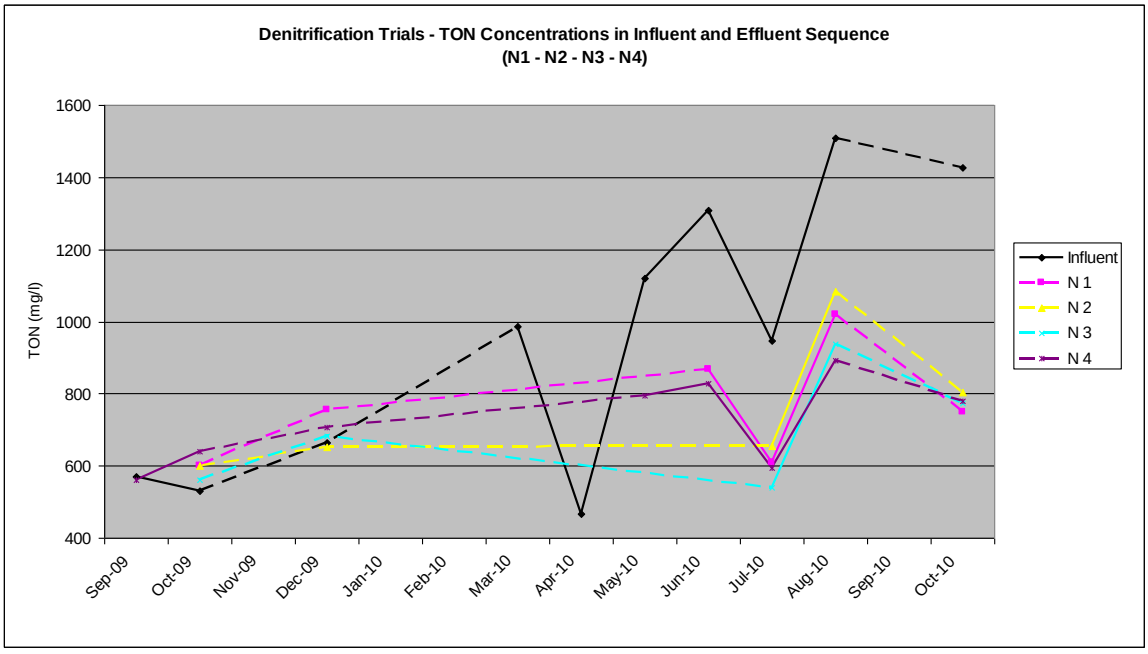


Figure 8.118(a) TON Concentrations in Influent and Denitrification Units (N1 – N4)

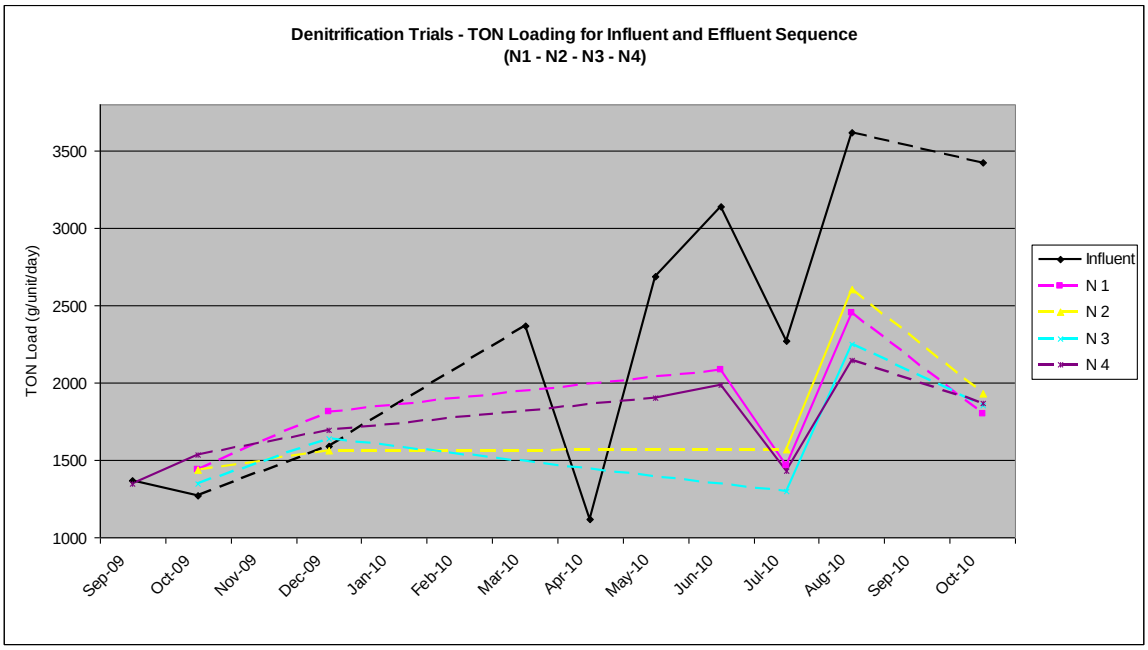


Figure 8.118(b) TON Loading for Influent and Denitrification Units (N1 – N4)

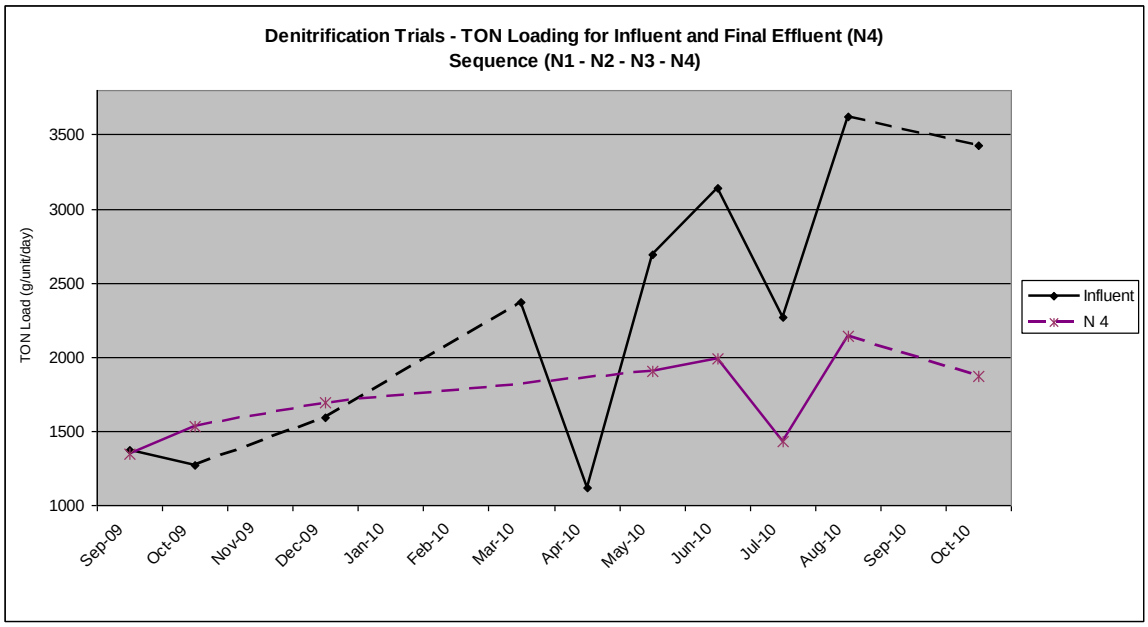


Figure 8.118(c) TON Loading for Influent and Final Effluent from Denitrification Unit N4

Table 8.131(b) Summary of N Loading and Removal Rates for Denitrification Units N1 – N4

N Load - Denitrification Units	N1	N2	N3	N4
Influent Load g/unit/day	549	418	413	382
Effluent Load g/unit/day	418	413	382	397
Load Removal g/unit/day	130	5	31	-15
Cumulative Load Removal g/unit/day	130	136	167	151
Cumulative Load Removal as % per unit	24	25	30	28

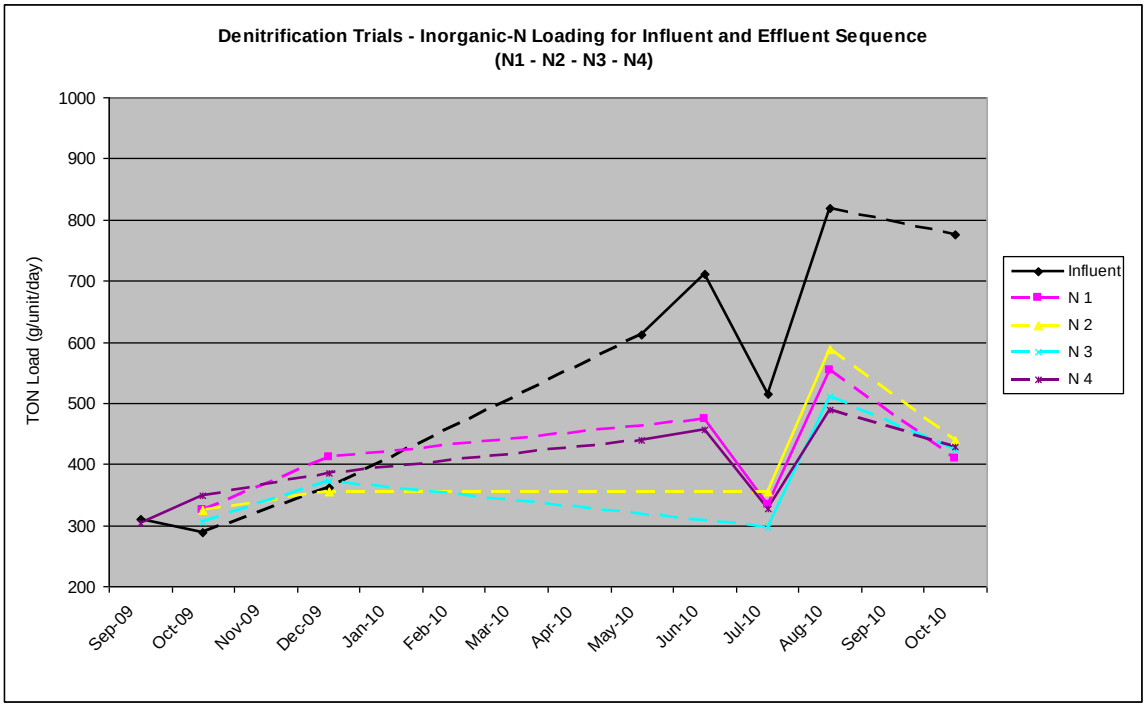


Figure 8.118(d) N Loading for Influent and Denitrification Units (N1 – N4)

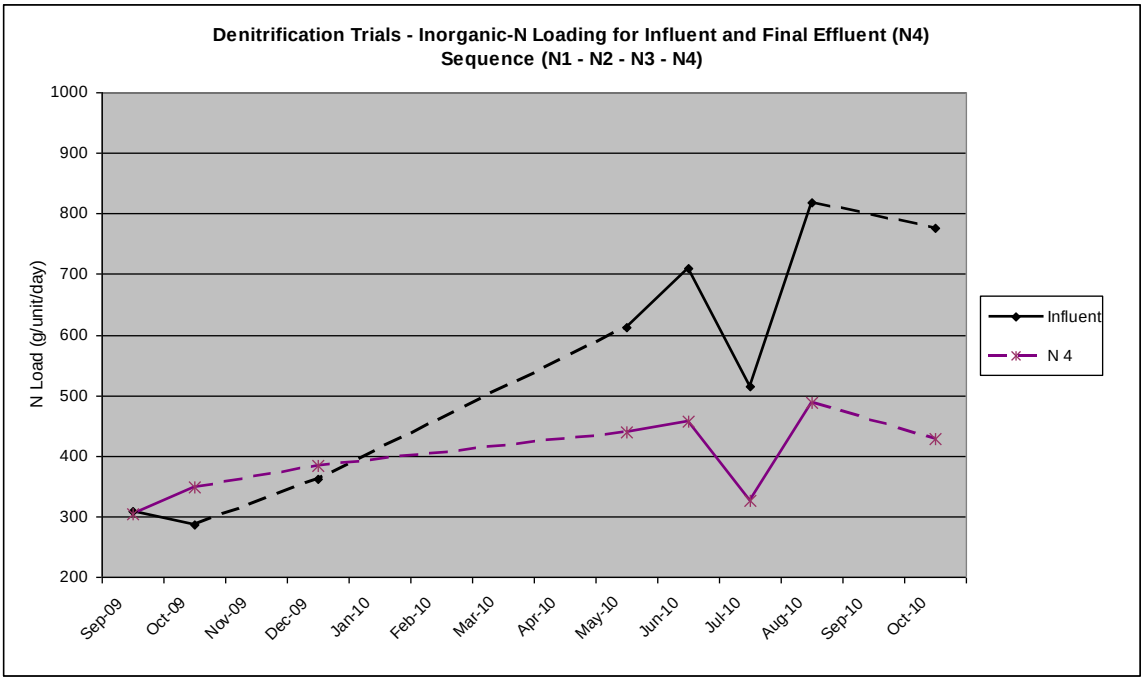


Figure 8.118(e) N Loading for Influent and Final Effluent from Denitrification Unit N4

Interpretation of De-nitrification Trials

Analysis of the data for nitrate loads within the denitrification units displayed an average overall end of sequence removal rate of 24%. In all, 548g/unit/day (TON) was removed across the four denitrification units, with the majority of denitrification occurring in the primary denitrification unit, N1, where load removal was 445g(TON)/unit/day (19% removal).

Unit N4 tended to add nitrate to the effluent, thus reducing the overall efficiency of the denitrification system.

The averaged results for all denitrification units (N1 – N4) are distorted by two negative load removal events at the start of the denitrification trials (October and December 2009) where 264g(TON)/unit/day and 106g(TON)/unit/day were added to the final effluent load.

However, following these initial setbacks, a balance of the carbon - nitrogen ratio was achieved (coupled with the addition of P) so that denitrification within the reactors could progress. It is interesting to note that if the initial poor denitrification results were discounted (i.e. discount all results prior to May 2010) the removal rate at unit N4 effluent would average 38% (Figures 8.118(b) – (c)).

The mass balance calculation for N revealed an average reduction of 151gN/unit/day in the final effluent at N4. This represented a 28% reduction in N, with unit N1 accounting for the majority of the load reduction (130gN/unit/day, 24% removal). Once again, poor results early in the trial distorted the overall rate of N removal from the system. If these initial results were discounted (i.e. results from September 2009 to April 2010) then the N removal rate at unit N4 effluent would average 37% (Figures 8.118(d) – (e)).

8.3.3 Results of Metals and Salts Analysis

8.3.3.1 Introduction

This section details the results achieved from analysis of metals and salts. On average the range of metals and salts were sampled and analysed biannually however a number of parameters were only analysed once.

In all 16 parameters for metals and salts were tested for all 14 treatment units, as well as the raw leachate, raw leachate from the active area and the Tramore River. The list of parameters is detailed in Table 8.132 and the range of results achieved for each metal / salt is outlined in Tables 8.133 to 8.146 in the following format:

- Parameter Name
- Limit of Detection (LOD)
- Drinking Water Standard/Guide (EPA, 2004)
- Number of samples per unit (n), range of values, average and standard deviation
- Number of samples per unit above Drinking Water Standard/Guide for a particular parameter
- Where only one sample was analysed for a particular parameter, the effluent concentration per unit is inserted.

Interpretation of metals and salts results is detailed in section 8.3.3.2.

Table 8.132 List of Metals and Salts Analysed

Parameter	**Notation**		**Parameter**	**Notation**
Boron	B		Manganese	Mn
Cadmium	Cd		Mercury	Hg
Calcium	Ca		Nickel	Ni
Chromium	Cr		Phosphate (as P)	P
Copper	Cu		Potassium	K
Iron	Fe		Sodium	Na
Lead	Pb		Zinc	Zn
Magnesium	Mg		Alkalinity	Alk

Table 8.133 Boron Concentrations for Treatment Units

Parameter: Boron Limit of Detection: 0.01mg/l Drinking Water Standard: 1mg/l			
Unit / Sample	n	Range (mg/l)	Mean Concentration (mg/l)
Raw	2	1.34 - 1.36	1.35
Cell 1	2	1.33 - 1.39	1.36
Cell 2	0		
Cell 3	2	1.14 - 1.24	1.19
Cell 4	1	1.69	1.69
Cell 5	0		
Cell 6	0		
Cell 7	1	0.28	0.28
Cell 8	1	1.17	1.17
Cell 9	2	1.13 - 1.26	1.20
Cell 10	1	1.63	1.63
VF 1	1	1.83	1.83
VF 2	1	1.99	1.99
VP 1	1	0.93	0.93
VP 2	2	1 - 1.71	1.36
Tramore River	2	0.03 - 0.14	0.085
Raw Active	2	≤ 0.02 – 1.49	0.76
13 treated effluent samples > 1mg/l			

Table 8.134 Cadmium Concentrations for Treatment Units

Parameter: Cadmium Limit of Detection: 0.5µg/l Drinking Water Standard: 5µg/l				
Unit / Sample	n	Range (µg/l)	Mean Concentration (µg/l)	St Dev
Raw	6	0 - 2	1.50	0.84
Cell 1	5	0 - 2	0.60	0.89
Cell 2	1	1	1.00	
Cell 3	5	0 - 1	0.40	0.55
Cell 4	5	0 - 1	0.40	0.55
Cell 5	4	0 - 1	0.25	0.50
Cell 6	2	0 - 1	0.50	0.71
Cell 7	4	0 - 1	0.50	0.58
Cell 8	4	0 - 2	0.75	0.96
Cell 9	4	0 - 2	0.50	1.00
Cell 10	5	0 - 1	0.40	0.55
VF 1	5	0 - 6	1.40	2.61
VF 2	5	0 - 1	0.40	0.55
HF 1/VP 1	5	0 - 6	1.40	2.61
HF 2/VP 2	5	0 - 10	2.40	4.28
Tramore River	3	0	0.00	0.00
Raw Active	3	0 - 1	0.33	0.58
3 treated effluent samples ≥ 5µg/l VF 1 = 6µg/l (June 2009) VP 1 = 6µg/l (June 2009) VP 2 = 10µg/l (June 2009)				

Table 8.135 Calcium Concentrations for Treatment Units

Parameter: Calcium Limit of Detection: No Limit Drinking Water Guide: 50mg/l		
Unit / Sample	n	Concentration (mg/l)
Raw	1	144
Cell 1	1	134
Cell 2	0	
Cell 3	1	160
Cell 4	1	170
Cell 5	1	152
Cell 6	1	NA
Cell 7	1	170
Cell 8	1	184
Cell 9	1	120
Cell 10	1	176
VF 1	1	144
VF 2	1	128
VP 1	1	109
VP 2	1	128
Tramore River	1	64
Raw Active	0	
No sample ≥ 50mg/l		

Table 8.136 Chromium Concentrations for Treatment Units

Parameter: Chromium Limit of Detection: 0.5µg/l Drinking Water Standard: 50µg/l				
Unit / Sample	n	Range (µg/l)	Mean Concentration (µg/l)	St Dev
Raw	6	5 - 11	7.33	2.58
Cell 1	5	0 - 7	4.60	2.70
Cell 2	1	6	6.00	
Cell 3	5	0 - 10	4.40	3.65
Cell 4	5	0 - 5	3.40	1.95
Cell 5	4	0 - 7	3.00	2.94
Cell 6	2	3 - 5	4.00	1.41
Cell 7	4	0 - 8	4.50	3.32
Cell 8	4	1 - 5	3.50	1.73
Cell 9	4	0 - 7	4.00	2.94
Cell 10	4	3 - 9	5.25	2.63
VF 1	5	2 - 6	3.80	1.48
VF 2	5	1 - 5	2.80	1.79
HF 1/VP 1	4	0 - 3	2.00	1.41
HF 2/VP 2	5	0 - 3	2.00	1.41
Tramore River	3	0 - 2	0.67	1.15
Raw Active	3	21 - 87	64.33	37.54
No treated effluent sample ≥ 50µg/l				

Table 8.137 Copper Concentrations for Treatment Units

Parameter: Copper Limit of Detection: 1µg/l Drinking Water Standard: 2mg/l				
Unit / Sample	n	Range (µg/l)	Mean Concentration (µg/l)	St Dev
Raw	6	6 - 49	21	15.53
Cell 1	5	15 - 97	40	33
Cell 2	1	13	13	
Cell 3	5	15 - 87	42	29
Cell 4	5	9 - 80	35	28
Cell 5	4	27 - 91	51	28
Cell 6	2	14 - 26	20	8
Cell 7	4	19 - 202	92	79
Cell 8	4	21 - 92	63	30
Cell 9	4	11 - 111	46	46
Cell 10	5	10 - 89	50	30
VF 1	5	24 - 99	51	30
VF 2	5	24 - 5	57	37
HF 1/VP 1	4	32 - 101	65	38
HF 2/VP 2	5	21 - 98	53	41
Tramore River	3	7 - 57	27	26
Raw Active	3	2 - 48	23	23
No sample ≥ 2mg/l				

Table 8.138 Lead Concentrations for Treatment Units

Parameter: Lead Limit of Detection: 1µg/l Drinking Water Standard: 10µg/l				
Unit / Sample	n	Range(µg/l)	Mean Concentration (µg/l)	St Dev
Raw	7	0 - 1	0.57	0.53
Cell 1	5	0 - 5	1.80	1.92
Cell 2	1	1	1.00	
Cell 3	5	0 - 6	2.40	2.51
Cell 4	5	0 - 2	0.60	0.89
Cell 5	4	0 - 1	0.50	0.58
Cell 6	2	0 - 1	0.50	0.71
Cell 7	4	0 - 3	1.75	1.50
Cell 8	4	0 - 15	6.50	6.86
Cell 9	4	0 - 12	3.50	5.69
Cell 10	5	1 - 8	2.80	2.95
VF 1	5	0 - 5	1.60	1.95
VF 2	5	0 - 3	1.20	1.10
HF 1/VP 1	4	0 - 1	0.75	0.50
HF 2/VP 2	5	0 - 2	0.80	0.84
Tramore River	3	0 - 2	0.67	1.15
Raw Active	3	3 - 13	9.00	5.29
2 treated effluent samples ≥ 10µg/l Cell 8 = 15µg/l (June 2009) Cell 9 = 12µg/l (March 2010)				

Table 8.139 Magnesium Concentrations for Treatment Units

Parameter: Magnesium Limit of Detection: 0.01mg/l Drinking Water Standard: No Limit or Guide				
Unit / Sample	n	Range (mg/l)	Mean Concentration (mg/l)	St Dev
Raw	5	55 - 69	63	6
Cell 1	4	49 - 59	55	4
Cell 2	0			
Cell 3	4	47 - 70	59	10
Cell 4	4	55 - 78	67	9
Cell 5	4	52 - 65	59	6
Cell 6	1	62	62	NA
Cell 7	3	56 - 67	60	6
Cell 8	3	53 - 62	58	5
Cell 9	4	55 - 67	61	6
Cell 10	4	55 - 69	60	6
VF 1	4	55 - 71	63	7
VF 2	4	52 - 77	63	11
VP 1	3	56 - 57	57	0.47
VP 2	3	53 - 76	63	12
Tramore River	3	5.83 - 7.11	6.56	0.66
Raw Active	3	62 - 196	148	75

Table 8.140 Mercury Concentrations for Treatment Units

Parameter: Mercury Limit of Detection: 0.02µg/l Drinking Water Standard: 1µg/l			
Unit / Sample	n	Range (µg/l)	Mean Concentration (µg/l)
Raw	2	<0.02	<0.02
Cell 1	2	<0.02	<0.02
Cell 2	0		
Cell 3	2	<0.02	<0.02
Cell 4	1	<0.02	<0.02
Cell 5	0		
Cell 6	0		
Cell 7	1	<0.02	<0.02
Cell 8	1	<0.02	<0.02
Cell 9	2	<0.02	<0.02
Cell 10	1	<0.02	<0.02
VF 1	1	<0.02	<0.02
VF 2	1	<0.02	<0.02
VP 1	1	<0.02	<0.02
VP 2	2	<0.02	<0.02
Tramore River	1	<0.02	<0.02
Raw Active	0		
All samples < 0.02µg/l			

Table 8.141 Nickel Concentrations for Treatment Units

Parameter: Nickel

Limit of Detection: 1µg/l

Drinking Water Standard: 20µg/l

Unit / Sample	n	Range (µg/l)	Mean Concentration (µg/l)	St Dev
Raw	5	19 - 153	55	55
Cell 1	4	36 - 141	70	48
Cell 2	0			
Cell 3	4	36 - 56	46	8
Cell 4	4	35 - 64	48	12
Cell 5	4	33 - 72	49	17
Cell 6	1	45	45	
Cell 7	3	32 - 75	51	22
Cell 8	3	31 - 79	53	24
Cell 9	4	35 - 81	52	20
Cell 10	4	26 - 82	48	25
VF 1	4	5 - 76	44	29
VF 2	4	5 - 80	46	31
VP 1	3	42 - 74	57	16
HF 2/VP 2	4	5 -81	46	32
Tramore River	3	4 - 102	38	56
Raw Active	3	40 - 131	71	52

The majority of treated effluent samples ≥ 20µg/l

Table 8.142 Phosphate (as P) Concentrations for Treatment Units

Parameter: Phosphate (P)

Limit of Detection: 1µg/l

Drinking Water Guide: 5mg/l (as P_2O_5) ~ 2.19mg/l (as P)

Unit / Sample	n	Range (mg/l)	Mean Concentration (mg/l)	St Dev
Raw	2	0.50 - 0.90	0.70	0.28
Cell 1	2	0.37 - 1.02	0.69	0.46
Cell 2	0			
Cell 3	2	0.13 - 0.13	0.13	0.00
Cell 4	2	0.32 - 0.41	0.37	0.07
Cell 5	2	0.13 - 0.16	0.14	0.02
Cell 6	1	0.19	0.19	
Cell 7	1	0.29	0.29	
Cell 8	2	0.07 - 0.17	0.12	0.07
Cell 9	2	0.43 - 0.48	0.46	0.03
Cell 10	2	0.22 - 0.28	0.25	0.04
VF 1	2	0.18 - 0.30	0.24	0.08
VF 2	2	0.10 - 0.19	0.14	0.07
VP 1	2	0.06 - 0.12	0.09	0.04
VP 2	2	0.07 - 0.09	0.08	0.01
Tramore River	2	0.07 - 0.13	0.10	0.04
Raw Active	2	0.80 – 1.75	1.28	0.67

No sample ≥ 5mg/l (as P_2O_5)

Table 8.143 Potassium Concentrations for Treatment Units

Parameter: Potassium

Limit of Detection: 0.1mg/l

Drinking Water Standard: No Limit or Guide

Unit / Sample	n	Range (mg/l)	Mean Concentration (mg/l)	St Dev
Raw	7	171 - 225	194	18
Cell 1	5	156 - 257	187	40
Cell 2	1	197	197	
Cell 3	5	165 - 211	186	18
Cell 4	5	150 - 187	169	16
Cell 5	4	18 - 227	142	88
Cell 6	2	157 - 164	161	5
Cell 7	4	171 - 233	203	25
Cell 8	4	184 - 227	203	18
Cell 9	4	184 - 223	200	18
Cell 10	5	174 - 213	193	16
VF 1	5	173 - 217	192	17
VF 2	5	146 - 217	187	30
HF 1/VP 1	4	163 - 208	181	19
HF 2/VP 2	4	164 - 214	187	23
Tramore River	3	2.54 - 7.03	4.08	2.56
Raw Active	3	112 - 547	314	219

Table 8.144 Sodium Concentrations for Treatment Units

Parameter: Sodium

Limit of Detection: 0.1mg/l

Drinking Water Standard: 200mg/l

Unit / Sample	n	Range (mg/l)	Mean Concentration (mg/l)	St Dev
Raw	7	246 - 392	307	48
Cell 1	5	206 - 372	297	76
Cell 2	1	257	257	
Cell 3	5	184 - 376	291	80
Cell 4	5	214 - 904	409	285
Cell 5	4	213 - 471	343	106
Cell 6	2	174 - 251	212	54
Cell 7	4	219 - 462	344	100
Cell 8	4	253 - 437	342	75
Cell 9	4	284 - 434	351	62
Cell 10	5	224 - 419	313	80
VF 1	5	283 - 420	340	55
VF 2	5	239 - 427	330	76
HF 1/VP 1	4	203 - 422	309	93
HF 2/VP 2	4	252 - 381	330	55
Tramore River	3	13 - 44	24	18
Raw Active	3	260 - 1060	783	453
The majority of treated effluent samples ≥ 200 mg/l				

Table 8.145 Zinc Concentrations for Treatment Units

Parameter: Zinc Limit of Detection: 1µg/l Drinking Water Guide: 1000µg/l				
Unit / Sample	n	Range (µg/l)	Mean Concentration (µg/l)	St Dev
Raw	7	1 - 51	23	16
Cell 1	5	17 - 56	34	15
Cell 2	1	33	33	
Cell 3	5	8 - 143	85	50
Cell 4	5	29 - 74	49	16
Cell 5	4	23 - 99	54	32
Cell 6	2	16 - 36	26	14
Cell 7	4	11 - 311	124	131
Cell 8	4	11 - 166	76	66
Cell 9	4	14 - 166	59	45
Cell 10	5	57 - 81	66	9
VF 1	5	38 - 174	87	52
VF 2	5	52 - 120	77	26
HF 1/ VP 1	4	19 - 39	29	10
HF 2/VP 2	5	12 - 58	35	16
Tramore River	3	9 - 57	25	28
Raw Active	3	91 - 416	239	165
No sample ≥ 1000µg/l				

Table 8.146 Alkalinity Concentrations for Treatment Units

Parameter: Alkalinity Limit of Detection: No Limit Drinking Water Guide: 30mg/l		
Unit / Sample	n	Concentration (mg/l)
Raw	1	140
Cell 1	1	1100
Cell 2	0	
Cell 3	1	280
Cell 4	1	560
Cell 5	1	130
Cell 6	0	
Cell 7	1	700
Cell 8	1	360
Cell 9	1	1300
Cell 10	1	250
VF 1	1	240
VF 2	1	180
VP 1	1	180
VP 2	1	200
Tramore River	1	140
Raw Active	1	880
All Samples > 30mg/l		

Iron and manganese have not been included in the tables above as they have been interpreted in previous sections. However, for completeness, the Drinking Water Standard for iron is 200µg/l and for manganese is 50µg/l.

8.3.3.2 Interpretation of Metals and Salts Results

Analysis for metals and salts concentrations for influent and effluent for all treatment units displays a mixed set results in terms of removal of metals/salts throughout the trial plant. Although all fourteen units were analysed at some stage throughout the project for a range of metals and salts (see Table 8.32), only the treatment units operating in sequence (Cell 3 – Cell 5; Cell 7 – Cell 8 – VP 1 and Cell 9 → VP 2) shall be interpreted here (results for Cell 7 – Cell 8 and Cell 7 – Cell 8 – VP 1 have been presented together due to the low sampling number).

Interpretation of the treatment efficiency of the units within the sequences is limited somewhat by the low sampling number; typically for raw leachate n = 6 and for treatment units n = 5 and n = 2; however, despite this, each metal/salt shall be interpreted in the following manner:

- Raw leachate concentration*
- End sequence concentration*
- Concentration of leachate from active area (raw active)
- Tramore River concentration
- Reference to drinking water standard/drinking water guide
- Reference to typical parameter values for acetogenic and methanogenic leachates (see Tables 8.147 and 8.148 below)**

Note:

*A zero value in the data tables indicates the limit of detection for a given parameter.

**Tables 8.147 and 8.148 have previously been presented in Chapter 3 and are an amalgamation of data collected from different landfill sites by the UK Department of Environment (1995). The data were compiled from 35 samples for the acetogenic leachate and from 29 samples for the methanogenic leachate.

Table 8.147 Summary of Composition of Acetogenic Leachates sampled from large landfills with a relatively high dry waste input rate

	Overall Range		Overall Values	
Determinant	Minimum	Maximum	Median	Mean
pH-value	5.12	7.8	6.0	6.73
conductivity (µS/cm)	5,800	52,000	13,195	16,921
alkalinity (as $CaCO_3$)	2,720	15,870	5,155	7,251
COD	2,740	152,000	23,600	36,817
BOD_{20}	2,000	125,000	14,900	25,108
BOD_5	2,000	68,000	14,600	18,632
TOC	1,010	29,000	7,800	12,217
fatty acids (as C)	963	22,414	5,144	8,197
ammmoniacal-N	194	3,610	582	922
nitrate-N	<0.2	18.0	0.7	1.8
nitrite-N	0.01	1.4	0.1	0.2
sulphate (as SO_4)	<5	1,560	608	676
phosphate (as P)	0.6	22.6	3.3	5.0
chloride	659	4,670	1,490	1,805
sodium	474	2,400	1,270	1,371
magnesium	25	820	400	384
potassium	350	3,100	900	1,143
calcium	270	6,240	1,600	2,241
chromium	0.03	0.3	0.12	0.13
manganese	1.40	164.0	22.95	32.94
iron	48.3	2,300	475	653.8
nickel	<0.03	1.87	0.23	0.42
copper	0.02	1.1	0.075	0.13
zinc	0.09	140.0	6.85	17.37
arsenic	<0.001	0.148	0.010	0.024
cadmium	<0.01	0.1	0.01	0.02
mercury	<0.0001	0.0015	0.0003	0.0004
lead	<0.04	0.65	0.3	0.28

Note: All results in mg/l except pH value and conductivity (µS/cm)

(after UK DOE, 1995)

Table 8.148 Summary of Composition of Methanogenic Leachates sampled from large landfills with a relatively high dry waste input rate

	Overall Range		Overall Values	
Determinant	Minimum	Maximum	Median	Mean
pH-value	6.8	8.2	7.35	7.52
conductivity (µS/cm)	5,990	19,300	10,000	11,502
alkalinity (as $CaCO_3$)	3,000	9,130	5,000	5,376
COD	622	8,000	1,770	2,307
BOD_{20}	110	1,900	391	544
BOD5	97	1,770	253	374
TOC	184	2,270	555	733
fatty acids (as C)	<5	146	5	18
ammmoniacal-N	283	2,040	902	889
nitrate-N	0.2	2.1	0.7	0.86
nitrite-N	<0.01	1.3	0.09	0.17
sulphate (as SO_4)	<5	322	35	67
phosphate (as P)	0.3	18.4	2.7	4.3
chloride	570	4,710	1,950	2,074
sodium	474	3,650	1,400	1,480
magnesium	40	1,580	166	250
potassium	100	1,580	791	854
calcium	23	501	117	151
chromium	<0.03	0.56	0.07	0.09
manganese	0.04	3.59	0.30	0.46
iron	1.6	160	15.3	27.4
nickel	<0.03	0.6	0.14	0.17
copper	<0.02	0.62	0.07	0.13
zinc	0.03	6.7	0.78	1.14
arsenic	<0.001	0.485	0.009	0.034
cadmium	<0.01	0.08	<0.01	0.015
mercury	<0.0001	0.0008	<0.0001	0.0002
lead	<0.04	1.9	0.13	0.20

Note: All results in mg/l except pH value and conductivity (µS/cm)
(after UK DOE, 1995)

Boron Concentration

Boron concentrations in the raw leachate and effluent from the treatment units were low. The mean concentration in the influent and effluent with the exception of Cell 7 and VP 1 were above the drinking water standard of 1mg/l (see Table 8.133).

The concentration for raw leachate ranged from 1.34mg/l – 1.36mg/l (1.35mg/l mean conc.) and results for the Tramore River ranged from 30µg/l - 140µg/l.

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 9 ⇝ VP 2 = 1.36mg/l (slightly above the mean influent concentration)
- Cell 7 – 8 – VP 1 = 0.93mg/l (below the mean influent concentration).

Boron analyses for the raw active leachate revealed a concentration range of ≤ 0.02 mg/l – 1.49mg/l.

The author could not source data sets for typical boron concentrations for acetogenic and methanogenic leachates; however the Environmental Protection Agency defines the

minimum reporting value (MRV) for 'dirty' water (leachate) as 2mg/l and for 'clean' water 0.2mg/l (EPA, 2003).

Cadmium Concentration

Cadmium concentrations in the raw leachate and effluent from the treatment units were extremely low and all results were below the drinking water standard of 5µg/l with the exception of three results for VF 1, VP 1 (6µg/l each) and VP 2 (10µg/l) (see Table 8.134). The concentration for raw leachate ranged from 0.5µg/l - 2µg/l, leachate from the active area ranged from 0.5µg/l - 1µg/l and all samples from the Tramore River were at or below the limit of detection (0.5µg/l).

Final mean effluent concentrations from the units operating in sequence could not be calculated as the majority of samples were at or below the limit of detection.

All raw leachate analyses of Cd in this project were well below the typical cadmium concentrations for acetogenic and methanogenic leachates of 15µg/l and 20µg/l respectively.

Calcium Concentration

Calcium concentrations in the raw leachate and effluent from the treatment units was above the drinking water guide of 50mg/l (see Table 8.135)

Only one set of samples was analysed for Ca concentration (August 2009) so statistical interpretation was not possible. However based on the results, final effluent concentrations for sequences Cell 9 → VP 2 and Cell 7 – 8 – VP 1 were 16mg/l and 35mg/l respectively, lower than the influent concentration, with the reverse for sequence Cell 3 – 5 which presented a final effluent concentration of 152mg/l, 8mg/l higher than the influent.

Calcium concentration in the Tramore River sample was 64mg/l.

The Ca result for raw leachate (144mg/l) is very close to a typical methanogenic leachate with a mean Ca concentration of 151mg/l.

Chromium Concentration

Chromium concentrations in the raw leachate and effluent from the treatment units were extremely low and all results were below the drinking water standard of 50µg/l. Concentration for the raw leachate ranged from 5µg/l - 11µg/l, leachate samples from the active area ranged from 21µg/l - 87µg/l, whereas all results for the Tramore River were below the limit of detection (5µg/l) (see Table 8.136).

Final mean effluent concentrations from the units operating in sequence could not be calculated as the majority of samples were at or below the limit of detection.

Cr analysis for the filtered raw leachate was well below the typical concentrations for acetogenic and methanogenic leachates of 130µg/l and 90µg/l respectively.

Copper Concentration

Copper concentrations in the raw leachate and effluent from the treatment units were low and all results were below the drinking water standard of 2mg/l. The concentration for raw leachate ranged from 6µg/l - 49µg/l (mean conc. 21µg/l) and results for the Tramore River ranged from 7µg/l - 57µg/l (see Table 8.137).

Final mean effluent concentrations from the units operating in sequence were all above the mean raw influent concentration of 20µg/l. Final mean effluent concentrations were as follows:

- Cell 3 – Cell 5 = 51µg/l
- Cell 9 → VP 2 = 53µg/l
- Cell 7 – 8 – VP 1 = 65µg/l.

Cu analysis for the raw active leachate revealed a mean concentration of 23µg/l, which implied that all leachate results were well below the typical concentrations for acetogenic and methanogenic leachates of 130µg/l.

Lead Concentration

Lead concentrations in the raw leachate and effluent from the treatment units were extremely low and most of the results were below the drinking water standard of 10µg/l, the exceptions being Cell 8 and Cell 9 which displayed results of 15µg/l (June 2009) and 12µg/l (March 2010) respectively.

The lead concentration for all raw leachate samples revealed concentrations at or below the limit of detection, i.e. 1µg/l. Two of the three results for the Tramore River were below the limit of detection, whereas mean concentration for raw active was 9µg/l (see Table 8.138).

Final mean effluent concentrations from the units operating in sequence could not be calculated as the majority of samples were at or below the limit of detection.

Pb concentrations for all raw leachate sampled (filtered and raw active) was well below the typical concentrations for acetogenic and methanogenic leachates of 280µg/l and 200µg/l respectively.

Magnesium Concentration

Magnesium concentrations in the raw leachate and effluent from the treatment units were relatively low. The concentration for raw leachate ranged from 55mg/l – 69mg/l (63mg/l mean conc.) and results for the Tramore River ranged from 5.83mg/l – 7.11mg/l (see Table 8.139).

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 3 – Cell 5 = 59mg/l (below the mean influent concentration)
- Cell 9 → VP 2 = 63mg/l (equal to the mean influent concentration)
- Cell 7 – 8 – VP 1 = 57mg/l (below the mean influent concentration).

There is no drinking water standard or guide for magnesium, however the Environmental Protection Agency has set a minimum reporting value (MRV) for ‘dirty’ water (leachate) of 10mg/l (Mg) and 1mg/l (Mg) for ‘clean’ water (EPA, 2003).

Magnesium analysis for the raw active leachate revealed a concentration range of 62mg/l – 196mg/l, with a mean concentration of 148mg/l.

The Mg result for all leachate samples (filtered and raw active) was well below typical concentrations for acetogenic and methanogenic leachates of 384mg/l and 250mg/l respectively.

Mercury Concentration

Mercury concentrations in the raw leachate and effluent from the treatment units were low and all results were at or below the limit of detection (0.02µg/l) and consequently below the drinking water standard of 1µg/l (see Table 8.140).

Mercury concentrations for raw active leachate samples were all at or below the limit of detection, and the same applied to results for the Tramore River.

Final mean effluent concentrations from the units operating in sequence could not be calculated as all results were at or below the limit of detection.

Hg concentrations for all raw leachate samples (filtered and raw active) were well below the typical concentrations for acetogenic and methanogenic leachates of 0.4µg/l and 0.2µg/l respectively.

Nickel Concentration

Nickel concentrations in the raw leachate and effluent from the treatment units were in the moderate to low range. The mean concentrations in the influent and effluent were above the drinking water standard of 20µg/l.

The concentration for raw leachate ranged from 19µg/l – 153µg/l (55µg/l mean conc.) and results for the Tramore River ranged from 4µg/l – 102µg/l (38µg/l mean conc.).

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 3 – Cell 5 = 49µg/l (below the mean influent concentration)
- Cell 9 → VP 2 = 46µg/l (below the mean influent concentration)
- Cell 7 – 8 – VP 1 = 57µg/l (slightly above the mean influent concentration)
  (see Table 8.141 for statistical analysis of results).

Nickel analysis for the raw active leachate revealed a concentration range of 40µg/l – 131µg/l, with a mean concentration of 71µg/l.

The Ni result for all leachate samples (filtered and raw active) was below typical concentrations for acetogenic and methanogenic leachates of 420µg/l and 170µg/l respectively.

Phosphate (P) Concentration

Phosphate (measured as P) concentrations in the raw leachate and effluent from the treatment units were extremely low and all results were below the drinking water guide of 5mg/l as P_2O_5 (2.9mg/l as P).

The concentration for raw leachate ranged from 0.5mg/l – 0.9mg/l (0.7mg/l mean conc.) and results for the Tramore River ranged from 70µg/l – 130µg/l (100µg/l mean conc.).

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 3 – Cell 5 = 140µg/l (below the mean influent concentration)
- Cell 9 → VP 2 = 80µg/l (below the mean influent concentration)
- Cell 7 – 8 – VP 1 = 90µg/l (below the mean influent concentration)
  (see Table 8.142 for statistical analysis of results).

Analysis of P for the raw active leachate revealed a concentration range of 0.80mg/l – 1.75mg/l, with a mean concentration of 1.28mg/l.

The P results for all leachate samples (filtered and raw active) were below typical concentrations for acetogenic and methanogenic leachates of 5mg/l and 4.3mg/l respectively.

Potassium Concentration

Potassium concentrations in the raw leachate and effluent from the treatment units were moderately low.

Concentrations for raw leachate ranged from 171mg/l – 225mg/l (194mg/l mean conc.) and results for the Tramore River ranged from 2.54mg/l – 7.03mg/l.

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 3 – Cell 5 = 142mg/l (below the mean influent concentration)
- Cell 9 → VP 2 = 187mg/l (below the mean influent concentration)
- Cell 7 – 8 – VP 1 = 181mg/l (below the mean influent concentration)
  (see Table 8.143 for statistical analysis of results).

There is no drinking water standard or guide for potassium; however the Environmental Protection Agency has set a minimum reporting value (MRV) for 'dirty' water (leachate) of 10mg/l (K) and for 'clean' water 1mg/l (K) (EPA, 2003).

Potassium analysis for the raw active leachate revealed a concentration range of 112mg/l – 547mg/l, with a mean concentration of 314mg/l.

The K results for all leachate samples (filtered and raw active) were well below typical concentrations for acetogenic and methanogenic leachates of 1143mg/l and 854mg/l respectively.

Sodium Concentration

Sodium concentrations in the raw leachate and effluent from the treatment units were moderate. The mean concentration in the influent and effluent was above the drinking water standard of 200mg/l.

Concentrations for the raw leachate ranged from 246mg/l – 392mg/l (307mg/l mean conc.) and for the Tramore River ranged from 13mg/l – 44mg/l.

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 3 – Cell 5 = 343mg/l (above the mean influent concentration)
- Cell 9 → VP 2 = 330mg/l (above the mean influent concentration)
- Cell 7 – 8 – VP 1 = 309mg/l (above the mean influent concentration)

  (see Table 8.144 for statistical analysis of results).

Sodium analysis for the raw active leachate revealed a concentration range of 260mg/l – 1060mg/l, with a mean concentration of 783mg/l.

The Na results for all leachate samples (filtered and raw active) were below typical concentrations for acetogenic and methanogenic leachates of 1371mg/l and 1480mg/l respectively.

Zinc Concentration

Zinc concentrations in the raw leachate and effluent from the treatment units were extremely low. The mean concentrations in the influent and effluent were below the drinking water standard of 1000µg/l.

Concentrations for raw leachate ranged from 1µg/l – 51µg/l (23µg/l mean conc.) and for the Tramore River ranged from 9µg/l – 57µg/l.

Final mean effluent concentrations from the units operating in sequence were as follows:

- Cell 3 – Cell 5 = 54µg/l (above the mean influent concentration)
- Cell 9 ↛ VP 2 = 35µg/l (above the mean influent concentration)
- Cell 7 – 8 – VP 1 = 29µg/l (above the mean influent concentration)

  (see Table 8.145 for statistical analysis of results).

Zinc analyses for the raw active leachate revealed a concentration range of 91µg/l – 416µg/l, with a mean concentration of 239µg/l.

Zn results for all leachate samples (filtered and raw active) were below typical concentrations for acetogenic and methanogenic leachates of 17.37mg/l and 1.14mg/l respectively.

Alkalinity Concentration

Alkalinity concentration in the raw leachate and effluent from the treatment units was above the drinking water guide of 30mg/l (see Table 8.146).

Only one set of samples was analysed for alkalinity concentration (August 2009) so statistical interpretation was not possible. However based on the results, final effluent concentrations for sequences Cell 9 ↛ VP 2 and Cell 7 – 8 – VP 1 were 200mg/l and 180mg/l respectively, higher than influent concentration, with the reverse for sequence Cell 3 – 5 which presented a final effluent concentration of 130mg/l, 10mg/l lower than the influent.

The Environmental Protection Agency has set a minimum reporting value (MRV) for ‘dirty’ water (leachate) of 50mg/l (Alk) and 5mg/l (Alk) for ‘clean’ water (EPA, 2003).

Alkalinity in the Tramore River sample was 140mg/l.

The alkalinity result for all leachate samples (filtered, conc. 140mg/l and raw active conc. 880mg/l) was well below typical concentrations for acetogenic and methanogenic leachates of 7.25g/l and 5.38g/l respectively.

8.3.3.3 Removal Mechanisms for Metals and Salts

The main removal mechanisms for metals and salts within the various treatment units and sequences are likely to be immobilisation in the media (both organic and inorganic) and within the leaf litter through sedimentation and filtration coupled with microbially mediated processes resulting in metal precipitation.

Other likely removal mechanisms are biomass uptake; specifically in the reed and grass stems and roots; sorption within the root zone and rhizosphere as well as complexation and subsequent immobilisation with other metals.

Expanding on some of these removal mechanisms, Cooper *et al*., (1996) describes metal removal through microbially mediated processes resulting from a combination of metal oxidising bacteria in the aerobic zones and sulphate reducing bacteria in anaerobic zones, which cause precipitation of metals as oxides and sulphides. Metals that precipitate as oxides include nickel, copper, lead, zinc, silver and gold. Microbially mediated sulphate reduction consumes sulphate ions and produces hydrogen sulphide and alkalinity (as the bicarbonate ion). The hydrogen gas is released, whereupon it ionises to give sulphide ions, which in turn react with a range of metal ions. This process ultimately produces metal sulphide precipitates.

Whilst each of these microbially mediated processes are possible mechanisms for metals immobilisation, it is likely that oxidation is the dominant of the two as the treatment units are mainly aerobic reactors.

Co-precipitation of heavy metals (Cd, Ni, Pb, Cr, Hg, Cu, As) in the ferric oxyhydroxide plaque matrix that forms on the surface of wetland plant systems at the root/sediment interface has been mooted as another possible method of metal immobilisation (Taylor *et al.,* 1983). This is particularly relevant when the iron plaque that had developed on a number of the treatment units, as described in Chapter 7, is taken in to account.

Interpretation of metals and salts concentrations in the influent and effluent for treatment units operating in sequence was limited by the low sampling number and in many cases by the high standard deviation of results about the mean concentration. Consequently, phosphate (as P) is the only parameter where it can be definitively stated that a significant reduction (with a low standard deviation) in concentration from influent to final effluent across the three sequences occurred (see Table 8.142).

A small reduction in the mean influent to effluent concentration occurred for magnesium, nickel and potassium, however due to the high standard deviation, this reduction was not deemed significant.

There was a mixed set of effluent results for calcium and boron from the treatment units (above and below influent concentration) whereas results for cadmium, chromium, lead and mercury were indeterminate in terms of treatment efficiency due to the fact that results for final mean effluent concentrations could not be calculated as they were at or below the limit of detection.

A point of particular interest is the initial concentration levels of metals and salts in the raw filtered leachate, which is extremely low when compared to the acetogenic and methanogenic leachates in Tables 8.147 and 8.148. In many instances, the parameter of concern was measured at or below the limit of detection (Pb, Hg) and/or within the drinking water standard or guide (Cr, Cu, P, Zn). Reasons for the low metal concentrations are probably due to a multitude of factors relating to waste age, composition, temporary cover materials (typically subsoil and compost) and landfilling techniques employed during the operational phase of the Kinsale Road Landfill Site.

The mechanisms for immobilization will be similar to those mentioned above, with filtration, sedimentation, sorption and complexation-precipitation likely to dominate. It is a known fact that when pH is close to neutral (as is the case at KRLF), slightly reducing conditions tend to persist. This can lead to biogeochemical equilibrium within the landfill thus providing permanent storage within the landfill body and low metal-leachate emission levels (Modin, 2012).

Calculations by several authors (Bozkurt *et al*., 2000; van Praagh *et al*., 2007; Östman *et al*., 2008) have shown that organic matter and sulphides are more than enough to bind all the heavy metals in a municipal solid waste landfill and that competition with other elements is insignificant. Furthermore, the capacity of the landfill to buffer changes in pH has been found sufficient for maintaining a neutral pH over very long periods, thus limiting the risk of metal solubilisation due to pH changes (Flyhammar and Hakansson, 1999; Bozkurt *et al*., 2000; Östman *et al*., 2008).

In conclusion to this section on heavy metals concentration in the leachate, the author postulates that in the event of heavy metal leaching from the waste body, it is likely that the natural geological stratigraphy of peat and clay sequences that underlie the majority of the site (thus providing a natural geological barrier to downward migration of leachate) would contain and re-immobilise the metals and metal complexes at the interface between the waste and natural sediments. Allen (2002), in a paper on low cost solutions for landfill management has suggested that thick sequences of peats and low permeability clays laid down during the Holocene epoch provide stable attenuation barriers for immobilisation of metals due to their high filtration, sorption and ion exchange capacities as well as low hydraulic conductivities. Therefore, the low level of heavy metal leaching from Kinsale Road Landfill Site can be expected to continue well into the future.

8.3.4 Results and Interpretation of List I and List II Substances

8.3.4.1 Introduction

List I and List II Substances are catalogues of chemical compounds that are classed as hazardous (List I) or have a deleterious effect (non-hazardous but requiring control) (List II) to groundwater and to the aquatic environment. The substances were selected primarily on the basis of their likely use or presence in the environment and their potential impacts on waters by virtue of toxicity, persistence and bioaccumulation as well as their potential for biomagnification.

The range of substances is drawn from the following groups set out in Table 8.149 (EPA, 1997).

Table 8.149 List I and List II Substances

List I	List II
1. Organohalogen compounds and substances which may form such compounds in the aquatic environment 2. Organophosphorus compounds 3. Organotin compounds 4. Substances which possess carcinogenic, mutagenic or teratogenic properties in or via the aquatic environment 5. Mercury and its compounds 6. Cadmium and its compounds 7. Persistent mineral oils and hydrocarbons of petroleum origin 8. Persistent synthetic substances which may float, remain in suspension or sink and which interfere with any use of the water.	1. The following metalloids and metals and their compounds: 1. Zinc 2. Copper 3. Nickel 4. Chrome 5. Lead 6. Selenium 7. Arsenic 8. Antimony 9. Molybdenum 10. Titanium 11. Tin 12. Barium 13. Beryllium 14. Boron 15. Uranium 16. Vanadium 17. Cobalt 18. Thallium 19. Tellurium 20. Silver. 2. Biocides and their derivatives not appearing in List I 3. Substances which have a deleterious effect on the taste and/or smell of the products for human consumption derived from the aquatic environment and compounds liable to give rise to such substances in water 4. Toxic or persistent organic compounds of silicon, and substances which may give rise to such compounds in water, excluding those which are biologically harmless or which are rapidly converted in water into harmless substances 5. Inorganic compounds of phosphorus and elemental phosphorus 6. Non persistent mineral oils and hydrocarbons of petroleum origin; 7. Cyanides and Fluorides 8. Substances which have an adverse effect on the oxygen balance, particularly: ammonia and nitrites.

(after EPA, 1997)

During the course of this project a total of 138 compounds contained within the List I and II catalogue were analysed annually during 2009 and 2010 by an external laboratory. A full list of the compounds determined is detailed in Appendix 1.

The samples were taken on 26th June 2009 and 17th August 2010 and samples from the following units were sent for analysis:

2009 Samples: Raw leachate, raw active leachate, Cell 1, Cell 3, Cell 9, VP 2 and Tramore River.

2010 Samples: Raw leachate, raw active leachate, Cell 1, Cell 3, Cell 4, Cell 7, Cell 8, Cell 9, Cell 10, VF 1, VF 2, VP 1, VP 2, N1, N4 and Tramore River.

Sampling during 2009 was limited to seven due to budget constraints, however this was deemed satisfactory as the sample spread encompassed all variations in treatment media (with the exception of the VF reed beds).

Interpretation of all 138 parameters is outside the remit of this thesis; instead, a much shortened list of 29 substances is presented in Table 8.150. Following scrutiny of literature produced by the Environmental Protection Agency and the Environment Agency (England and Wales) pertaining to drinking water standards, environmental quality standards and hydrogeological risk assessments for landfill sites, the 29 substances were chosen based on the following principles:

- The importance attributed by each agency to the substance
- The existence of a Drinking Water Standard for the substance
- To achieve a representative sample from each subcategory; namely volatile organic carbons (VOC), semi-volatile organic carbons (SVOC), polycyclic aromatic hydrocarbons (PAH), organophosphorus pesticides/compounds, chlorinated pesticides/polychlorinated biphenyl's (PCB), acid herbicides and triazines
- The author's knowledge and familiarity with specific substances.

Table 8.150 Selected Results for List I and List II Substances

Category & Compound	LOD (µg/l) 2009 Results	LOD (µg/l) 2010 Results	Sample Results 2009 (µg/l)	Raw Active Results 2009 (µg/l)	Sample Results (inc. Raw Active) 2010 (µg/l)	Drinking Water Standard / MRV* / EQS** (µg/l)
Chlorinated Pesticides (PCB)						
Aldrin	0.01	0.05	All <0.025	<0.025	All <0.05	0.030
Dieldrin	0.01	0.05	All <0.025	<0.025	All <0.05	0.030
Heptachlor	0.01	0.05	All <0.025	<0.025	All <0.05	0.030
Heptachlor Epoxide	0.01	0.05	All <0.025	<0.025	All <0.05	0.030
Organophosphorus Pesticides						
Parathion	0.01	0.05	All <0.025	<0.025	All <0.05	0.01*
Disulfoton	0.01	NA	All <0.025	<0.025	-	0.01*
Methyl parathion	0.01	0.05	All <0.025	<0.025	All <0.05	0.015*
Acid Herbicides						
2,4-D ester	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Pentachlorophenol	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Triazines						
Atrazine	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Simazine	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
PAH						
Benzo -a-pyrene	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Benzo(b)fluoranthene	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Benzo(g,h,i)perylene	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Benzo(k)fluoranthene	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Benzo -a-pyrene	0.01	0.05	All <0.025	<0.025	All <0.05	0.1
Naphthalene	0.01	0.05	All <0.025	<0.025	All <0.05	10 (100)**
VOC						
Vinyl Chloride / Chloroethene	0.5	0.5	ND***	<50	ND	0.5
Chlormethyl Cyanide / Chloroacetonitrile	0.5	0.5	ND	<50	ND	50[#]
11 Dichloroethane	0.5	0.5	ND	<50	ND	3.0
Trichloromethane / Chloroform	1.0	1.0	ND	<100	ND	100
Benzene	0.1	0.1	ND	<10	ND	1.0
12 Dichloroethane	0.1		ND	<10	ND	3.0
Trichloroethylene / Trichloroethene	0.1	0.1	ND	<10	ND	3.0
Bromodichloromethane	2.0	2.0	ND	<200	ND	100
Toluene	0.5	0.5	ND	<50	ND	10[##]
Tetrachloroethylene / Tetrachloroethene	0.1	0.1	ND	<10	ND	3.0
Dibromochloromethane	1.0	1.0	ND	<100	ND	100
Bromoform	1.0	1.0	ND	<100	ND	100

* MRV = Minimum Reporting Value as set by the Environment Agency for England and Wales

** EQS = Environmental Quality Standard (EQS) is a water quality and biological standard for a surface watercourse. Figures for EQS are for fresh water and are Annual Average Concentrations with Maximum Allowable Concentrations in brackets (Environment Agency, 2003)

*** ND = Not Detected, concentration below limit of detection

[#] = Drinking Water Standard (DWS) for Chlormethyl Cyanide / Chloroacetonitrile is actually for Cyanide

[##] = EQS for Toluene (EPA, 2006)

8.3.4.2 Interpretation of Results for List I and List II Substances

Results from analysis of the two sets of samples from the raw leachate and effluent from the treatment units showed extremely low concentration levels for all substances across all units. With the exception of raw active leachate, all of the 29 selected parameter results from the treatment units and raw filtered leachate were either below the drinking water standard, detected but not quantifiable (i.e. detected but under range) or not detected (i.e. <LOD).

The reporting limit for VOC results for raw active was raised as the sample was very dirty and required dilution of 1:100. While all 82 volatile organic compounds analysed were detected, the exact concentration could not be determined.

While there were only two sets of samples sent for analysis over the course of the project; providing a low sample count of n = 2 for the influent and effluent; similar analysis of the raw leachate in May 2003 (fulfilling a licence requirement for a once off analysis of List I and List II substances within the leachate) revealed similar results for all substances; with the exception of Naphthalene (conc. 98ng/l) and Benzo(g,h,i)perylene (conc. 10ng/l); with concentrations at or below the drinking water standard, detected but not quantifiable or not detected.

The reason for the apparent lack of/extremely low concentrations of List I and List II substances within the leachate stream is unknown. It is possible that (a) the substances were simply never landfilled at the facility; (b) the substances were landfilled but remain *in situ* and have never found their way into the leachate stream or (c) have become immobilized through similar process as mentioned for metals and salts. However, given the age of the landfill and the fact that it was in operation long before the current waste licensing regime (a) is improbable and a more credible explanation lies with a combination of (b) and (c).

8.3.5 Results and Interpretation of Toxicity Tests

8.3.5.1 Introduction

Toxicity tests were carried out on selected samples (river, raw leachate and treated leachate) by an external laboratory (Shannon Aquatic Toxicity Laboratory) on two separate occasions during the course of the project (June 2009 and August 2010).

Seven samples were sent for testing in 2009 and eight in 2010. On each occasion, the following test species were used: *Daphnia magna* (freshwater crustacean (water flea)) and *Vibrio fischeri* (freshwater bacteria). Due to budget limitations the range of samples sent for analysis was limited to raw leachate, raw active leachate, Tramore River, Cell 1 (coarse grade compost), Cell 3 (timber chippings), Cell 9 (coarse compost – timber chip mix) and VP 2 (vegetated grass plane). N4 (end of sequence denitrification unit) was added to the 2010 batch of samples. The treatment units chosen for sample analysis was based on gaining information on the effluent from the different media types within the trial plant and on assessing effluent toxicity from what the author deemed as the most successful sequence of treatment units, i.e. Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 - VP 2 – N1 – N2 – N3 – N4.

The results of the toxicity tests are detailed in Tables 8.151 and 8.152 and for guidance Table 8.153 previously presented in chapter 7 outlines the categories of acute toxicity.

A full suite of tests were carried out on the samples sent for toxicity tests, namely heavy metals analysis, analysis of List I and List II substances as well testing for standard wastewater parameters. Since it is valuable to relate the results from toxicity tests to specific chemical and biological parameters, the following range of parameter results are presented in Tables 8.154 and 8.155; ammonium, nitrate, nitrite, COD, TOC, chloride, conductivity, pH, suspended solids, K, Mg, Ca and alkalinity.

In presenting this data, it was hoped that results from the toxicity bioassays could be attributed to the presence or absence of certain parameters at high concentrations.

Table 8.151 Toxicity Tests for Raw Leachate and Selected Treatment Units for June 2009
All figures expressed as Toxic Units (TU)

Toxicity Test - June 2009	Raw	Raw Active	Cell 1	Cell 3	Cell 9	VP 2	Tramore River
48 h EC 50 to *Daphnia magna*	5.10	13.30	2.90	1.30	3.10	< 1	< 1
5 min EC 50 to *Vibrio fischeri*	< 2.2	52.90	< 2.2	< 2.2	< 2.2	< 2.2	< 2.2
15 min EC 50 to *Vibrio fischeri*	< 2.2	69.40	< 2.2	< 2.2	< 2.2	< 2.2	< 2.2

Table 8.152 Toxicity Tests for Raw Leachate and Selected Treatment Units for August 2010
All figures expressed as Toxic Units (TU)

Toxicity Test - August 2010	Raw	Raw Active	Cell 1	Cell 3	Cell 9	VP 2	N 4	Tramore River
48 h EC 50 to *Daphnia magna*	5.60	40.00	5.40	1.40	7.90	<1	<1	<1
15 min EC 50 to *Vibrio fischeri*	<2.2	52.60	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2

Table 8.153 Classification of Acute Toxicity Expressed as Toxic Units

Toxic Units	Description
< 3	Non Toxic
3 - 10	Slightly Toxic
10 - 50	Toxic
50 - 100	Very Toxic
> 100	Extremely Toxic

(after SATL, 2011(b))

Table 8.154 Results for Toxicity Tests, Selected Metals and Salts and Chemical Parameters for Raw Leachate and Treatment Units for June 2009

Parameter	Raw	Raw Active	Cell 1	Cell 3	Cell 9	VP 2	Tramore River
48 h EC 50 to *Daphnia magna*	5.10	13.30	2.90	1.30	3.10	< 1	< 1
5 min EC 50 to *Vibrio fischeri*	< 2.2	52.90	< 2.2	< 2.2	< 2.2	< 2.2	< 2.2
15 min EC 50 to *Vibrio fischeri*	< 2.2	69.40	< 2.2	< 2.2	< 2.2	< 2.2	< 2.2
Ammonium	407	841	268	52	295	<LOD	1
Nitrate	<LOD	<LOD	211	1109	284	1137	29.00
Nitrite	0.019	0.032	0.01	1.00	1.00	4.00	0.057
COD	345	1050	296	251	413	170	9
TOC	93	413	67	66	72	67	1.3
Chloride	474	1092	425	440	434	411	23
Conductivity ms/cm	4.67	10.19	3.80	3.41	4.18	3.03	0.368
pH	7.31	7.40	7.37	6.97	7.45	7.60	7.6
Suspended Solids	30	224	14	8	14.50	11.50	2
K	195	547	177	182	206	197	2.5
Ca	144	118	134	160	120	128	64
Mg	55.31	195.60	49.01	55.25	59.73	53.18	6.75
Alk	140	880	1100	280	1300	200	140

Note: All data in mg/l except for Toxicity Tests, expressed as Toxic Units (TU), pH as pH units and Conductivity as mS/cm

Table 8.155 Results for Toxicity Tests, Selected Metals and Salts and Chemical Parameters for Raw Leachate and Treatment Units for August 2010

Parameter	Raw	Raw Active	Cell 1	Cell 3	Cell 9	VP 2	N 4	Tramore River
48 h EC 50 to *Daphnia magna*	5.60	40.00	5.40	1.40	7.90	<1	<1	<1
15 min EC 50 to *Vibrio fischeri*	<2.2	52.60	<2.2	<2.2	<2.2	<2.2	<2.2	<2.2
Ammonium	458	1380	305	53	420	<LOD	6	2
Nitrate	124	634	39	1400	<LOD	1508	864	32
Nitrite	0.018	31	11.00	4.00	12.00	0.01	29.00	4
COD	385	2014	318	260	372	125	251	13
TOC	116	411	89	60	103	22	66	3.0
Chloride	522	1353	496	479	493	519	468	14
Conductivity mS/cm	5.21	13.63	4.22	4.03	4.96	4.05	3.48	0.384
pH	7.33	7.67	7.50	7.63	6.26	7.51	7.12	7.74
Suspended Solids	34.50	185.00	11.00	20.00	71.00	59.50	30.00	2.5
K	224.5	282.0	257.0	210.5	223.0	214.0	201	7
Mg	65.49	186.43	56.60	69.96	66.63	76.26	72.94	7.11

Note: All data in mg/l except for Toxicity Tests, expressed as Toxic Units (TU), pH as pH units and Conductivity as mS/cm

8.3.5.2 Interpretation of Results for Toxicity Tests

Analysis of toxicity results for June 2009 and August 2010 reveals a general reduction in toxicity to *Daphnia magna* (Effective Concentration 50 after 48 hours) from influent (raw leachate) to effluent from each treatment unit within each sampling period. The exception to this was Cell 9 effluent for August 2010, which showed a rise in toxicity from 5.6 toxic units (TU) in the raw leachate to 7.9 TU. However, this had dropped to <1 TU in the effluent at sequence end from N4.

Results for Cell 3 effluent (August 2010) were also surprisingly high (5.4 TU) showing a drop of only 0.2 TU from influent to effluent.

Based on the classification of acute toxicity (Table 8.153), the treated effluent was less toxic, moving from the slightly toxic category (3 – 10 TU) for raw leachate to the non-toxic category (< 3 TU). The exceptions to this were Cell 9 (TU of 3.1 and 7.9 for 2009 and 2010 respectively) and Cell 1 (TU of 5.4 in August 2010) each remaining in the slightly toxic band.

It is noticeable that, with the exception of raw active leachate, the toxicity assay *Vibrio fischeri* (5 min EC 50 and 15 min EC 50 for 2009 and 15 min EC 50 for 2010) did not exhibit a toxic response to the filtered raw leachate or the effluent from the treatment units, thus limiting further interpretation. It has been reported elsewhere that high strength NH_4, high concentrations of TOC (Modin, 2012) and COD (Pivato *et al*., 2006) are strong contributors to toxicity in *V. fischeri*. The high concentrations of these parameters in the raw active leachate; i.e. NH_4 conc. of 841mg/l and 1380mg/l for 2009 and 2010 respectively; COD conc. of 1050mg/l and 2014mg/l and TOC conc. of 413mg/l and 411mg/l for 2009 and 2010 respectively; were sufficient to cause significant toxic inhibition to the *V. fischeri* battery test. In fact, the concentrations of these parameters tended to be over twice the corresponding parameter concentration in the raw filtered leachate.

Toxicity may also be caused by growth inhibition relating to a lack of or imbalance in nutrients such as K, Ca, Mg, which tended to be higher in the raw active leachate. High alkalinity has previously been suspected of increasing the toxic effect of ammonia (Clément *et al*., 1997).

Daphnia magna seems to be more suited as a test battery for toxicity to the raw filtered leachate and the effluent from the treatment units. Results for toxicity tests for *D. magna* display progressive treatment and lowering of toxicity from the influent (raw filtered leachate) through the treatment units. The 2010 result for Cell 9 is anomalous as it shows a rise of 3.2 TU from influent to effluent, which is the opposite for the 2009 result where a 2 TU reduction was recorded (it should be noted that Cell 1, Cell 3 and Cell 9 are all primary treatment units whereas VP 2 and N4 are end sequence polishing units).

An exact interpretation for the rise in toxicity is difficult to explain due to the complex matrix of leachate constituents (and toxicity is not caused by one parameter alone), however the author postulates that it is related to the following:

1 An unusually high nitrate concentration in the influent (123mg/l) (although NO_3 only tends to be toxic to *Daphnia magna* (48h EC 50) at concentrations in excess of 2000mg/l (US EPA, 2010; Environment Canterbury, 2009)

2 A slightly higher K, Na and Cl concentration in the influent (225, 292 and 522mg/l respectively); *D. magna* being a freshwater crustacean, it is likely to have a strong reaction to the presence of high chloride and other salts in the wastewater stream

3 A correspondingly high electrical conductivity of 5.21mS/cm and NH_4 concentration of 458mg/l in the influent.

It is possible that the combined effect of the increased concentrations of the parameters mentioned above were at least a partial cause of the increase in toxicity.

It is also interesting to note that nitrate concentration in the effluent from Cell 9 was at or below detection levels (1mg/l), possibly indicating simultaneous nitrification (ammonium conc. decreased by 38mg/l) and denitrification within the unit. The effluent pH value also dropped to 6.26 pH units, down from the influent pH of 7.33.

In conclusion to this section on interpretation of toxicity within the leachate and effluent from the treatment units, the author believes that given the low concentrations of heavy metals and List I and List II substances throughout, it is likely that *D. magna* were reacting to the higher concentration of ammonium, particularly in the raw leachate. This is supported by the fact that as ammonium concentrations decreased from influent to

effluent through the process units (due to nitrification and other processes) there was a corresponding fall in toxicity (except for Cell 9).

Comparisons of influent, effluent and Tramore River toxicity to *Daphnia magna* with selected parameters for June 2009 and August 2010 are graphed in Figures 8.119 and 8.120 below.

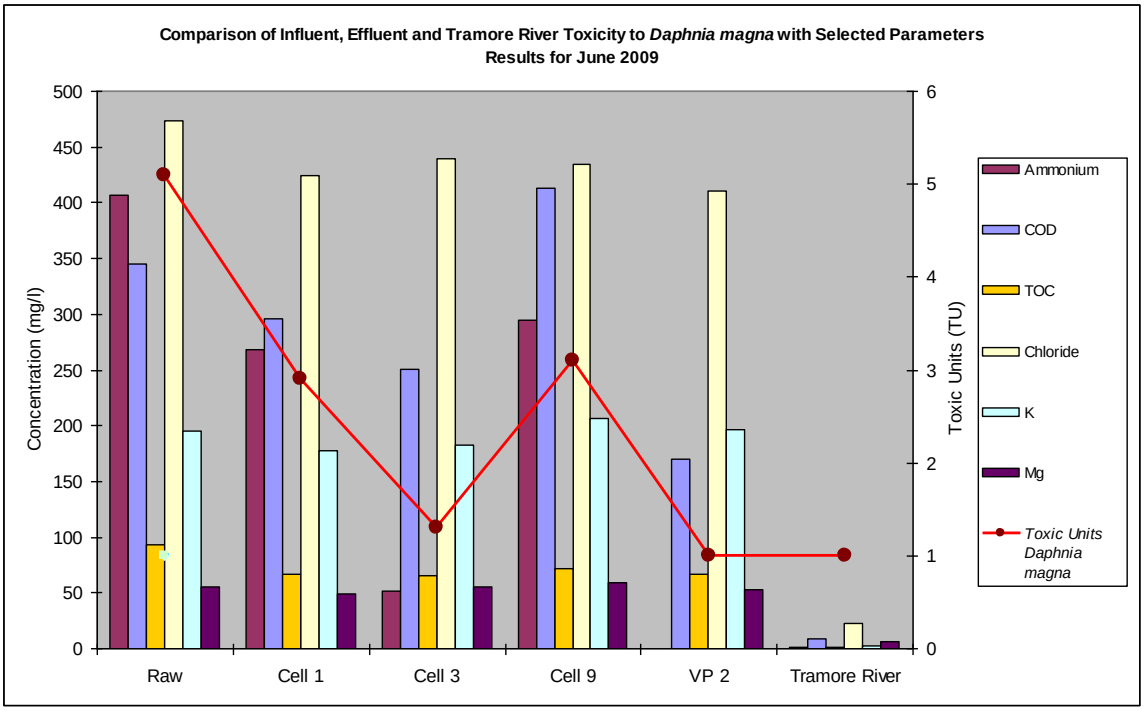


Figure 8.119 Comparison of influent, effluent and Tramore River toxicity to *Daphnia magna* with selected parameters for June 2009

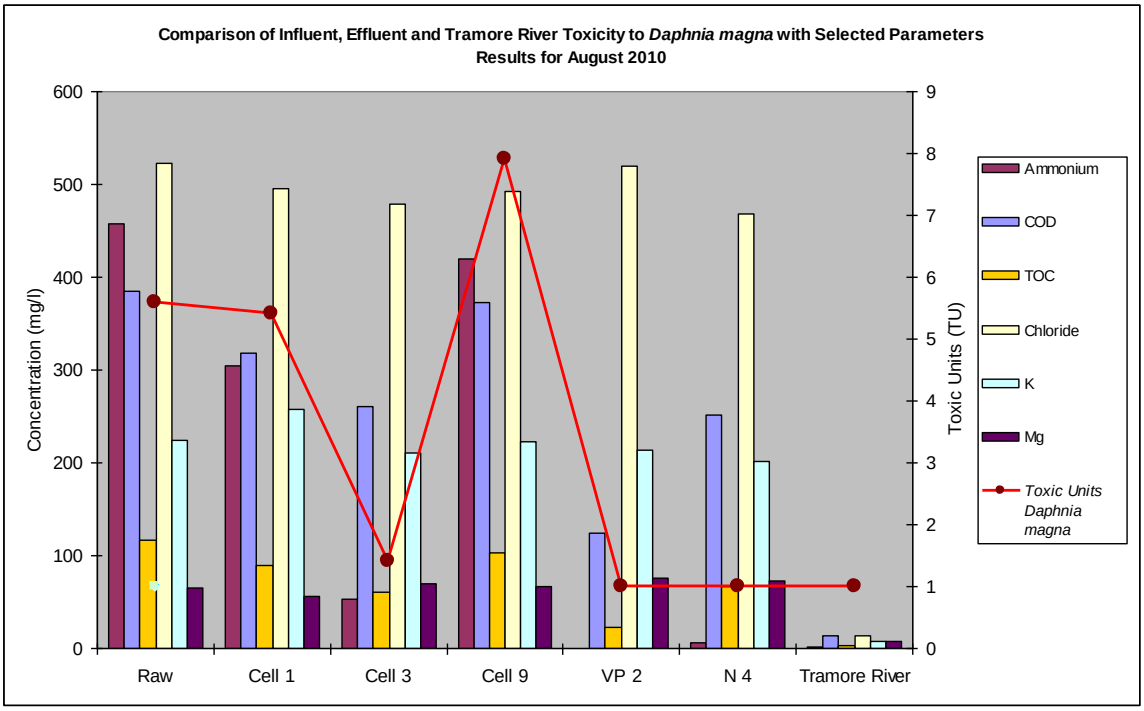


Figure 8.120 Comparison of influent, effluent and Tramore River toxicity to *Daphnia magna* with selected parameters for August 2010

8.4 Phase 5 Plant Operations – Results and Interpretation

8.4.1 Introduction

Phase 5 plant operations involved bacteriological sampling and analysis of the raw leachate, the Tramore River and selected treatment units. Total Coliforms and *Escherichia coli* (*E. coli*) were used as indicator bacteria to assess the presence of pathogens in the influent, effluent and in the Tramore River. Surface water quality standards for total coliforms and *E. coli* are presented in Tables 8.160(b) and 8.165(b) for comparison with results attained from the Tramore River samples. These standards are set out in the EC (Quality of Surface Water Intended for the Abstraction of Drinking Water) Regulations, 1989 (S.I. 294/1989)) and outline the limits for a range of parameters which must be adhered to in order to extract surface water for transformation in to drinking water. The standards typically apply to a section of the river or lake from a set point upstream to the point of abstraction at the water treatment works and the range or limit for each parameter is divided in to three treatment categories (S.I. 294/1989):

Category A1 – simple physical treatment and disinfection

Category A2 – normal physical treatment, chemical treatment and disinfection

Category A3 - intensive physical and chemical treatment, extended treatment and disinfection.

For completeness the bathing water quality standard for *E. coli* for inland waters is presented in Table 8.165(c) (Bathing Water Quality Regulations, 2008 (S.I. 79/2008)).

Bacteriological analysis was not within the original scope of the trial project; however, following a request from a visiting Erasmus PhD exchange student for some practical work experience, a programme of sampling and testing the leachate from the trial treatment plant for microbiological parameters (*E. coli* and total coliforms) was put together. Trial plant operations were reinitiated on a phased basis during June – October 2011 (the plant had been idle for eight months) and the following treatment units and sequences were brought back in to operation:

- Raw → Cell 9 – Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
- Raw → Cell 1
- Raw → Cell 3 – Cell 5

- Raw → Cell 7 – Cell 8

Cell 9, Cell 10, VF 1, VF 2, VP 1 and VP 2 were turned on in June (29th and 30th June 2011) and the remainder of the cells were switched on in October (13th October 2011). Cells 2, 4 and 6 remained non-operational.

Sampling and analysis was carried out over nine consecutive weeks from October to December 2011. Sampling was carried out under sterile conditions and testing was a relatively straightforward procedure using a pre-prepared test kit. Where there was a positive result for the presence of total coliforms and *E. coli*, the bacteriological count was expressed using a statistical table as Most Probable Number (MPN)/100 ml.

8.4.2 Results of Bacteriological Analysis of Leachate

The treatment and removal of bacteriological parameters (total coliforms and *E. coli*) from the system is presented in this section. A series of tables detailing the results for total coliforms and *E. coli* are presented in sections 8.4.2.1 and 8.4.2.2 respectively. Interpretation of bacteriological analysis is presented in section 8.4.2.3.

8.4.2.1 Results for Total Coliforms

A summary of Total Coliforms count (MPN/100ml) and average cumulative removal efficiency (%) for treatment unit Cell 1 and units operating in sequence; Cell 3 – Cell 5; Cell 7 – Cell 8 and Cell 9 – Cell 10 – VF 1 – VF 2 –VP 1 – VP2 for phase 5 is presented below in Tables 8.156(a) to 8.159(b). Total Coliforms count (MPN/100ml) for the Tramore River is presented in Table 8.160(a) with the Total Coliforms limit for categories A1, A2 and A3 for surface water quality standard for drinking water extraction set out in Table 8.160(b).

Total Coliforms: Raw – Cell 1

Cell 1 – Medium: Coarse Grade Compost

Operational Period: 13th October 2011 – 22nd December 2011

Average daily flow = 1200L/unit/day (472L/m^2/day)

Table 8.156(a) Summary of Total Coliforms count (MPN/100ml) for Cell 1

Total Coliforms	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	5.74×10^3 - 3.77×10^4	1.48×10^4 ($\pm 1.19 \times 10^4$)
Effluent Cell 1	7	2.04×10^3 – 2.09×10^4	7.89×10^3 ($\pm 6.97 \times 10^3$)

Table 8.156(b) Summary of Total Coliforms Average Removal Efficiency (%) for Cell 1

Total Coliforms Raw - Cell 1 Average Removal Efficiency (%)	
	Cell 1
Average (%)	45

Total Coliforms: Raw – Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: 13th October 2011 – 22nd December 2011

Average daily flow = 480L/unit/day (189L/m^2/day)

Table 8.157(a) Summary of Total Coliforms count (MPN/100ml) for sequence Cell 3 – Cell 5

Total Coliforms	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	5.74×10^3 - 3.77×10^4	1.48×10^4 ($\pm 1.19 \times 10^4$)
Effluent Cell 3	7	4.61×10^2 – 1.98×10^4	1.00×10^4 ($\pm 6.33 \times 10^3$)
Effluent Cell 5	7	1.18×10^3 – 1.98×10^4	7.26×10^3 ($\pm 6.59 \times 10^3$)

Table 8.157(b) Summary of Total Coliforms Average Removal Efficiency (%) for sequence Cell 3 – Cell 5

Total Coliforms Raw - Cell 3 - Cell 5 Average Cumulative Removal Efficiency (%)		
	Cell 3	Cell 5
Average (%)	16	52

Total Coliforms: Raw – Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: 13th October 2011 – 22nd December 2011

Average daily flow = 300L/unit/day (118L/m^2/day)

Table 8.158(a) Summary of Total Coliforms count (MPN/100ml) for sequence Cell 7 – Cell 8

Total Coliforms	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	5.74×10^3 - 3.77×10^4	1.48×10^4 (± 1.19×10^4)
Effluent Cell 7	3	3.07×10^3 – 4.61×10^3	3.64×10^3 (± 8.39×10^2)
Effluent Cell 8	5	7.20×10^2 – 9.93×10^3	3.66×10^3 (± 3.80×10^3)

Table 8.158(b) Summary of Total Coliforms Average Removal Efficiency (%) for sequence Cell 7 – Cell 8

Total Coliforms Raw - Cell 7 - Cell 8 Average Cumulative Removal Efficiency (%)		
	Cell 7	Cell 8
Average (%)	49	62

Total Coliforms: Raw – Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.*) in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.*) in Stratified Sand/Grit/Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: 29th June 2011 – 22nd December 2011

Average daily flow = 2400L/unit/day (945L/m^2/day to Cells; 96L/m^2/day to VF/VP units)

Table 8.159(a) Summary of Total Coliforms count (MPN/100ml) for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

Total Coliforms	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	5.74×10^3 - 3.77×10^4	1.48×10^4 (± 1.19×10^4)
Effluent Cell 9	6	2.75×10^3 – 1.55×10^4	8.06×10^3 (± 5.77×10^3)
Effluent Cell 10	7	2.09×10^3 – 7.94×10^3	4.14×10^3 (± 1.88×10^3)
Effluent VF 1	5	3.08×10^2 – 1.73×10^3	1.17×10^3 (± 5.34×10^2)
Effluent VF 2	4	4.61×10^2 – 4.83×10^3	2.49×10^3 (± 2.02×10^3)
Effluent VP 1	6	2.40×10^2 – 8.16×10^2	4.53×10^2 (± 2.00×10^2)
Effluent VP 2	7	$1{,}21 \times 10^2$ – 3.97×10^3	7.63×10^2 (± 1.41×10^3)

Table 8.159(b) Summary of Total Coliforms Average Removal Efficiency (%) for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

Total Coliforms Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 Average Cumulative Removal Efficiency (%)						
	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2
Average (%)	32	62	90	70	95	90

Tramore River

Table 8.160(a) Summary of Total Coliforms count (MPN/100ml) for Tramore River

Total Coliforms	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Tramore River	6	>2419.6*	>2419.6

Note* Refers to maximum range in the IDEXX Quanti Tray/2000 Most Probable Number (MPN) Table

Surface Water Quality Standard for Drinking Water Extraction

Table 8.160(b) Surface Water Quality Standard for Total Coliforms (per 100ml)

	Category		
Parameter	A1	A2	A3
Total Coliforms/100ml	5,000	25,000	100,000

8.4.2.2 Results for E. coli

A summary of the *E. coli* count (MPN/100ml) and average cumulative removal efficiency (%) for treatment unit Cell 1 and units operating in sequence; Cell 3 – Cell 5; Cell 7 – Cell 8 and Cell 9 – Cell 10 – VF 1 – VF 2 –VP 1 – VP2 for phase 5 is presented below in Tables 8.161(a) to 8.164(b). *E. coli* count (MPN/100ml) for the Tramore River is presented in Table 8.165(a) with the *E. coli* limit for categories A1, A2 and A3 for surface water quality standard for drinking water extraction set out in Table 8.165(b).

The bathing water quality standard for *E. coli* for inland waters is presented in Table 8.165(c).

E. coli: Raw – Cell 1

Cell 1 – Medium: Coarse Grade Compost

Operational Period: 13th October 2011 – 22nd December 2011

Average daily flow = 1200L/unit/day (472L/m^2/day)

Table 8.161(a) Summary of *E. coli* count (MPN/100ml) for Cell 1

E. coli	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	135 - 1782	630 (± 672)
Effluent Cell 1	7	30 - 670	163 (± 231)

Table 8.161(b) Summary of *E. coli* Average Removal Efficiency (%) for Cell 1

E. coli Raw - Cell 1 Average Removal Efficiency (%)	
	Cell 1
Average (%)	76

E. coli: Raw – Cell 3 – Cell 5

Cell 3 – Medium: Timber Chippings

Cell 5 – Media: Sand, Grit, Gravel

Operational Period: 13th October 2011 – 22nd December 2011

Average daily flow = 480L/unit/day (189L/m^2/day)

Table 8.162(a) Summary of *E. coli* count (MPN/100ml) for sequence Cell 3 – Cell 5

E. coli	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	135 - 1782	630 (± 672)
Effluent Cell 3	7	20 - 556	187 (± 227)
Effluent Cell 5	7	10 - 455	118 (± 171)

Table 8.162(b) Summary of *E. coli* Average Removal Efficiency (%) for sequence Cell 3 – Cell 5

E. coli Raw - Cell 3 - Cell 5 Average Cumulative Removal Efficiency (%)		
	Cell 3	Cell 5
Average (%)	72	84

E. coli: Raw – Cell 7 – Cell 8

Cell 7 – Medium: Timber Chippings

Cell 8 – Medium: Timber Chippings

Operational Period: 13th October 2011 – 22nd December 2011

Average daily flow = 300L/unit/day (118L/m^2/day)

Table 8.163(a) Summary of *E. coli* count (MPN/100ml) for sequence Cell 7 – Cell 8

E. coli	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	135 - 1782	630 (± 672)
Effluent Cell 7	7	1 - 288	68 (± 101)
Effluent Cell 8	7	1 - 32	11 (± 12)

Table 8.163(b) Summary of *E. coli* Average Removal Efficiency (%) for sequence Cell 7 – Cell 8

E. coli Raw - Cell 7 - Cell 8 Average Cumulative Removal Efficiency (%)		
	Cell 7	Cell 8
Average (%)	91	98

E. coli: Raw – Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

Cell 9 – Media: Coarse Compost and Timber Chippings

Cell 10 – Media: Coarse Compost and Timber Chippings

VF 1 – Vertical Flow Reed Bed (*Phragmites sp.*) in Stratified Sand/Grit/Gravel Matrix

VF 2 – Vertical Flow Reed Bed (*Typha sp.*) in Stratified Sand/Grit/Gravel Matrix

VP 1 – Vegetated Grass Plane

VP 2 – Vegetated Grass Plane

Operational Period: 29th June 2011 – 22nd December 2011

Average daily flow = 2400L/unit/day (945L/m^2/day to Cells; 96L/m^2/day to VF/VP units)

Table 8.164(a) Summary of *E. coli* count (MPN/100ml) for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

E. coli	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Influent	7	135 - 1782	630 (± 672)
Effluent Cell 9	7	30 - 703	183 (± 247)
Effluent Cell 10	7	2 - 135	46 (± 48)
Effluent VF 1	7	1 - 18	7 (± 5)
Effluent VF 2	7	1 - 58	10 (± 21)
Effluent VP 1	7	1 - 2	1 (± 0.4)
Effluent VP 2	7	1	1

Table 8.164(b) Summary of *E. coli* Average Removal Efficiency (%) for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

E. coli Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 Average Cumulative Removal Efficiency (%)						
	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2
Average (%)	71	92	98	96	99.6	99.6

Tramore River

Table 8.165(a) Summary of *E. coli* count (MPN/100ml) for Tramore River

E. coli	n	Range (MPN/100ml)	Average (MPN/100ml) (± sd)
Tramore River	6	297 - 2240	1175 (± 814)

Surface Water Quality Standard for Drinking Water Extraction

Table 8.165(b) Surface Water Quality Standard for *E. coli* (per 100ml)

	Category		
Parameter	A1	A2	A3
E. coli per 100ml	1,000	5,000	40,000

Bathing Water Quality Standard for Inland Waters

Table 8.165(c) Bathing Water Quality Standard for *E. coli* (colony forming units (cfu)/100ml)

	Quality Status			
Parameter	Excellent	Good	Sufficient	Poor
E. coli (cfu/100ml)	500*	1,000*	900**	>900**

*Based upon a 95-percentile evaluation

**Based upon a 90-percentile evaluation

8.4.2.3 Interpretation of Bacteriological Analysis of Leachate

Analysis of total coliforms (TC) and *E. coli* results for effluent from the treatment units reveals a high purification potential with a low pathogen count (MPN/100ml) at end of sequence for each parameter.

The range of values for total coliforms and *E. coli* in the raw leachate was 5.74×10^3 - 3.77×10^4 MPN/100ml (TC) and 135 – 1782 MPN/100ml (*E. coli*) respectively. It is difficult to place these values in context with leachates from other landfill sites as data for TC and *E. coli* are very limited for these parameters. However, two references were found in published literature. Denton *et al*., (2008) in their paper on the impact on aqueous emissions from a municipal waste dump site on a local river in Guam quote a TC and *E. coli* range of 9.6×10^4 – 241×10^4 MPN/100ml (TC) and 1,515 – 137×10^3 MPN/100ml (*E. coli*) respectively. In a paper on survival of pathogenic and indicator organisms in groundwater and landfill leachate in north-eastern France, Grisley *et al*. (2010) present a TC and *E. coli* range of 15 – 20×10^3 Colony Forming Units (CFU)/100ml (TC) and 15– 15.1×10^3 CFU/100ml (*E. coli*) respectively. Unfortunately, due to the dearth of data from other published works, it is difficult to compare or draw any conclusions from the range of values for TC and *E. coli* in leachate from KRLF other than being highly variable across the sampling period (although the *E. coli* range is quite low compared to the two cited examples).

<u>Cell 1</u>

Cell 1 revealed average removal efficiency for TC and *E. coli* of 45% and 76% respectively. Removal efficiency for TC varied from a high of 83% on 21st October to a low of 7% on 12th December. The range for *E. coli* was 87% to 59%.

<u>Cell 3 - Cell 5</u>

Treatment units Cell 3 – Cell 5 revealed end of sequence average cumulative removal efficiency for TC and *E. coli* of 52% and 84% respectively. The primary treatment unit; Cell 3; provided high *E. coli* removal rates throughout the test period, accounting for 72% average removal from the system. This was however reversed for TC where Cell 3 only provided 16% average removal, with treatment and purification within Cell 5 accounting

for the remaining 36% removal. The result for Cell 3 was however skewed by two negative removal MPN/100ml counts of -10% on 24th October and -108% on 5th December.

Cell 7 - Cell 8

Treatment units Cell 7 – Cell 8 displayed end of sequence average cumulative removal efficiency for TC and *E. coli* of 62% and 98% respectively. The primary treatment unit; Cell 7; provided high removal rates throughout the test period, accounting for 49% (TC) and 91% (*E. coli*) average removal from the system.

There is however a caveat to the set of results for TC due to the low sampling number (n = 3) for Cell 7. Owing to the fact that three of the seven results were over range (i.e. >2419.6 MPN/100ml) and the result for 28th November was excluded as an outlier (most likely due to a laboratory error); only three results for Cell 7 could be included for statistical analysis, thus limiting interpretation.

Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

Inspection of the results obtained for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2 revealed end of sequence average cumulative removal efficiency for TC and *E. coli* of 90% and 99.6% respectively.

TC results for individual units displayed strong positive removal for Cell 9, Cell 10 and VF 1 (32%, 62% and 90% cumulative removal respectively); however, VF 2 and VP 2 results revealed negative removal of -20% and - 5% respectively. Three sets of results for VF 2 were excluded from calculations as they were over range (>2419.6 MPN/100ml) giving a low sample number of n = 4. TC results for VP 2 were skewed somewhat by a poor result of 3972 MPN/100ml on 12th December. The typical range for the other results for VP 2 was 121 – 365 MPN/100ml; however the result for 12th December could not be considered an outlier as the TC count in preceding units was >2419.6 MPN/100ml.

E. coli results for individual units displayed strong positive removal throughout the sequence with the exception of VF 2, which presented a cumulative removal efficiency of -2%. The majority of pathogen removal occurred in Cell 9 and Cell 10 (cumulative

removal of 71% and 92% respectively) with the remaining treatment units providing further effluent polishing.

Tramore River

The average TC and *E. coli* result for the Tramore River was >2419.6 MPN/100ml (i.e. maximum range in IDEXX Quanti Tray/2000 MPN Table) and 1175 MPN/100ml respectively. While neither result is surprising, the *E. coli* count result does show the influence of anthropogenic activity (possibly from combined sewer overflow) in addition to some influence from farming activity further upstream.

Once again, there is dearth of data from other published works on typical TC and *E. coli* ranges from other rivers. However, *E. coli* results for samples from the Tramore River (approximately 0.5 km upstream from the landfill site); collected by Cork City Council's Environmental Enforcement Team during suspected pollution events not associated with this project for the period October 2008 to March 2012 show the following ranges:

8th October 2008, *E. coli* range: 160 – 630 MPN/100ml (n = 4)

10th September 2009, *E. coli* range: 866 – 1733 MPN/100ml (n = 4)

June – December 2010 (sampling dates 24th June, 27th September and 17th December), *E. coli* range: 649 – 6570 MPN/100ml (n = 12)

23rd March 2012, *E. coli* range: 435 – 866 MPN/100ml (n = 4).

While the results display a high degree of variability, the range of values for *E. coli* attained during project sampling (297 - 2240 MPN/100ml (n = 6)) compares somewhat to those further upstream. It should be noted that *E. coli* results from rivers tend to be highly variable in time and fluctuate considerably with weather (i.e. low counts during hot and dry periods and vice versa after heavy rainfall events).

When compared to the surface water quality standards for *E. coli* (S.I. 294/1989) in Table 8.165(b), the average *E. coli* value for the Tramore River would fall in to Category A2 (5000 units/100ml). This is comparable to the category applied to the stretch of the river Lee (the main source of drinking water for the Cork city area) between Inniscarra and the intake point at the Water Treatment Works on the Lee Road in Cork city. However, due to the low sampling number (n = 6) and the high standard deviation of results achieved

for this project, no statistical significance can be attached to the mean *E. coli* count for the Tramore River.

The TC results for the Tramore River could not be placed in a category for surface water quality standards (S.I. 294/1989) as all results were over the limit of detection (>2419.6 MPN/100ml).

In terms of the bathing water quality standard for *E. coli* for inland waters (S.I. 79/2008) in Table 8.165(c), the Tramore River would be classed as being of Poor quality.

Overall, the sequence of treatment units provided high purification capacity for total Coliforms and *E. coli* with sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2 providing almost complete removal of enteric bacteria from the system with just 1 MPN/100ml remaining in the final effluent (the drinking water standard for *E. coli* is zero MPN/100ml and the MRV for total and faecal coliforms in 'dirty' water is 10 MPN/100ml). While complete removal of TC was not realised across the treatment units, the result was not unexpected as a certain percentage of the TC count is most likely of non-anthropogenic origin, existing in the general environment in nutrient-rich waters and in soil with decaying plant material.

In most cases high purification and treatment was effected in the primary treatment units with the remainder of the units in the sequence providing secondary and tertiary pathogen removal.

It is likely that the majority of pathogen retention and destruction occurred through biological processes, in particular in the units containing compost and compost-timber chippings mix, where the media provided a readily available source of carbon and high surface area for biomat and biofilm development. It is also possible that a secondary biomat developed at the base of the treatment cells at the interface between the media and the drainage gravels, provided the base of the unit did not remain waterlogged for long periods of time and that aerobic conditions persisted at depth (Gill *et al*., 2005).

The units containing stratified sand, grit and gravel with above and below ground biomass (and leaf litter); i.e. VF reed beds and grass vegetated planes; would have provided sites for absorption, microbial breakdown and physical straining of the effluent, preventing significant bacteria transit through the system.

CHAPTER 9

9. DISCUSSION

9.1 Introduction

This chapter sets out to place the main findings and results from this project in context with similar investigations cited in the literature. The referenced examples are compared and contrasted to the best-fit treatment unit in the trial plant.

A number of summary observations are made regarding the characteristics of the leachate at Kinsale Road Landfill Site and on the effects of weather on the trial treatment system.

Finally, a draft up-scaled treatment plant is presented based on results attained.

9.2 Results from Trial Treatment Plant in Context with Previous Investigations

In this section, a series of studies on leachate treatment using natural systems (both trial and full-scale plants) are described from referenced material. The studies are grouped by media/treatment type and results are evaluated against similar treatment processes in this project.

Compost and Wood Chip Treatment Media

The use of compost and timber chippings have been used as treatment media in a number of studies involving aerobic treatment of wastewaters (ammonium, BOD, COD) and as denitrification media involving laboratory based column tests and pilot scale denitrification beds.

Tyrell *et al.* (2008) describe the design and operation of a series of aerobic trial treatment units for ameliorating the NH_4, COD and suspended solids components of compost-derived leachate. Nine biofilters were constructed using 240 litre receptacles (1060mm x 730mm x 585mm (height, depth, width) and loosely filled with composted green waste (placed through a 10mm screen), oversize material (coarse fraction >10mm removed from the compost post-trommelling) and granite chips (12mm – 37mm size). The liquor, a compost derived leachate, was applied in four sequential batches daily, at a rate of 10 to 50 litres to each unit over 1.5 hours for a 12-month period (see Tables 9.1 and 9.2 for

selected chemical properties of the compost derived leachate and dosing volumes applied over time to the trial plant). The initial loading of each parameter applied to the biofilters is detailed in Table 9.3.

The filtered samples were tested for ammoniacal nitrogen, total oxides of nitrogen, pH, conductivity, COD, phosphate (as P) and potassium.

Results from the system displayed strong treatment capacity across all units for NH_3/NH_4 and mixed results for BOD and COD attenuation. The units containing oversize material outperformed the others in terms of ammoniacal nitrogen removal with over 89% of samples showing significant treatment effect (effluent concentration of NH_3/NH_4 <10mg/l for 95% of samples) . The number of samples displaying a significant treatment effect for NH_3/NH_4 was 70% and 51% respectively for the granite chip medium and compost medium (see Figure 9.1).

Interestingly, despite the high nitrification rates, very low concentrations of total oxidised nitrogen (TON, NO_2 + NO_3) were produced in the effluent from the units containing compost and oversize material. Less than 1% of NH_3/NH_4 removed by compost was detected as TON, and 28% of NH_3/NH_4 removed by the oversize medium was detected as TON (the equivalent figure for granite chippings was 80%).

COD removal was not significant across the treatment units; the compost medium tended to add COD to the effluent, the granite medium had negligible effects on COD removal and the unit containing oversize material displayed removal efficiencies from <1% at start-up to 24% during the final phase of plant operation.

Results were not presented for suspended solids removal; however the oversize medium performed best with >46% of samples showing a significant treatment effect.

Although the above example refers to a compost-derived leachate which is significantly less potent than landfill leachate (see Table 9.2) there are some interesting similarities as well as some distinct contrasts between data sets presented by Tyrell *et al.* (2008) and this project.,

Cell 1, containing coarse grade compost and cell 4 (fine grade compost) are the closest equivalents to the oversize medium and compost (<10mm) medium described above. It terms of treatment efficiency for NH_4/NH_3, at first glance both the compost medium and oversize medium seem to outperform cell 1 and cell 4 in terms of percentage treatment

efficiency. However, results for cell 1 and cell 4 during phase 1 plant operations shows mean load removals of 130g/m^2/day (influent 361gNH_4/m^2/day, effluent 231gNH_4/m^2/day) and 33g/m^2/day (influent 326gNH_4/m^2/day, effluent 293gNH_4/m^2/day) respectively with mean effluent concentrations of 245mg/l and 310mg/l.

Comparison of COD removal was equally poor with a load removal for cell 1 of 33g/m^2/day (10% removal) and negligible removal 1g/m^2/day (1% removal) for cell 4. With the exception of Batch 4c, with a COD load of 181g/m^2/day applied to the oversize material, the loading rates applied to the other batches in the experiment of Tyrrel *et al.* (2008) were well below the COD loading rates applied to cell 1 and cell 4 of 326g/m^2/day and 254g/m^2/day respectively.

Results for suspended solids removal within the units containing oversize material irrigated with liquor from Batch 4c were comparable to this project (remaining SS concentration in the treated effluent was 82mg/l, suggesting a load removal of 25g/m^2/day when an irrigation rate of 0.223m^3/m^2/day is applied). Average SS load removal for cell 1 was 15g/m^2/day (33% removal) with a load removal of 25g/m^2/day (58% removal) recorded in cell 4 effluent. It is interesting to note the much lower influent SS concentration for cells 1 and 4 in this project (mean conc. of 48mg/l and 40mg/l respectively).

When compared to cell 10 (coarse grade compost) for phases 3 and 4 plant operations between August 2008 – May 2009 only, the results show a mean load removal of 39g/m^2/day for NH_4 (29% treatment efficiency, influent 134g/m^2/day, effluent 95g/m^2/day), 25g/m^2/day removal for COD (11% treatment efficiency), just under 1g/m^2/day removal for SS (1% treatment efficiency) and a load increase of 33g/m^2/day for TON. When an N balance was calculated, a load removal of 23g/m^2/day (11% removal) occurred from influent to effluent (see Table 9.4). The NH_4 load reduction was most likely accounted for by an increase in TON effluent load, with the remaining NH_4 load removal probably accounted for through mineralisation within the compost column.

While results for treatment within cells 1, 4 and 10 are below the percentage removal rates recorded by Tyrell *et al.* (2008), one must be cognisant of the contrasts in the concentrations of each of the influent leachates, the application rates and more importantly the loading rates of the various parameters. Mean concentrations of NH_4 for

landfill leachate dosed to cells 1, 4 and 10 was 390mg/l, 325mg/l and 179mg/l respectively compared to NH_3/NH_4 concentrations in the compost-derived leachate ranging from 6.49mg/l to 32.07mg/l.

Influent parameter loading rates to cells 1, 4 and 10 were 361g/m^2/day, 326g/m^2/day and 134g/m^2/day for NH_4 respectively whilst the maximum loading to the system of Tyrrel *et al*. (2008) was 5.45g/m^2/day (Batch 4c).

Influent COD concentrations for the compost-derived leachate was 2-3 times that of the landfill leachate and is likely to have contained a much higher percentage of recalcitrant substances (humic organics), which are unlikely to be readily biodegradable in aerobic biological systems.

Given that loading to the compost medium and oversize medium (dosed with compost-derived leachate) ranged from 23litres/m^2/day to 116 litres/m^2/day for 90% of the project duration and 223litres/m^2/day for the remaining 10% of the project, the removal rates achieved for NH_4, COD and SS in this project were impressive considering the significantly higher unit hydraulic loading rates (cell 1 = 945 litres/m^2/day; cell 4 = 945 litres/m^2/day and cell 10 = 768 litres/m^2/day) and associated parameter loading rates.

Table 9.1 Volumes of Leachate Applied to Filters

Date	Volume (m^3) applied per filter per day	Volumetric loading rate m^3/m^3/day*	Surface loading m^3/m^2/day
08/12/03 – 15/01/04	0.01	0.05	0.023
16/01/04 – 31/05/04	0.02	0.10	0.047
01/06/04 – 01/10/04	0.025	0.125	0.058
01/10/04 – 18/10/04#	0.025	0.125	0.058
19/10/04 – 15/11/04#	0.05	0.25	0.116
16/11/04 – 09/12/04#	0.1	0.5	0.223

oversize filters only

* assumes effective volume of filter is 0.2 m^3

(after Tyrell *et al*., 2008)

Table 9.2 Selected Chemical Properties of Compost Derived Leachate (mean ± sd)

	Batch 1	Batch 2	Batch 3	Batch 4
Suspended solids (mg/l)	86 ± 6	101 ± 5	180 ± 9	192 ± 12
NH_3-N/NH_4-N (mg/l)	6.49 ± 0.21	18.67 ± 0.37	32.07 ± 0.72	24.11 ± 0.80
NO_2-N/NO_3-N (mg/l)	0.09 ± 0.01	0.25 ± 0.02	0.36 ± 0.04	1.26 ± 0.37
EC mS/cm	2.86 ± 0.01	3.74 ± 0.03	5.05 ± 0.05	4.11 ± 0.09
pH	8.62 ± 0.02	8.74 ± 0.02	8.79 ± 0.02	8.59 ± 0.02
COD mg/l	530 ± 15	938 ± 14	1152 ± 36	804 ± 23
BOD_5 (ATU) mg/l	20	93	261	nd
P mg/l	nd	nd	1.5	2.4 ± 0.1
K mg/l	nd	nd	988	886 ± 26

nd – no data

(Compost sourced from Lount Composting Facility, Leicestershire, after Tyrell *et al*., 2008)

Table 9.3 Initial Volumetric and Parameter Loading to the Biofilter System

	Batch 1	**Batch 2**	**Batch 3**	**Batch 4a**	**Batch 4b**	**Batch 4c**
Surface Loading (m^3/m^2/day)	0.023	0.047	0.058	0.058	0.116	0.223
Parameter (g/m^2/day)	**Batch 1**	**Batch 2**	**Batch 3**	**Batch 4a**	**Batch 4b**	**Batch 4c**
Suspended Solids	1.98	4.75	10.44	11.14	22.27	42.82
NH_3/NH_4-N	0.15	0.88	1.86	1.40	2.80	5.38
NO_2/NO_3-N	0.002	0.01	0.02	0.07	0.15	0.28
COD	12.19	44.09	66.82	46.63	93.26	179.29
BOD_5	0.46	4.37	15.14			
P			0.09	0.14	0.28	0.54
K			57.30	51.39	102.78	197.58

(Calculated from Tyrell *et al*., 2008) (all parameter data expressed as g/m^2/day)

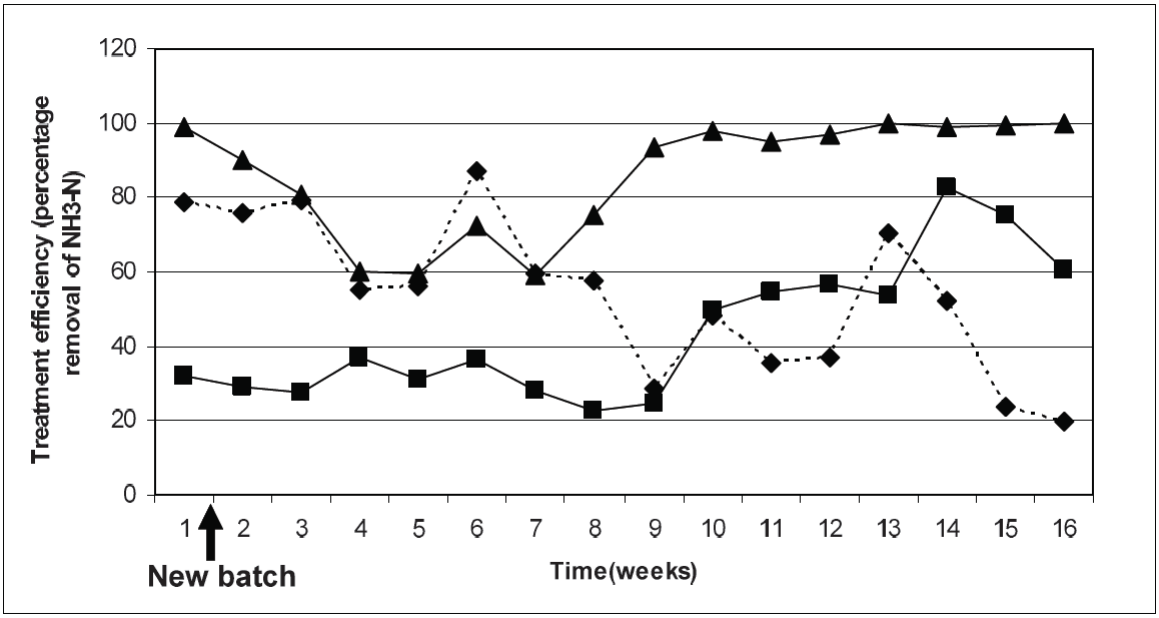


Figure 9.1 Ammonium Treatment Efficiency (% removed) in Treatment Media for Batch 1 (8/12/03 – 15/01/04) and Batch 2 (16/01/04 – 31/05/04) Leachates
▲ = Oversize ■ = Granite Chips ◆ = Compost (after Tyrell *et al*., 2008)

Table 9.4 Selected Parameter Loadings to Cells 1 and 4 (Phases 1 and 2 Operations) and Cell 10 (Phases 3 and 4 Operations)

Parameter: NH_4			
(g/m^2/day)	Cell 1	Cell 4	Cell 10
Influent	361	326	134
Effluent	231	293	95
Load Removal	130	33	39
Load Removal as %	36	11	29

Parameter: Suspended Solids			
(g/m^2/day)	Cell 1	Cell 4	Cell 10
Influent	46	43	16.45
Effluent	31	18	15.59
Load Removal	15	25	0.86
Load Removal as %	33	58	5

Parameter: TON			
(g/m^2/day)	Cell 1	Cell 4	Cell 10
Influent	NA	NA	494
Effluent	NA	NA	527
Load Increase			33
Load Increase as %			17

Parameter: COD			
(g/m^2/day)	Cell 1	Cell 4	Cell 10
Influent	326	254	218
Effluent	293	253	193
Load Removal	33	1	25
Load Removal as %	10	1	11

Parameter: N (TON + NH_4)			
(g/m^2/day)	Cell 1	Cell 4	Cell 10
Influent	NA	NA	216
Effluent	NA	NA	193
Load Removal			23
Load Removal as %			11

Key	Period of Results
Cell 1 = Coarse Compost (oversize)	Aug 07 – Oct 07
Cell 4 = Fine Compost	Aug 07 – Apr 08
Cell 10 = Coarse Compost (oversize)	Aug 08 – May 09

In a paper describing biological nitrogen removal from municipal landfill leachate using low-cost nitrification biofilters and laboratory scale *in situ* denitrification; Jokela *et al.* (2002) describe the use of laboratory filters for nitrification involving crushed brick and mature compost (with timber chip bulking agent) and lab scale column tests for biological denitrification using mature municipal solid waste. The objective of the study was to develop a low-cost, low maintenance method for the removal of nitrogen from landfill leachate specifically for low population areas where landfills tend to be smaller and often at a distance from sewage treatment systems. In addition to this, there was a requirement that the treatment processes used should also function in colder climates.

The leachate utilized in the study was collected from Mustankorkea municipal landfill in Jyväskylä (Finland) and delivered in bulk containers to the laboratory. Of particular interest in this study is the downflow (DF) column reactor containing mature MSW derived compost with timber chip bulking.

The ammonium nitrogen (NH_4-N) of the feed was typically 60–170 mg/l (as N), i.e. 77 – 219mg/l NH_4 (approx.), biological oxygen demand (BOD_7) was 18mg/l and the chemical oxygen demand (COD) was 230–510 mg/l.

The DF column was made of 600mm PVC pipe (total volume 9.4 l, surface area $1.57x10^{-2}$ m^2) sealed with PVC flanges.

The reactor operated continuously with a HRT of 9.6 days for 58 d, HRT of 5.1 days from day 59 – 90 and HRT of 7.3 days from day 91 – 180. The rates of ammonia and N loading are outlined in Table 9.5.

Table 9.5 Compost-Timber Chip Downflow (DF) Reactor Operation

Reactor Volume 9.4L Surface Area $1.57x10^{-2}$ m^2						
	Reactor Operation					
	Day 0 - 58		Day 59 - 90		Day 91 - 180	
	HRT 9.6 Days (d)		HRT 5.1 Days		HRT 7.3 Days	
HLR (L/unit/day)	1L/unit/day		1.84L/unit/day		1.28L/unit/day	
HLR (L/m^2/day)	63L/m^2/day		117L/m^2/day		81.5L/m^2/day	
	N	NH_4	N	NH_4	N	NH_4
Influent Loading (mg/l/day)	10 (mg/l/d)	12.86 (mg/l/d)	78 – 97 (mg/l/d)	100 – 125 (mg/l/d)	78 – 97 (mg/l/d)	100 – 125 (mg/l/d)
Influent Loading (g/m^2/day)	0.630 (g/m^2/d)	0.810 (g/m^2/d)	9.13 - 11.35 (g/m^2/d)	11.17 - 14.62 (g/m^2/d)	9.13 - 11.35 (g/m^2/day)	11.17 - 14.62 (g/m^2/d)
Effluent Loading (g/m^2/day)	<LOD	<LOD	0.117 - 2.45 (g/m^2/day)	0.150 - 3.15 (g/m^2/d)	0.117 - 2.45 (g/m^2/d)	0.150 - 3.15 (g/m^2/d)
NH_4 Effluent Conc. (mg(N)/l)	<LOD	<LOD	<1 - 21mg/L		<1 - 21mg/L	

(adapted from Jokela *et al*., 2002)

Results show effluent NH_4-N and TON were below the detection limit (1 mg/l) at HRT 9.6 days (possibly associated with TON consumption by the compost filter coupled with the presence of denitrifiers). However after day 70 of operations, effluent TON started to increase (probably due to N saturation). Nitrification efficiency throughout the trial was reported as above 90% and effluent NH_4 concentration ranged from <1mg/l to 21mg(N)/l (Figure 9.2). The pH of the effluent varied between 6.5 and 7.0 during the study and no COD removal was observed.

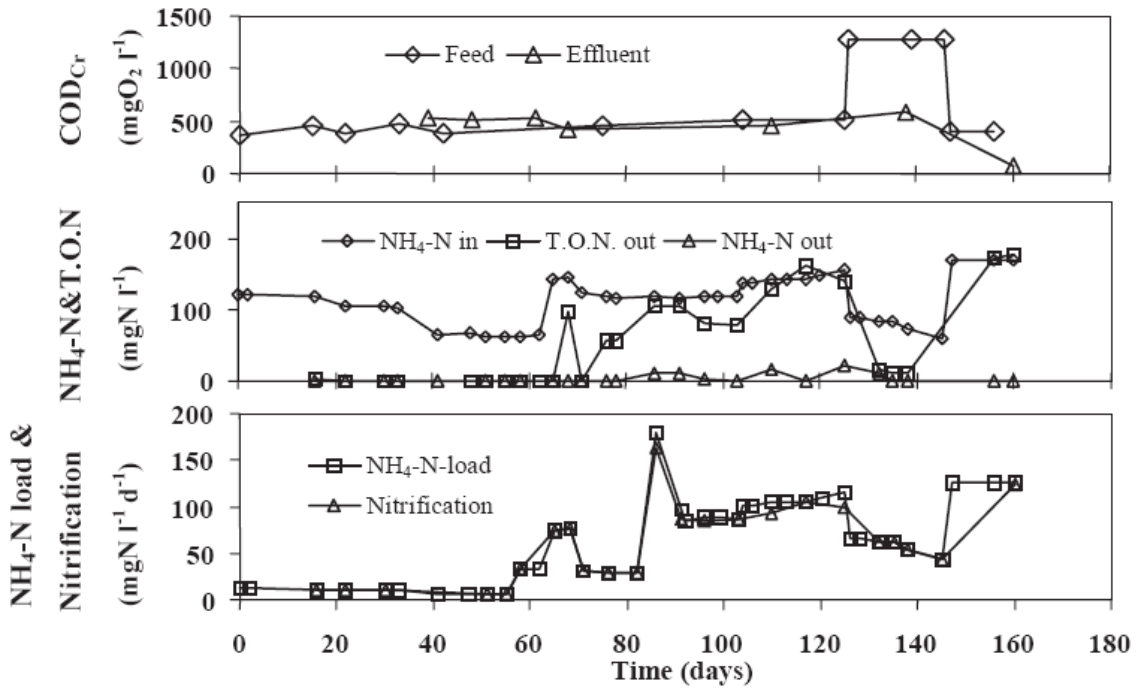


Figure 9.2 Feed and effluent characteristics with nitrification efficiency in DF unit containing mature compost.
HRT: 9.6 d, 5.1 d and 7.3 d between days 1–58, 59–91, and 92–160
(after Jokela *et al*., 2002)

Cell 9, containing coarse grade compost and timber chip mix, is the closest equivalent to the DF media described above. It terms of treatment efficiency for NH_4, the DF reactor delivered extremely high removal rates (>90%) throughout the trial. Results for cell 9 during phase 3 and 4 plant operations show a mean load removal of 66g/m^2/day for NH_4 (i.e. 23% removal) (influent load of 284g/m^2/day (NH_4), effluent load 218g/m^2/day (NH_4)), with a mean effluent concentration of 246mg/l, down from a mean influent concentration of 323mg/l.

In terms of N (NH_4 + TON) removal from cell 9, the calculated averaged results showed a small increase in N effluent of 2g/m^2/day (effluent load increased to 237g/m^2/day). The N balance calculations reveal that the majority of nitrification was accounted for by an increase in TON (mainly NO_3). The graphed TON data for the DF reactor (Figure 9.2) show a similar increase of TON in the effluent load after day 70 (associated with an increase in HLR).

However, since the DF unit was a laboratory scale column test with a much smaller surface area (approx. 0.6% surface area of the trial cells in this project) and a loading rate

of between 10 - 125mg/l(NH_4) per day, it can be difficult to compare between the trial units from each study. Nevertheless, it seems that if scaled up, the column test described by Jokela *et al.* (2002) achieved close to full ammonium removal at a loading of 11gNH_4/m^2/day (total N removal was achieved at a loading of <1g/m^2/day). This compares with 23% removal from cell 9 with an influent load of 284gNH_4/m^2/day and effluent load of 218gNH_4/m^2/day. These results (for this project) are favourable, given the disparity between loading rates. In all likelihood, the Finnish column reactor test was capable of operating at much higher loading rates (c. 10 times that reported) whilst still maintaining high rates of nitrification.

Peat Filters

Peat filters have been found to be effective in treating septic tank effluent and have been widely described in the literature as an efficient low cost solution to treating secondary sewage effluent with high load and concentration removal for P, BOD, N and pathogens (McKee *et al*., 1998; Gill *et al*., 2005; Brooks *et al*., 1984).

A number of studies have been reported regarding the use of peat filters to treat landfill leachate.

Heavey (2003) describes the operation of a full-scale leachate treatment plant at Kyletalesha landfill site in County Laois (RoI). The plant set up has previously been described in Chapter 4. The peat filter beds (4 no.) were intermittently dosed with leachate at varying rates. The study outlined the operation of two of the beds in detail. Bed no. 1 contained unprocessed peat from the upper surface of the local bog and was dosed with leachate at a rate of 20mm/day. Bed no. 2 contained a modified, dried peat harvested in 30cm blocks. Leachate was applied at a rate of 60mm/day.

The mean leachate concentrations for the site was characterized as BOD 190mg/l, COD 625mg/l, NH_4 218mg/l, NO_3 3.5mg/l, pH 7.9, PO_4 2.13mg/l and Cl 557mg/l (see Table 9.6).

Table 9.6 Leachate Characteristics Over 3 Years at Kyletalesha Landfill Site

Parameter	Max.	Min.	Mean	Median	No. of samples
BOD	1192	2	190	100	177
COD	3025	237	625	530	254
NH_4-N	415	63	218	211	236
NO_3-N	15.7	1.3	3.5	2.65	191
pH	8.5	6.65	7.9	7.98	289
PO_4-P	4.8	0.1	2.13	2.4	164
CL_2	801	337	557	523	177

(after Heavey, 2003)

Results for peat bed 1 revealed upper values for BOD removal of 3.3kg per day (11.5gBOD/m^2/day) (Figure 9.3). The median ammonia removal rate for bed No. 1 was calculated as 3.4g/m^2/day (NH_4-N), with ammonia removal increasing as the temperature of the applied leachate increased in the summer months (Figure 9.4).

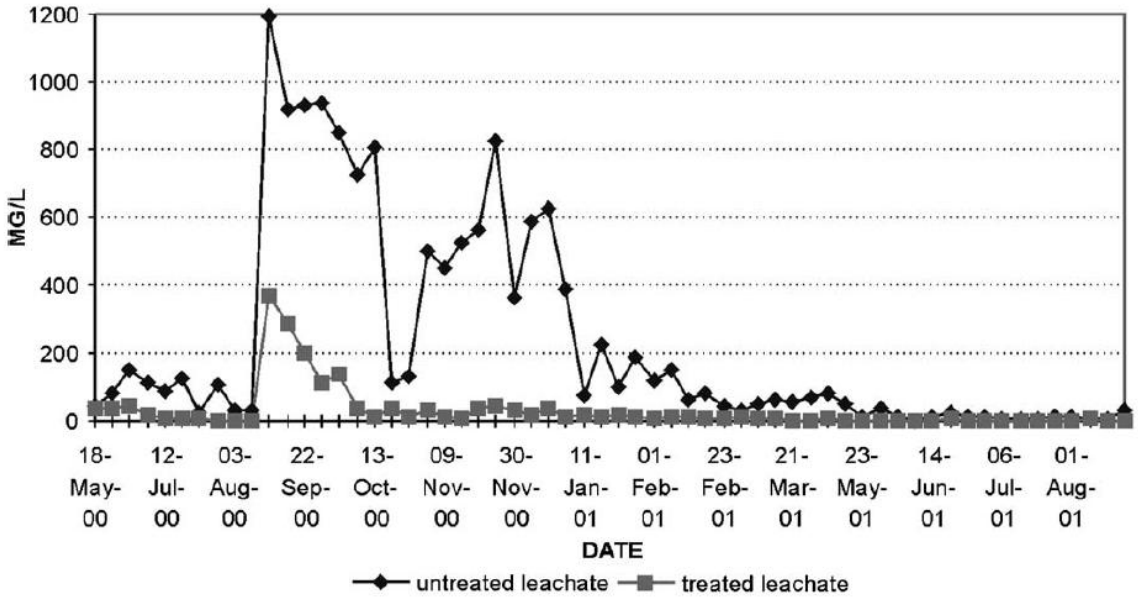


Figure 9.3 Carbonaceous (C) BOD Treatment in Peat Bed 1 (after Heavey, 2003)

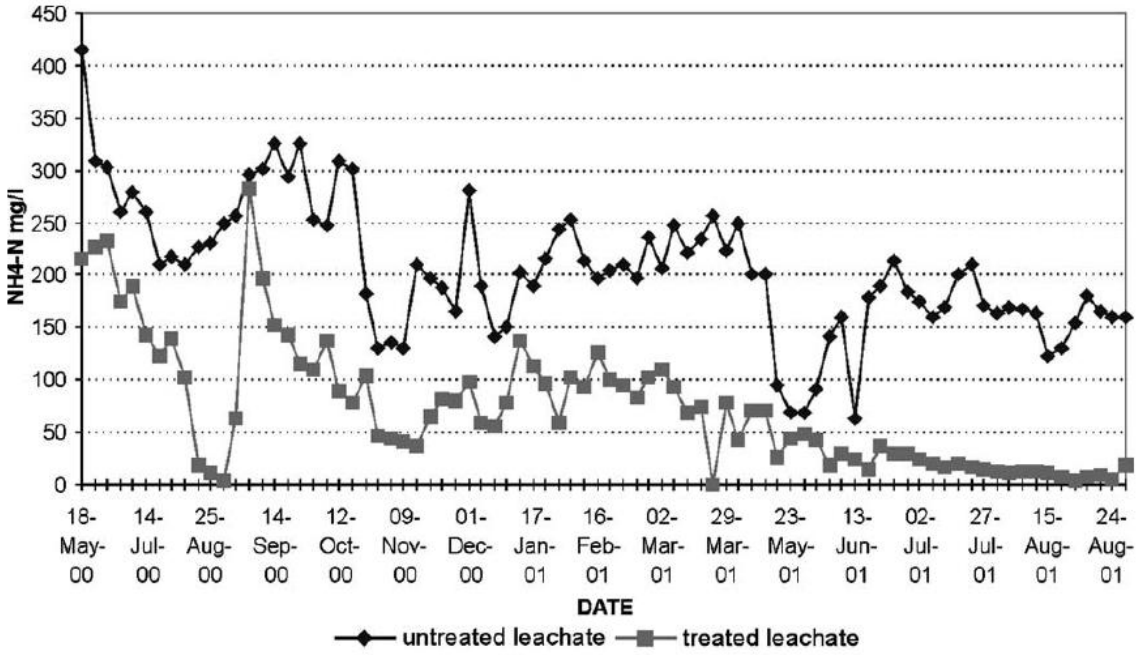


Figure 9.4 Ammonia Treatment in Peat Bed 1 (after Heavey, 2003)

Bed no. 2 removal rates for BOD were in excess of 36g/m^2/day, with almost 100% BOD removal from the outset (Figure 9.5). High rates of ammonia removal (>11g/m^2/day) were also demonstrated (see Figure 9.6). Nitrification resulted in effluent nitrate concentrations in excess of 200mg/l-N.

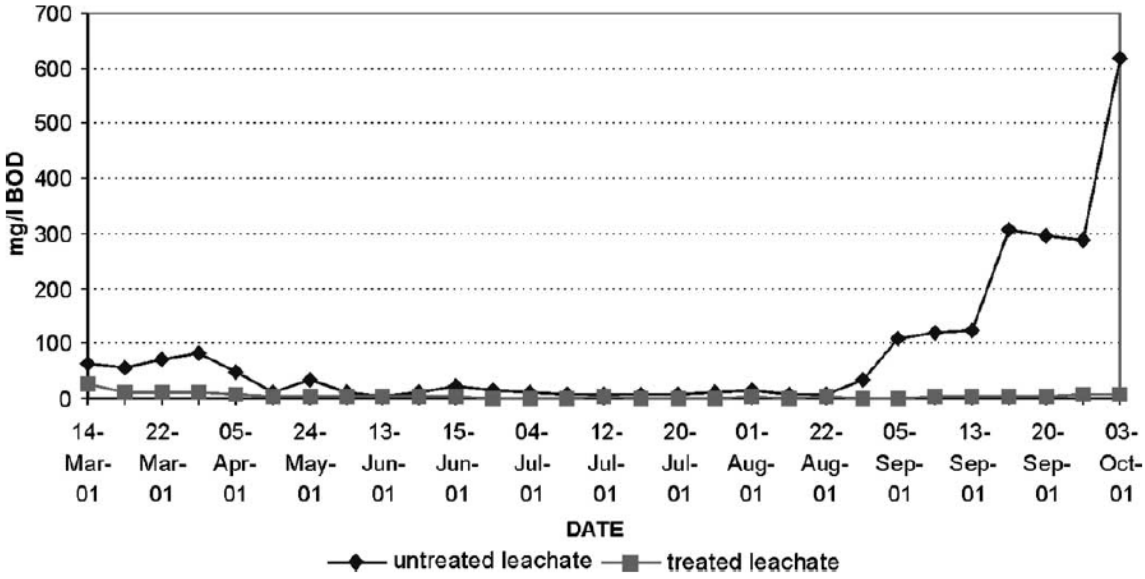


Figure 9.5 Carbonaceous (C) BOD Treatment in Peat Bed 2 (after Heavey, 2003)

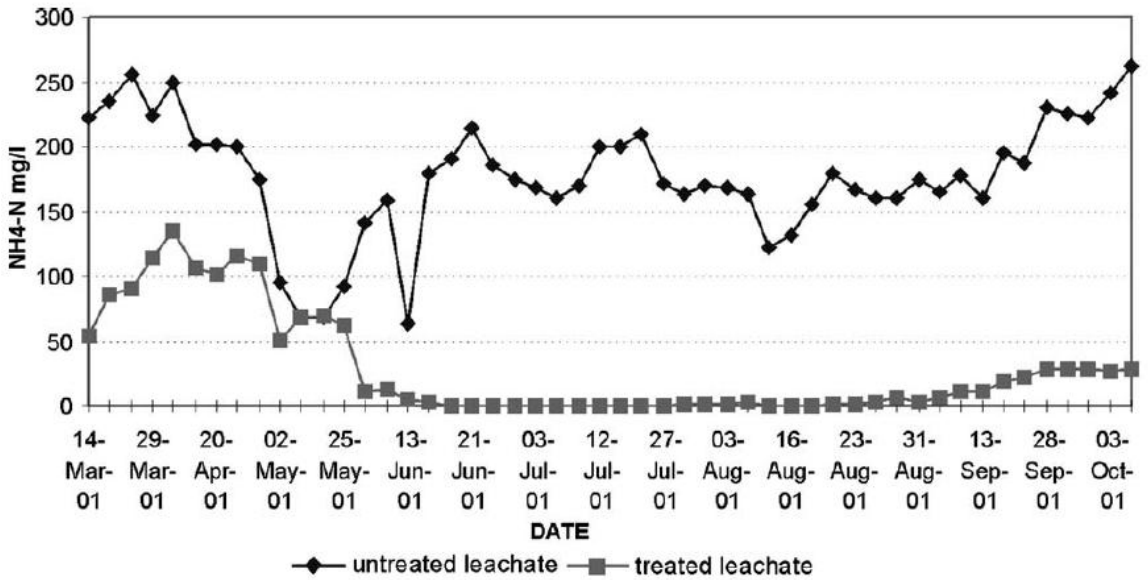


Figure 9.6 Ammonia Treatment in Peat Bed 2 (after Heavey, 2003)

Later during plant operations, denitrification trials were initiated in a laboratory column, filled with modified dried peat. Treated leachate from bed no. 2 was dosed to the column and methanol was added to the leachate as an additional carbon source to give a combined daily application rate to the reactor of 56mm per day. Within two weeks of operation, NO_3 concentrations in the filtered column effluent were below 20mg/l.

In a trial demonstration project at Väätsa landfill site in Estonia, Kõiv *et al*. (2009) describe the operation of two vertical flow peat beds and a horizontal flow peat bed treating leachate in an effort to demonstrate compliance with Estonian emission limit values to surface waters. The vertical flow peat beds contained two filter materials; moderately mineralised sphagnum peat (VV1) and a mixture of peat and oil-shale ash sediment with a high calcite content (VV3). The horizontal flow peat bed contained mineralized sphagnum peat and remained fully saturated during treatment trials.

The VF filters had a volume of 0.86m^3, and HF filters 1.24m^3. Both the VF filters (D = 1000mm, h = 1.5 m) and the HF filters (D = 1200mm, h = 1.5 m) were made of PVC pipe and contained filter material to a depth of 1.1m.

All filters were operated in sequence and were intermittently dosed on timed pumping cycle of 12 times a day (every 2 hours) at 5 litres per dose. The loading rate was 76mm/day for VF filters, and 53mm/day for HF filters. The average flow rate for all

filters was 60 litres/day. The median concentration ranges for the applied leachate were; BOD_7 12.3 – 25.4mg/l; COD 526 – 1050mg/l; total phosphorus (TP) 2.9 – 4.1mg/l; total nitrogen (TN) 142 – 214mg/l, total suspended solids 54 – 75mg/l and pH 8.8 – 8.7 (pH units).

Results from the treatment trials revealed TP median removal efficiencies in VV1 and VV3 of 67% per unit. TP removal in VH3 was variable and in many instances released phosphorus back into the effluent stream. No significant removal was recorded for COD, but VV1 and VV3 demonstrated high removal capacities for BOD (75% and 64%) and NH_4 (97% and 63%).

The horizontal flow peat filter proved unsuitable for the removal of organics and NH_4, showing higher effluent concentrations.

All units displayed good TSS removal (>60%), total nitrogen removal within the vertical flow peat beds (VV1 and VV3) was poor (<10%), however the horizontal flow peat bed (VH3) displayed total N load removal of 5.57g/m^2/day (49% treatment) based on a worked calculation of the irrigation rates and the median concentration values (see Tables 9.7 – 9.9).

Table 9.7 Nitrogen Species Median Concentrations of Väätsa Leachate and Effluent from Treatment Units

	Parameter Median Concentration (mg/l)			
Unit	Total N	NH_4	NO_3	Organic N
Influent	180	0.44	84.5	71.6
VV1 (effluent)	150	0.08	120	25.8
VV3 (effluent)	150	0.2	130	9.9
VH3 (effluent)	110	6.05	92	10.7

(after Kõiv *et al*., 2009)

Key
VV1 = Vertical Flow Peat Bed containing moderately mineralised sphagnum peat
VV3 = Vertical Flow Peat Bed containing a mixture of peat and oil-shale ash sediment with a high calcite content
VH3 = Horizontal Flow Peat Bed containing mineralised sphagnum peat)

Table 9.8 Nitrogen Species Loadings to Treatment Units at Väätsa Landfill

	Load (g/m^2/day)			
Unit	Total N	NH_4	NO_3	Organic N
Influent	13.68	0.03	6.42	5.44
Effluent VV1	11.40	0.01	9.12	1.96
Effluent VV3	11.40	0.02	9.88	0.75
Effluent VH3	5.83	0.32	4.88	0.57

(Calculated from Kõiv *et al*., 2009) (all parameter data expressed as g/m^2/day)

Table 9.9 Nitrogen Species Load Removal in Treatment Units at Väätsa Landfill

	Load Removal ($g/m^2/day$)			
Unit	Total N	NH_4	NO_3	Organic N
VV1	2.28	0.02	-2.70	3.48
VV3	0.00	-0.01	-0.76	1.21
VH3	5.57	-0.31	5.00	0.19
System Load Removal ($g/m^2/day$)	7.85	-0.29	1.55	4.87
System Load Removal as %	57	-859	24	90

(Calculated from Kõiv *et al.*, 2009) (all parameter data expressed as $g/m^2/day$)

Overall, the VF peat beds provided good pollutant removal capacities for P, BOD_7, TSS and NH_4, albeit at very low influent ammonium concentrations (< 1mg/l). Whilst the HF peat bed did release NH_4 back in to the effluent stream, based on the calculations above, it did seem effective in removing total N from the treated effluent.

Roy Group Consultants (www.enviroaccess.ca, 2000) describe a low cost innovative approach to tertiary leachate treatment at Red Pine sanitary landfill site in Allardville, New Brunswick, Canada. The technology involves filtration though an artificial peat filter, subsequent to treatment in an aerobic pond. BOD and COD reductions of 90% for the tertiary effluent are described at a loading of less than $40mm/m^2$ per day. It is described as an easy to install system, with minimal labour, maintenance and energy requirements and can operate continuously. The limiting factor, as with any natural/semi natural aerobic system is the requirement for surface area, which will be dependent on leachate volumes and effluent characteristics.

It is estimated that the treatment system was installed and commissioned for $140,000; annual operating costs are in the order of $80,000 and the system has a treatment capacity of $15,000m^3$ per year.

Novella *et al.* (1998) describe a peat treatment system for treating secondary leachate from Gairloch landfill site in Ross-Shire, northern Scotland. The aerobically treated leachate was sprayed over an area of prepared peat moorland prior to discharge to a high quality stream. Up to $30m^3$ of leachate per day was treated utilising the *in situ* peat as a polishing medium. High treatment efficiencies for iron (90%), manganese (95%), COD (85%), BOD (99%) and ammoniacal-N (99%) were achieved, employing the combined aerobic (SBR) and peat polishing system.

The peat filter system accounted for 80% reduction in Ca concentration, 72% for Cl, 11% for SS, 91% for nitrate and 46% for sodium.

There were slight increases in ammonia and COD in the final effluent from the peat treatment system.

The results from the combined SBR-peat treatment system are outlined in Table 9.10.

Table 9.10 Gairloch Leachate Treatment Plant Typical Performance

Parameter	Leachate	SBR Effluent	Final Effluent (Peat System)
COD	1050	106	115
BOD	500	<1	
Ammonia-N	49	0.4	0.6
pH	7.0	7.1	6.2
Cl	179	261	71
SS	54	17	15
Nitrate-N	0.3	35	2.4
Nitrite-N	<0.1	0.1	<0.1
Na	137	92	49
Mg	121	80	41
K	67	45	19
Ca	309	160	31
Cr	0.03	<0.03	
Mn	8.64	0.2	
Fe	13.6	0.5	
Ni	<0.03	<0.03	
Cu	0.04	0.04	
Zn	2.94	0.09	
Cd	<0.01	<0.01	
Pb	<0.04	<0.04	

(after Novella *et al*., 1998) All results mg/l, except pH

The use of a poorly humified peat filter as an adsorbent for heavy metals in landfill leachate and acid mine drainage is described by Ringqvist *et al*. (2002). A series of batch and column experiments were run on leachate collected from an industrial landfill site near Umeå and from Laver abandoned copper mine both in northern Sweden.

Of particular interest in this study was the laboratory column tests carried out on the leachate.

A variety of filter materials were utilised, peat derived from *Sphagnum* and *Carex sp.* as well as inorganic adsorbents from flue scrubbers.

The trial set up for the peat column tests entailed a glass column, Ø 30mm, with a plastic net at the base covered with a glass fibre filter. The adsorbents were placed in the columns, 0.5g peat at a height of 3.0cm. Water flow was regulated to achieve a contact time of 20 min. The effluent was collected in 4 x 25ml fractions, giving a total volume of 100ml, corresponding to five bed volumes.

The initial heavy metals concentrations of the leachate was low (Table 9.11).

Results for metal removal from the landfill leachate were lower than the sulphide mine leachate; however, removal rates of up to 55% were achieved for Fe, 56% for Zn, 21% for Cu and 15% for Ni. Cadmium was released from the two peat columns (*Sphagnum* Sect. *Acutifolia* and *Sphagnum* Sect. *Cuspidata*) (see Table 9.12).

The lower metal removal, and initial release of metals bound to the adsorbents in the landfill leachate described by Rindqvist *et al*. (2002) could be attributed to a high ionic strength and formation of metal-carbonate and organic complexes.

Table 9.11 Initial concentration (mg/l) heavy metals in leachate from the sulphide mine in Laver and Dåvamyran landfill

	Sulphide mine leachate	Landfill leachate	
		Dec 1995	Dec 1996
Ca	13.5	173	247.2
Fe	0.8	2.2	3.5
K	1.7	652	679
Mg	2.3	59.6	49.6
Na	2.3	1145	1140
Al	0.3	0.2	0.01
Mn	0.4	0.2	0.3
Ba	0.01	0.2	—
Zn	298×10^{-3}	53.5×10^{-3}	94.7×10^{-3}
Cu	70.9×10^{-3}	21.6×10^{-3}	45.0×10^{-3}
Co	2.9×10^{-3}	7.4×10^{-3}	8.4×10^{-3}
Ni	3.4×10^{-3}	39.1×10^{-3}	56.2×10^{-3}
Cr	$<0.500 \times 10^{-3}$	25.4×10^{-3}	54.2×10^{-3}
Cd	0.8210^{-3}	0.7×10^{-3}	0.6×10^{-3}
Pb	0.6×10^{-3}	3.1×10^{-3}	2.4×10^{-3}
Hg	$<0.200 \times 10^{-3}$	0.25×10^{-3}	n.m.

(from Ringqvist *et al*., 2002)

Table 9.12 Metal and TOC Removal (%) in Column Experiments with Sulphide Mine and Landfill Leachate at Five Bed Volumes

Metal and TOC removal (%) in column experiments with sulphide mine and landfill leachate, when approximately 5 bed volumes (100 mL) leachate had passed through the column

	Sulphide mine leachate				Landfill leachate			
Metal ion	*Sphagnum Cuspidata* peat	*Sphagnum Cuspidata* peat and glauconite	*Carex* peat	*Carex* peat and clinoptilolite	*Sphagnum Acutifolia* peat	*Sphagnum Acutifolia* peat and glauconite	*Sphagnum Acutifolia* peat and clinoptilolite	*Sphagnum Cuspidata* peat
Fe	51	47	10	23	55	45	59	50
Zn	77	94	97	98	55	46	53	56
Cu	80	92	85	86	21	20	41	15
Ni	70	91	88	97	15	19	37	17
Cd	75	88	88	88	−50	−17	23	−33
TOC	10	9	−72	0	2	11	—	2

(from Ringqvist *et al*., 2002)

Peat and compost filter beds have been described by Heeney *et al*. (2007) and De Combret (2009) for use in denitrification filter beds for landfill leachate, industrial wastewaters and urban waste water. However, further interpretation of these facets is beyond the scope of this project.

Conclusions on Peat Filters

Although peat filters do not have an exact simile within this project, they do compare somewhat with the compost cells (coarse and fine grade) as well as the combined compost – timber chip cells. Selected parameter loadings to Cells 1 and 10 (Phase 2 Operations) and Cells 9 and 10 (Phases 3 and 4 Operations) (this project) are presented and compared to data from referenced literature in Table 9.13 below.

The results for cell 9 and 10 (compost-timber chip mix) for phase 3 and 4 plant operations detail average load removal rates of 66g/m^2/day and 100g/m^2/day respectively for ammonium. The results for cell 1 (coarse grade compost) and cell 4 (fine grade compost) for phase 1 plant operations detail average load removal rates of 130g/m^2/day and 33g/m^2/day respectively for ammonium. The results for cell 1 should be treated with caution as these high removal rates occurred at the start-up phase where the compost provided a large area for initial NH_4 mineralisation.

A more accurate result for NH_4 removal in coarse grade compost is for phase 2 operations (November 2007 – April 2008) where cell 1 displayed a mean ammonium load removal of 65g/m^2/day. The equivalent removal rate for cell 10 (coarse grade compost) during the same period is 24g/m^2/day.

These compare very favourably to Heavey (2003) (3.3g/m^2/day for bed 1 (unprocessed peat) and >11g/m^2/day for bed 2 (modified dried peat)) and show the high treatment potential of the compost and compost-timber chip media for ammonium removal.

Total N removal for cells 9 and 10 (Phases 3 and 4 operations) was calculated as minus 2g/m^2/day (i.e. 2g increase to effluent load) and 29g/m^2/day respectively. The latter figure compares favourably with the calculated loadings from Kõiv *et al.* (2009) which displayed total N load removal of 2.28g/m^2/day for VV1 effluent (peat and oil-shale ash mix) and 5.57g/m^2/day for VH3 effluent (mineralized sphagnum peat).

The removal rates for BOD_5 for this project were variable. Phase 1 removal rates were 3g/m^2/day for cell 1 and -23g/m^2/day for cell 4.

Phase 2 BOD_5 removal rates were -10g/m^2/day for cell 1 (Nov 2007 – April 2008) and -11g/m^2/day for cell 10 (Nov 2007 – April 2008).

Phases 3 and 4 removal rates for BOD_5 fared little better with -8g/m^2/day for cell 9 and 1g/m^2/day for cell 10.

These results compare very poorly with the results attained by Heavey (2003); BOD_5 load removal of 11.5g/m^2/day for bed 1 and 36g/m^2/day for bed 2; and with Kõiv *et al*. (2009) where BOD_7 removal rates of 75% and 65% were recorded (note BOD_7 results are not directly comparable to BOD_5 results).

Due to a lack of data regarding application rates in the other studies referenced above further comparisons could not made.

Table 9.13 Selected Parameter Loadings to Cells 1, 9 and 10 as Compared with Peat Treatment Units in Referenced Literature

Parameter: NH_4									
	Phase 2 (this project)		Phases 3 and 4 (this project)		Kõiv *et al*., 2009			Heavey, 2003	
(g/m^2/day)	Cell 1	Cell 10	Cell 9	Cell 10	VV1	VV3	VH3	Bed 1	Bed 2
Influent	264	232	284	218	0.03	0.01	0.02		
Effluent	199	208	218	118	0.01	0.02	0.32		
Load Removal	65	24	66	100	0.02	-0.01	-0.30	3.3	>11
Load Removal (%)	25	10	23	46					
Parameter: TON									
	Phase 2 (this project)		Phases 3 and 4 (this project)		Kõiv *et al*., 2009			Heavey, 2003	
(g/m^2/day)	Cell 1	Cell 10	Cell 9	Cell 10	VV1	VV3	VH3	Bed 1	Bed 2
Influent	NA	NA	66	300	6.42	9.12	9.88	NA	NA
Effluent	NA	NA	300	512	9.12	9.88	4.88	NA	NA
Load Removal			-234	-212	-2.7	-0.76	5		
Load Removal (%)									
Parameter: Total N									
	Phase 2 (this project)		Phases 3 and 4 (this project)		Kõiv *et al*., 2009			Heavey, 2003	
(g/m^2/day)	Cell 1	Cell 10	Cell 9	Cell 10	VV1	VV3	VH3	Bed 1	Bed 2
Influent	NA	NA	235	237	13.68	11.4	11.4	NA	NA
Effluent	NA	NA	237	208	11.4	11.4	5.83	NA	NA
Load Removal			-2	29	2.28	0	5.57		
Load Removal (%)			-1	12					
Parameter: BOD									
	Phase 2 (this project)		Phases 3 and 4 (this project)		Heavey, 2003				
(g/m^2/day)	Cell 1	Cell 10	Cell 9	Cell 10	Bed 1	Bed 2			
Influent	20	19	18.51	26.98					
Effluent	30	30	26.98	26.03					
Load Removal	-10	-11	-8.47	0.95	11.4	36			
Load Removal (%)	-50	-58	-46	4					

Key
Cells 1 and 10 = Coarse Compost (Phase 2)
Cell 9 and 10 = Compost / timber chip mix (Phases 3 and 4)
Bed 1 = Undrained peat
Bed 2 = Modified dried peat
VV1 = moderately mineralised sphagnum peat
VV3 = peat and oil-shale ash mix
VH3 = mineralised sphagnum peat

Note: All data in g/m^2/day expect for Load removal %
Loadings for Kõiv *et al*. (2009) are calculated from median values; therefore, the data does not necessarily match with the stated parameter removal rates outlined in the text
Total N for Kõiv *et al*. (2009) includes organic and inorganic N
Total N for this project includes inorganic N only

Based on the data presented, it is apparent that the irrigation rates to the various cells in this project were much too high (HLR range 883 litres/m^2/day to 945 litres/m^2/day) to accommodate BOD_5 removal to any significant level. However, NH_4 load removal was significantly greater at these application rates than reported elsewhere in the literature. It should be noted that in phase 3 and 4 plant operations, despite initial BOD_5 addition / negligible removal in primary and secondary units, a high degree of BOD removal was achieved in the final effluent for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – (HF 2) – VP 1 – VP 2.

A comparison of metal removal rates between the study by Rindqvist *et al*. (2002) and this project is difficult due to the low initial concentrations in each of the leachates (in many cases below the limit of detection) and variations in application rates.
However, from an overall viewpoint the Swedish data shows good removal capacity for the two peat filters containing *Sphagnum* Sect. *Acutifolia* and *Sphagnum* Sect. *Cuspidata* with high removal for Zn (55% and 56% respectively), moderate removal for Ni (15% and 17%) and Cu (21% and 15%). Negative removal was recorded for Cd (-50% and -33%).

These figures compare very well against this project. As previously stated in Section 8.3.3.3, interpretation of metals and salts concentrations in the influent and effluent for all treatment units was limited by the low sampling number and in many cases by the high standard deviation of results about the mean concentration. Phosphate (as P) was the only parameter where a significant reduction (with a low standard deviation) in concentration from influent to effluent occurred. Influent P concentration was 0.70mg/l and effluent P concentrations were; 0.69mg/l for cell 1 (no change/ not significant), 0.37mg/l for cell 4, 0.46mg/l for cell 9 and 0.25mg/l for cell 10.
Again one must again be cognisant of the vast differences in application rates and the surface area available to each experiment (883 - 945L/m^2/day this project versus 0.1 litre across an area of $7x10^{-4}m^2$/day).

Sand Filters

The use of sand filters has been mentioned in a number of studies involving secondary treatment of septic tank and RBC effluents. Described as intermittent or stratified sand filters, their basic design involves lined or unlined shallow beds (600 - 900mm deep) containing stratified sand and gravel. The design may fine up, fine down or alternate between gravel – sand – gravel - sand. Sediment sizes vary but they all operate on the principles of attaining good effluent distribution across the surface area (intermittently pumped) and maintaining aerobic conditions coupled with maximum sediment contact time.

Only one paper has been uncovered examining the efficiency of sand filters for leachate treatment. In an experimental pilot plant involving application of primary treated landfill leachate and municipal wastewater to a vertical flow sand filter, Wichern *et al*. (2008) outline some promising results for ammonium and COD removal.

The plant set up involved a small scale SBR with a secondary sand filter in series. The sand filter had a volume of 0.55m^3 and a depth of 700 mm. The filter material consisted of a homogenous mixture of sand and gravel (Ø 0.06–3.00 mm) with a gravel material at the base (100mm deep).

The pollutant concentrations of the landfill leachate from a site in Bavaria (primary effluent) were relatively low (COD = 150g/m^3; NH_4-N = 120g/m^3; BOD_5 = 90g/m^3; AOX < 0.2g/m^3). It was reported that the sand filter was capable of treating ammonium peaks of 10gNH_4/m^2/day at hydraulic loadings of up to 200L/m^2/day. A selected set of results from the study are presented in Table 9.14.

Table 9.14 Influent and Effluent Concentrations to Sand Filter

Case/scenario	Influent sand filter		Effluent sand filter		
	COD/NH_4-N measured [g/m^3]	NH_4-N-surface load [g/($m^2_{reactor}$ × d)]	COD_{hom} measured/ simulated [g/m^3]	NH_4-N measured/ simulated [g/m^3]	NO_3-N measured/ simulated [g/m^3]
Case 1	71.0/46.4	7.4	60.6/57.8	0.1/0.1	62.0/66.5
Case 2	62.6/40.2	5.1	50.6/50.4	0.0/0.1	59.5/65.9
Case 3	74.2/48.2	6.1	60.0/60.1	0.3/0.1	81.6/88.3
Case 4 (Methanol)	66.0/39.8	6.4	53.9/52.8	2.4/0.1	44.0/46.7
Case 5 (Methanol)	79.0/35.0	5.6	61.7/61.3	1.4/0.1	38.3/45.1

(after Wichern *et al*., 2008)

Note: Data Range September 2002 – March 2003
Measured data on left, model simulation on right

The data presented above detail ammonium removal efficiencies between 96% and 99.9% at loading rates of 5.1 to 7.4g/m^2/day. The equivalent removal efficiencies for COD were reported as being between -25% and -74%, displaying higher effluent concentrations throughout.

Nitrification resulted in NO_3 effluent concentrations of 38mg/l to 81mg/l.

Literature pertaining to sand filters for municipal wastewater treatment is much more abundant and has been described by Gill *et al*. (2005), USEPA (1999), EPA (2000(b)) and Nichols *et al*. (1997).

Gill *et al*. (2005) in an investigation into the performance of subsoils and stratified sand filters for the treatment of wastewater from on-site systems reports a COD load reduction of 83%, from 41g/m^2/day to 7g/m^2/day (conc. reduced from 1432mg/l to 219mg/l) and a load reduction of 82% for NH_4, from 1.35g/m^2/day to 0.24g/m^2/day (conc. reduced from 47mg/l to 7.4mg/l), in a 6m^2 sand filter unit. A high degree of pathogen removal was achieved at a hydraulic loading rate of 28.6 litres/m^2/day with *E. coli* counts reduced from >10,000cfu/100ml to a range 10–100cfu/100ml. These data were collected at one of two investigation trial sites involving stratified sand filters and septic tank effluent (Three Wells, Co. Wicklow, RoI). Selected parameter loadings to the stratified sand filter at the Three Wells site are presented in Table 9.15.

Table 9.15 Selected Parameter Loadings to a Stratified Sand Filter at Three Wells

	Parameter				
(g/m^2/day)	NH_4	NO_2	NO_3	Total N	COD
Influent	1.35	0.015	0.07	1.42	41
Effluent	0.24	0.012	0.40	0.65	7.12
Load Removal	1.11	0.003	-0.33	0.78	33.88
Load Removal (%)	82	22		55	83

(after Gill *et al*., 2005)

At the second site, (Killaveney, Co. Wicklow, RoI) pollutant load removal rates were described as follows; COD load reduction of 9%, from 8.85g/m^2/day to 8.08g/m^2/day (conc. reduced from 216mg/l to 184mg/l), and 54% reduction in NH_4 loading, from 0.27g/m^2/day to 0.13g/m^2/day (conc. reduced from 6.5mg/l to 2.8mg/l), again in a sand

filter unit of $6m^2$. Results for pathogen removal were inconclusive due to low influent count. The average hydraulic loading rate for this site was 41 litres/m^2/day

Selected parameter loadings to the stratified sand filter at the Killaveney site are presented in Table 9.16.

Table 9.16 Selected Parameter Loadings to a Stratified Sand Filter at Killaveney

	Parameter				
(g/m^2/day)	NH_4	NO_2	NO_3	Total N	COD
Influent	0.27	0.010	1.72	2.01	8.85
Effluent	0.13	0.007	1.82	1.94	8.08
Load Removal	0.15	0.003	-0.10	0.06	0.77
Load Removal (%)	54	33	-6	3	9

(after Gill *et al*., 2005)

The United States Environmental Protection Agency (1999) report high removal rates for intermittent sand filters (ISF) for residential septic tanks in operation in Placer County, California, USA, (surface area of $33m^2$ and HLR of 50L/m^2/day) for the following parameters; 98% removal for $cBOD_5$, 78% removal for TSS, 90% removal for NH_4, 99% removal for Total Coliforms and Faecal Coliforms. A summary of results for 30 such intermittent sand filters in operation is detailed in Table 9.17.

Table 9.17 Comparison of Effluents from Single Family Residential Septic Tanks and Intermittent Sand Filters for 30 Systems in Placer County, California

Effluent Characteristic	**Septic Tank Effluent**	**n**	**ISF Effluent**	**n**	**% Change**
$cBOD_5$	160.2	15	2.17	44	98
TSS	72.9	15	16.2	44	78
NO_3	0.1	15	31.1	44	99
NH_3	47.8	15	4.6	44	90
TKN	61.8	15	5.9	44	90
Total N	61.8	15	37.4	44	40
Total Coliforms (TC)	6.82×10^5	13	7.30×10^2	45	99 (3 logs)
Faecal Coliforms (FC)	1.14×10^5	13	1.11×10^2	43	99 (3 logs)

(after USEPA, 1999) (All data in mg/l except for TC and FC, MPN/100ml)

Cell 5 containing stratified sand, and gravel (fining up) is the closest equivalent to the sand filter media described above. During phases 3 and 4 plant operations (August 2008 – October 2010) the unit received primary treated effluent from cell 3 (containing timber chippings).

It terms of treatment efficiency for NH_4, the sand filter described by Wichern *et al*. (2008) delivered extremely high load removal rates ranging from 5.1g/m^2/day to 7.38g/m^2/day NH_4 removal (≥94%) for all 5 cases presented, whereas results for cell 5 during phases 3 and 4 plant operations showed a mean NH_4 load removal of 5.9g/m^2/day (64% removal) with a mean effluent concentration of 31mg/l, down from a mean influent concentration of 86mg/l. NH_4 load removal from the other referenced literature was considerably lower. Data presented by Gill *et al*. (2005) show NH_4 load removal of 1.11g/m^2/day for the Three Wells site and 0.15g/m^2/day for the Killaveney site whereas calculated loading data for the Placer County ISFs (USEPA, 1999) show NH_4 load removal of 2.16g/m^2/day.

In terms of total N removal, the 5 scenarios presented by Wichern *et al*. (2008) and cell 5 (this project) show similar rates of N load removal; 2.26 – 3.51g/m^2/day for cases 1 – 5 (Wichern *et al.*, 2008) and 2g/m^2/day for cell 5.

N species loading to cell 5 as compared with stratified sand filters in referenced literature is presented in Table 9.18.

Table 9.18 N Species Loadings to Cell 5 as Compared with Stratified Sand Filters in Referenced Literature

	Case 1 (HLR 159 l/m^2/day)			Case 2 (HLR 127 l/m^2/day)			Case 3 (HLR 127 l/m^2/day)		
(g/m^2/day)	NH_4	NO_3	Total N	NH_4	NO_3	Total N	NH_4	NO_3	Total N
Influent	7.4	0	5.76	5.1	0	3.97	6.1	0	4.75
Effluent	0.02	9.89	2.25	0	7.55	1.71	0.04	10.33	2.36
Load Removal	7.38		3.51	5.10		2.26	6.06		2.38
Load Removal (%)	99.8		61.0	100		57	99.4		50.2
	Case 4 (HLR 161 l/m^2/day)			Case 5 (HLR 160 l/m^2/day)			Placer County (HLR 50 l/m^2/day)		
(g/m^2/day)	NH_4	NO_3	Total N	NH_4	NO_3	Total N	NH_3	NO3	Total N
Influent	6.4	0	4.98	5.6	0	4.36	2.39	0.01	3.09
Effluent	0.39	7.08	1.90	0.22	6.13	1.56	0.23	1.56	1.87
Load Removal	6.01		3.08	5.38		2.80	2.16		1.22
Load Removal (%)	94		61.9	96		64.2	90		39
	Three Wells (HLR 28.6 l/m^2/day)			Killaveney (HLR 41 l/m^2/day)			Cell 5 (HLR 98 l/m^2/day)		
(g/m^2/day)	NH_4	NO_3	Total N	NH_4	NO_3	Total N	NH_4	TON	Total N
Influent	1.35	0.07	1.42	0.27	1.72	2.01	9.20	85	26
Effluent	0.24	0.40	0.65	0.13	1.82	1.94	3.30	93	24
Load Removal	1.11		0.78	0.15		0.06	5.90		2
Load Removal (%)	82		55	54		3	64		8

Note: all data expressed as g/m^2/day (Except for HLR and Load Removal %)
(Case 1 – 5 data, after Wichern *et al*., 2008; Placer County data, after USEPA, 1999; Three Wells and Killaveney data, after Gill *et al*., 2005; Cell 5 data, this project)

COD load removal for Wishern *et al.* (2008) was low for all five scenarios presented, ranging from 1.5g/m^2/day to 2.8g/m^2/day (between 19% and 22% load removal). Results for cell 5 and for Killaveney (Gill *et al*., 2005) were equally poor displaying load removal/increase of -2.16g/m^2/day and 0.77g/m^2/day respectively (-10% and 9% load increase/removal).

The figures for the Three Wells site (Gill *et al*., 2005) are impressive showing COD removal of 33.88g/m^2/day (i.e. 83% load removal). However, it should be noted that this high COD removal rate was achieved using sewage wastewater as opposed to landfill leachate.

COD loading to cell 5 as compared with stratified sand filters in referenced literature is presented in Table 9.19.

Table 9.19 COD Loadings to Cell 5 as Compared with Stratified Sand Filters in Referenced Literature

Parameter: COD	Case 1	Case 2	Case 3	Case 4	Case 5
HLR	159 l/m^2/day	127 l/m^2/day	127 l/m^2/day	161 l/m^2/day	160 l/m^2/day
Influent (g/m^2/day)	11.3	8.0	9.4	10.6	12.6
Effluent (g/m^2/day)	9.6	6.4	7.6	8.7	9.9
Load Removal	1.7	1.5	1.8	1.9	2.8
Load Removal (%)	15	19	19	18	22

Parameter: COD	Three Wells	Killaveney	Cell 5
HLR (l/m^2/day)	28.6 l/m^2/day	41 l/m^2/day	98 l/m^2/day
Influent (g/m^2/day)	41.00	8.85	21.55
Effluent (g/m^2/day)	7.12	8.08	23.71
Load Removal	33.88	0.77	-2.16
Load Removal (%)	83	9	-10

Note: all data expressed as g/m^2/day (Except for HLR and Load Removal %)
(Case 1 – 5 data, after Wichern *et al*., 2008; Three Wells and Killaveney data, after Gill *et al*., 2005; Cell 5 data, this project)

The intermittent sand filters described by the USEPA for secondary wastewater treatment from septic tank systems performed well against cell 5 although its design hydraulic loading rate is just under half that of cell 5 (50 l/m^2/day versus 98 l/m^2/day).

Overall, results from cell 5 demonstrate that it has performed well against established systems and proves that stratified sand filters work well as secondary treatment units for removal of NH_4.

Results were less convincing for SS where there was an increase in effluent loading from 0.89g/m^2/day to 1.37g/m^2/day (-54% removal), BOD_5 showed a decrease in effluent loading from 2.56g/m^2/day to 1.27g/m^2/day (50% removal) and *E. coli* and total coliforms showed a 37% and 27% removal rate respectively. However, one must be cognisant of the fact that the HLR was two to three times that of the units receiving septic tank effluent (Gill *et al.*, 2005 and USEPA, 1999) and of the different characteristics of the wastewater streams in each study (i.e. landfill leachate versus sewage wastewater).

The performance of Cell 5 could be improved by lowering the HLR by 50%, which may possibly facilitate further pathogen and BOD_5 removal.

Willow Short Rotation Coppice and Non-engineered Forest Land for Leachate Treatment

Land-based treatment systems are an attractive alternative for landfill operators as they utilise an existing land resource, they are considered to be cheap to build and operate, and are not perceived to need sophisticated management.

The potential for the use of willow or other short rotation tree crops such as poplar as a vegetation filter for wastewater purification has been discussed in numerous articles by Duggan (2005), Larsson *et al*. (2003) and Aronsson *et al*. (2010).

Their use is appropriate due to high treatment potential, ease of propagation, high growth rates and high transpiration rates, and the application of landfill leachate has been shown to be a good fertilizer for short rotation coppice (SRC) (Hasselgren, 1992); in particular leachate from older landfills.

In an early paper on leachate application to non-engineered forest soils, Cohen (1983) details leachate application rates of 1676mm and 660mm sprayed across two separate plots over a six-month period. The plots located beside an abandoned landfill at Centre County, Pennsylvania, USA, contained a mixed tree species containing oak, willow, maple and aspen. Each spray zone and the control plot were also outfitted with suction lysimeters at variable depths (15cm, 60cm and 1m and 1.5m).

The applied leachate had the following mean parameter concentrations: 856mg/l $CaC0_3$ as alkalinity, 800mg/l COD, 22.4mg/l TKN, 183mg/l Ca, 270 mg/l Fe, 6.05mg/l Mn, 6.93 mg/l Zn, and 83µg/l Pb.

Results from the study revealed N concentrations below 1mg/l in the 1m lysimeter, Ca removal of 98%, Mg removal of 70% and over 90% removal for Fe, Zn, Cd, Pb, Cu, K EC and COD. Na and Cl were more mobile and the initial high iron concentration resulted in extensive precipitation of iron hydroxide across the forest plot.

In a five year study of leachate application to a forest soil Menser *et al*. (1983) report reductions in effluent concentrations of 84% for Na, 92% for K, 83% for COD, 90% for Zn, 95% for Fe and a drop in EC from 1.9mS/cm to 0.2mS/cm. The influent and effluent values are detailed in Table 9.20, no loading data were provided in the study.

Table 9.20 Results of a 5 year Study of Leachate Application to Forest Soil

Constituent	Influent leachate	Effluent
Na	194 (145)	32
K	80 (49)	7
COD	1878 (912)	239
pH	7.25 (0.64)	6.84
EC	1.9 (0.7)	0.2
Zn	0.89 (1.11)	0.09
Fe	77 (110)	4

Note: All values in mg/l (except for EC, mS/cm). Data presented are mean values with standard deviation in brackets (after Menser *et al*., 1983)

In each of these studies, it was concluded that the majority of parameter removal occurred in the soil column and that limited treatment was provided by tree uptake of nutrients or metals.

A short-rotation tree plantation was studied over a six-year period at Lahiti sanitary landfill in southern Finland (Etala, 1988). Experiment plots of $100m^2$ were irrigated with leachate over the growing season at a rate of 200mm per month (May – September).
Production was measured by height and shoot diameter of stands from which biomass equations were calculated. Data are limited in terms of treatment potential across the willow plots; however, the paper describes growth disturbance during July 1984, 1986 and 1987 due to high Na and Cl leachate concentrations resulting in excessive Na and Cl concentration in leaves (max recording of 11mg/g Na dry matter and 8.9mg/g dry matter Cl). The poor growth was also attributed to low leaf calcium concentrations (with concurrent high sodium and chloride concentrations) coupled with warm and dry periods.
In concluding remarks, Etalla (1988) states that SRC irrigation not exceeding 500mm (500 l/m^2) during the growing season has a beneficial influence on the growth of short-

rotation plantations. Irrigation above this is likely to result in growth inhibition, due to high sulphate, sodium and chloride concentrations in the leachate.

A combined constructed wetland with recirculation to a willow (*Salix purpurea*) plane planted on a landfill in Slovenia was studied by Justin *et al*. (2009). The leachate was first treated in six interconnected HF and VF reed beds. The effluent was then irrigated across a 1.1ha willow plantation (planted on part of the waste body) and allowed to percolate back in to the waste body generating a closed loop system.

The pipes of the irrigation system were sited 30 cm deep beneath the tree rows with 3m distance between each pipe lateral.

The willow plantation was loaded all year round at rates ranging from 154m^3 per month to 1096m^3 per month (416m^3 per month on average, or 37.8 l/m^2 per month).

Loadings and concentrations to the willow plantation were reported as being above agricultural irrigation practices for Na, nitrate and Cl.

Mean concentrations of irrigated leachate to willow were, nitrate 136mg/l, sodium 476mg/l and chloride 795mg/l (recommended concentrations for irrigation in agriculture according to Justin *et al.* (2009) is, Nitrate 30mg/l, Na 200mg/l, Cl 350 mg/l).

The annual loading to the willow plantation for sodium and chloride was 1999.7kg/ha and 3867.9kg/ha respectively. The amounts of annually applied nitrogen was 1092.7kg/ha. Monthly loading of metals to the system are detailed in Table 9.21.

Table 9.21 Estimated Average Monthly Load of Leachate Components to Willow Plantation (Jan 05 – Sept 06)

Parameter	**Al**	**Cr**	**Mn**	**Fe**	**Ni**	**Cu**	**Zn**	**Cd**	**Ba**	**Sn**	**Ti**	**V**	**As**	**B**	**Mo**
Mass load (g/ha)	104	116	254	1320	32.9	29.7	40.7	1.6	3.9	0.7	1.2	7.8	5.0	796	3.18
Parameter	**Cl^-**	**NH_4^+**	**Total N**	**Na^+**	**K^+**	**Mg^{2+}**	**Ca^{2+}**	**P**	**TOC**	**COD**	**BOD_5**				
Mass load (kg/ha)	322	71.3	91.1	167	194	18.1	17.7	0.6	118	351	29.0				

(after Justin *et al*., 2009)

Soil analysis revealed no noxious buildup of salts or heavy metals at depths between 0 and 90 cm in the top layer of soil during the two-year study.

Metals decreased in the soil except for Zn and As, the reason for the decrease was most likely due to complexation with salts and organics in the soil horizon. Soil pH was reported as remaining stable during the monitoring period, despite high mass loads of organic compounds, ammonium, Na, Ca and Mg.

Plant material analysis indicated beneficial growth of willows with leachate irrigation, and a buildup of nitrogen, Na, K, B, Cu, Mn and Cd in leaf wood material was detailed.

Justin *et al.* (2009) concluded that longer periods were required for the establishment of the dynamic ecological equilibrium of the system to indicate significant trends in the soil–plant system.

Ammonia removal rates of up to 99 % have been reported using willow stands in Sweden (Hasselgren, 1998), with total N reductions of up to 93% from an initial input of 1600kg(N)/ha/year down to 100kg(N)/ha/year. However, a more typical rate of nitrogen removal from landfill leachate in SRC systems is estimated at 100kg(N)/ha/year.

In another Swedish study, Arsonsson *et al*. (2010) describe irrigation of leachate across sixteen SRC willow (*Tora* and *Gudrun sp.*) plots, each with an area of 400m^2 at a landfill in the Upplands-Bro region of the country. Cumulative application rates over the three years of the study ranged from 33mm – 99mm in year 1, 164mm – 492mm in year 2 and 282mm – 846 for year 3 (Table 9.22). Ammonium application rates were in the order of 66kg/ha/year to 419kg/ha/year with a mean NH_4 concentration of 205mg/l in year 1 to 44mg/l and 50mg/l for years 2 and 3 respectively (Table 9.23).

Non-destructive techniques were performed to ascertain biomass uptake of the various parameters as well as establishing the relative retention in the soil–plant system (i.e. irrigated load minus leaching load/irrigation load)

Table 9.22 Cumulative Irrigation Loads in a 3-year field experiment in Upplands-Bro, central Sweden

Year	Start of irrig.	End of irrig.	Irrigation loads (mm)			
			Control	Treatment 1	Treatment 2	Treatment 3
2005	20 July	27 Sept.	33	33	66	99
2006	1 June	21 Sept.	164	164	328	492
2007	11 May	28 Sept.	282	282	564	846

(after Aronsson *et al*., 2010)

Table 9.23 Element Irrigation Loads and Mean Concentrations to the field experiment in Upplands-Bro, central Sweden

		Ctrl (kg/ha)	Treat. 1 (kg/ha)	Treat. 2 (kg/ha)	Treat. 3 (kg/ha)	Mean conc. (mg/L)
NO_3–N	2005	0.00	1.02	2.01	3.02	2.26
	2006	0.56	5.98	12.0	17.9	3.25
	2007	n.a.	289	578	867	103
NH_4–N	2005	0.0	66.5	132	198	205
	2006	0.0	66.8	134	200	43.7
	2007	n.a.	140	279	419	49.8
Tot-N	2005	0.0	78.5	156	234	242
	2006	0.9	173	346	519	106
	2007	n.a.	720	1440	2160	257
Chloride	2005	0.0	354	703	1060	1090
	2006	29.5	2180	4360	6540	1320
	2007	n.a.	2870	5740	8600	1020
TOC	2005	0.0	160	317	477	565
	2006	6.4[a]	607[a]	1210[a]	1820[a]	370[a]
	2007	n.a.	n.a.	n.a.	n.a.	n.a.
Tot-P	2005	0.00	0.49	0.96	1.45	1.49
	2006	0.00	7.44	14.9	22.3	4.83
	2007	n.a.	5.44	10.9	16.3	1.94

n.a.: not analysed.

[a] Only one sample analysed during the irrigation season.

(after Aronsson *et al*., 2010)

Although good results for retention capacity in the soil–plant system were recorded, a significant increase in ammonium, nitrate, chloride and TOC concentrations occurred in a nearby groundwater monitoring well (with peaks of 30mg/l (NH_4), 100mg/l (NO_3), 1000mg/l (Cl) and 300mg/l (TOC) respectively). While irrigation application did not negatively affect the plants in the study, the high leach loads to the groundwater system indicated massive overloading of the system (particularly at N loading of 720, 1440 and 2160kg/ha/yr which were well above recommended SRC loading of 100kg(N)/ha/yr).

Soil salinity and dosing willows with high ionic strength leachate has proven to be problematic in several studies (Duggan, 2005). Phytotoxic effects were observed by Cureton *et al*. (1991) when high strength leachate with an EC of 0.899 S/m was applied to weeping willows. The result was chlorosis of early foliage, and extensive leaf necrosis and desiccation (Cureton *et al*., 1991).

In a paper reviewing phytoremediation options for landfill leachate, Jones *et al*. (2006) report on a number of experiences where high chloride concentrations in leachate irrigated to short rotation willow coppice resulted in stunted plant growth or partial sward failure, whilst Stephens *et al*. (2000) reported that sustainable growth and development of willow (*Salix viminalis*) was not possible at chloride concentrations greater than 2500mg/l. In an experimental study, Dimitrou and Aronsson (2007) found plant stressing of willows at Na and Cl concentrations of 200mg/l and 600mg/l respectively

Stephens *et al*. (2000) concluded that leachates with a high electrical conductivity (>4 mS/cm) should not be used for irrigation, as in the long-term they would adversely affect tree growth and could result in long-term Na induced soil structural deterioration. They suggest an appropriate application rate for leachate to be in the region of 250m^3 - 500m^3 per ha per year.

Dobson and Moffat (1995) stated that leachate at EC 0.2–0.4 S/m can cause osmotic and ionic stress when irrigated to tree crops and concluded that soil salinity was the main limiting factor for leachate amelioration.

Regarding the removal of pathogens in SRC systems, Christensen *et al*. (1994) concluded that pathogenic organisms were of minor importance in landfill leachate and that they were unlikely to constitute a major environmental or public health hazard.

Conclusions to Willow Treatment Systems

Cells 2 and 6 in this project can be compared to the irrigation of leachate to SRC and non-engineered forest land presented above. Cell 2 contained two willow trees (*Terra Nova* variety) in fine grade compost and cell 6 contained two willow trees (same variety) in a subsoil medium.

When comparing operating parameters for cells 2 and 6 with cited examples, it is obvious that the cells were grossly overloaded with application rates far exceeding those mentioned in the literature. Cell 2 was dosed with leachate from August 2007 to March 2008 at a rate of 945 litres/m^2/day, this equates to $3.44x10^6$ cubic metres per hectare per year or $1.7x10^6$ cubic metres per hectare over the growing season (March to September).

Parameter loading would equate to; $1.07x10^6$kg per hectare per year for ammonium; $9.2x10^5$kgCOD/ha/yr; $1.34x10^6$kgCl/ha/yr with an influent EC concentration of 4.74mS/cm.

Cell 6 was dosed with leachate from August 2007 to June 2008 at a rate of 451 litres/m^2/day, equating to $1.65x10^6m^3$/ha/yr or $8.23x10^5m^3$/ha over the growing season (March to September).

Parameter loading would equate to; $5.39x10^5$kg per hectare per year for ammonium; $4.09x10^5$kgCOD/ha/yr; $6.62x10^5$kgCl/ha/yr with an influent EC concentration of 4.07mS/cm.

A comparison of parameter loading to SRC/Willow treatment planes for ammonium, COD, chloride and electrical conductivity data for this project with selected referenced literature is presented in Table 9.24.

Table 9.24 Parameter Loadings to Cell 2 and Cell 6 as Compared with Loadings to SRC/Willow Treatment Planes in Referenced Literature

	Cell 2	Cell 6	Justin *et al.*, 2009	T 1 2007	T 2 2007	T 3 2007	Thörneby *et al.*, 2006
HLR ($l/m^2/day$)	945	451	1.26	2	4	6	4.1
HLR ($m^3/ha/yr$)	3.44×10^6	1.65×10^6	4.60×10^3	2.82×10^3	5.64×10^3	8.46×10^3	1.5×10^4
Influent NH_4 conc. (mg/l)	310	327	190	50	50	50	60
Influent load ($kgNH_4/ha/yr$)	1.07×10^6	5.34×10^5	856	140	279	419	900
Influent COD conc. (mg/l)	270	248	890				
Influent load (kgCOD/ha/yr)	9.2×10^5	4.09×10^5	4.2×10^3				
Influent Cl conc. (mg/l)	392	401	795	1020	1020	1020	411
Influent Cl load (kgCl/ha/yr)	1.34×10^6	6.62×10^5	348	2.87×10^3	5.74×10^3	8.60×10^3	6.17×10^3
EC (mS/cm)	4.07	4.07	6.7				22

Note: (T1, T2, T3, after Aronsson *et al.*, 2010; Cell 2 and Cell 6, this project)
Irrigation to Cell 2, Cell 6 and in Justin *et al.*, 2009, was all year round
Seasonal irrigation in Aronsson *et al.*, 2010, (May – September) and Thörneby *et al*., 2006, (April – October)

Despite the excessive loading to the willow treatment cells in this project, each unit still performed reasonably well as regards ammonium removal, with cell 2 achieving 25% load reduction (i.e. $78g/m^2/day$) and cell 6 achieving 13% load reduction (i.e. $19g/m^2/day$). The equivalent reduction in COD loading was 13% ($32g/m^2/day$) and 6% ($7g/m^2/day$) respectively.

Given the fact that influent loading to each cell was far in excess of recommended loading rates to SRC plots ($250–500m^3/ha/yr$), it is not surprising that the trees experienced phytotoxicity in June 2008. The doubling of influent chloride concentration to 844mg/l (EC increased to 5.34mS/cm) coupled with warm weather seems to have tipped the balance causing osmotic shock to the trees. The damage (leaf desiccation and blackening of the branch ends) resulted in irreversible decline in tree health and the units were eventually switched off and abandoned.

Irrigation of leachate to SRC systems at the levels detailed in this project is unsustainable, as it leaves the trees very susceptible to shock loading and insect or fungal attack.

Grass Vegetated Planes for Leachate Treatment

Another type of land-based system adopted at many landfill sites is the leachate treatment plane or vegetated grass plane. Treatment planes are areas of vegetated, sloping land, usually constructed using low permeability soils onto which leachate is applied from a recirculation lagoon (Tyrell *et al*., 2002). Grass planes may be planted across restored areas of a landfill site, or on agricultural land, and may be lined or unlined.

Operating in much the same way as SRC systems, plant growth can often respond positively after the short-term addition of leachate to soil (Vasseur *et al*., 1998). Provided the system is not overloaded, the soil can act as a natural filter, providing zones for metal immobilisation and contributing to sustainable water quality improvements.

In an early study involving a land based phytoremediation scheme in which leachate was irrigated onto grassland at a rate of 50m^3/ha/day, Harrington and Maris (1986) reported parameter concentration reductions for suspended solids, NH_4, COD, BOD and Fe of 65%, 66%, 85%, 95% and 83% respectively. Original influent concentrations are outlined in Table 9.25.

Table 9.25 Leachate Influent and Effluent Concentrations to a Grassland Phytoremediation Scheme

Constituent	Influent leachate	Effluent
Suspended solids	70	25
NH_4^+–N	15	5
COD	400	60
BOD	300	15
Fe	12	2

Note: All values are in mg l^{-1}.

(after Harrington and Maris, 1986)

Bowman *et al*. (2002) found that recreational turf and parkland grassland could remove and immobilize up to 3500kgNH_4/ha/yr (equivalent to an irrigation rate of 4000m^3/ha/yr or 400 mm/yr) over a 12 month period. However, this application rate was not sustainable in the long-term due to a range of Na induced problems in soil quality.

Jones *et al*. (2006) calculated that leachate applications over a 10-year period should not exceed 250m^3/ha/yr (685 l/ha/day).

In similar short-term trials (2 months) with very high leachate addition rates, increased grass growth was observed at application rates equivalent to 10,000m^3/ha/yr, after which point a decline in herbage production was observed (Williamson, 2001). However, at these high rates, significant leaching of nitrate, Na and K to groundwater was observed along with a decline in a range of soil quality indicators.

In a paper reporting the findings of studies of experimental treatment planes designed to improve existing understanding of ammoniacal nitrogen dynamics in engineered grassland treatment systems, Tyrell *et al*. (2002) constructed 10 separate 25m long, 1m wide and 0.3 m deep, field-scale plots at a site in Bedfordshire, UK. The plots were lined for water balance calculations and were planted with *Agrostis stolonifera*, a salt and waterlogging tolerant grass species in a topsoil medium. Leachate from a nearby landfill site (Calvert) was dosed at the top end of the system and runoff was collected in receptor tanks and recirculated. Initial raw leachate concentrations are outlined in Table 9.26.

Table 9.26 Raw Leachate Quality from Calvert Landfill Site Used in Experimental Treatment Planes

Parameter	Mean ($n = 6$)	Maximum	Minimum
pH	8.29	7.6	8.7
Chemical oxygen demand	1930 mg/l	700 mg/l	9304 mg/l
Chloride	3611 mg/l	2375 mg/l	6800 mg/l
Ammoniacal-N	514 mg/l	214 mg/l	812 mg/l
Nitrite-N	128 mg/l	1 mg/l	449 mg/l
Nitrate-N	27 mg/l	2 mg/l	95 mg/l

(after Tyrell *et al.*, 2002)

Hydraulic loading rates were tested in the range 23-75 litres/m^2/day over a relatively short duration (10 – 25 days) as outlined in Table 9.27.

Leachate was applied to the plots over 5 hours, with a 19 hour rest period for the drain and dry process. Evapotranspiration rates were calculated at up to 3mm/day (75 l/25m^2 plot/day) during hot dry weather.

Table 9.27 Experimental Programme for Vegetated Plane Plots

Experiment	Duration (days)	Plot number	Plot length (m)	Hydraulic loading rate ($l/m^2/d$)
Start-up	13	Plots 1–10	25	Various
D	22	Plot 2	10	70
		Plot 6	20	24
		Plot 9	20	37
E	35	Plot 2	10	75
		Plot 4	10	45
		Plot 6	10	23
		Plot 9	10	45

Note: Plot length shortened during trials to accommodate varying HLR
(after Tyrell *et al.*, 2002)

Leachate samples were taken daily and analysed for NO_2, NO_3 and NH_3. Results for the various experimental runs indicated a highly variable rate of NH_3 removal, accounting for between 33% and 83% changes in inorganic N (Table 9.28).

Table 9.28 Nitrogen Balance at Beginning and End of Experimental Programme

Treatment identifier (experiment, plot/trough, number)	Total mass of inorganic N (kg) in leachate		% of inorganic N remaining at end	% of change in inorganic N accounted for by changes in:		
	Beginning	End		NH_3-N	NO_2-N	NO_3-N
DP2	1.587	0.0111	1	83	17	0
DP6	1.631	0.0512	3	83	19	−2
DP9	1.5379	0.0441	3	81	20	−1
EP2	1.5668	0.0409	3	33	65	2
EP4	1.7058	0.3877	23	41	55	4
EP6	1.7699	0.5063	29	53	45	2
EP9	1.5096	0.2408	16	42	55	3

Note: DP2 refers to Experiment D, Plot 2 etc. (after Tyrell *et al.*, 2002)

Tyrell *et al*. (2002) concluded that the mass of NH_3-N and NO_2-N removed from the leachate applied could not be accounted for by NO_3-N production in the final effluent (3%-11% could be attributed to above ground biomass) and that a combination of chemical and biological processes probably governed the fate of nitrogen in the system. They calculated an NH_3-N removal rate ($kg/m^2/d$) of 2×10^{-5} x NH_3-N concentration (mg/l), and suggested this could be utilised as a basis for a simple treatment plane simulation model.

To evaluate the effectiveness of an irrigated soil-plant system, Thörneby *et al*. (2006) describe the construction and operation of a lined grass plane test area of $400m^2$ at Moskogen landfill site in Sweden.

The main leachate treatment system at the facility comprised three consecutive ponds (the first one aerated) and an irrigated willow system (10ha). However, the willow system was not lined and a full appraisal of pollutant attenuation could not be made, so the lined test cell provided for full control and calculation of the water balance.

Leachate was delivered to the test cell from the same source as the willow irrigated system. Leachate production at the facility was reported as $150{,}000m^3$ per annum; however, exact irrigation volumes are not detailed. Leachate analyses included a number of sum parameters (nutrients, BOD, TOC), heavy metal ions, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs), including PCBs, PAHs and phenols.

Results for the test cell revealed an overall reduction in common leachate parameters as well as significant reduction in metals.

Influent and final effluent concentrations to/from the test cell are detailed in Tables 9.29 and 9.30.

Table 9.29 Influent and Effluent Concentrations for Wastewater Parameters at Moskogen Test Cell

Parameter	Influent (S5)	Effluent (S7)
pH	8.3	6.8
EC (mS/cm)	22	16
BOD_7 (mg/l)	10	3
TOC (mg/l)	50	40
Total N (mg/l)	70	8
NH_4-N (mg/l)	60	0.1
NO_X-N (mg/l)	0.2	8
Cl (mg/l)	410	330

Note: S5 is a sampling point at the outlet of the third treatment pond; S7 is the sampling point at the outlet of the grass plane test area (S5 effluent dosed to S7)

(after Thörneby *et al*., 2006)

Table 9.30 Influent and Effluent Concentrations for Metals at Moskogen Test Cell

Parameter	Influent Concentration (S5)	Effluent Concentration (S7)
K (mg/l)	100	90
Ca (mg/l)	190	60
Fe (mg/l)	2	0.2
Mn (mg/l)	0.7	0.1
Cr	3µg/l	<1µg/l
Ni	10µg/l	<9µg/l
Ba	180µg/l	<90µg/l

Note: S5 is a sampling point at the outlet of the third treatment pond; S7 is the sampling point at the outlet of the grass plane test area (S5 effluent dosed to S7)

(after Thörneby *et al*., 2006)

There were increases in effluent concentration for Zn, Cd, Pb, Cu, Al and Co.

Of particular interest in this study was the fact that 26 organic marker compounds (VOC, SVOC, PCB and PAH) were analysed along the various steps in the treatment system. 17 compounds had a removal efficiency of more than 17%, and four had removal efficiencies between 81% and 94% (Tables 9.31 and 9.32). Compounds in the phthalates group did not readily degrade through the system.

Table 9.31 Removal of Chosen Organic Marker Compounds (%) in the Moskogen Treatment System

Substances	Leachate	S3	S4	S5	S7
	ppb	%	%	%	%
2-Heptanol, 2-methyl	18.1	80.8	48.0	90.0	100
Benzoquinone, 2,6-ditertbutyl	0.51	34.5	90.6	82.3	22.1
Benzothiazole, 2-methylthio)-	0.41	100.0	100.0	100.0	100.0
Deca hydronaphtalene	0.05	78.6	60.1	44.7	85.1
Dibenzofuran	0.47	93.3	95.5	96.2	100.0
N,N-diethyl toluamide	3.0	98.3	98.4	96.8	99.6
Dihydroisopherone	3.0	98.3	99.5	99.6	100.0
Diphenylamine	0.22	100.0	100.0	100.0	100.0
Propyphenazone	0.13	26.1	71.2	87.6	100.0
Squalene	3.1	–450	–50	–750	–250
Tri-tertbutyl benzene	0.27	70.9	94.6	97.0	100.0
2,4,7,9-Tetramethyl-5-decyne-4,7-diol (TMDD)	4.6	–52.6	–1.7	21.2	88.4

Note: S3, S4, S5 are sampling points at the outlet of the first, second and third consecutive treatment pond, respectively, and S7 is the sampling point at the outlet of the grass plane test area (S5 effluent dosed to S7)

(after Thörneby *et al*., 2006)

Table 9.32 Removal of Chosen Organic Marker Group Compounds (%) in the Moskogen Treatment System

Substances		Leachate	S3	S4	S5	S7
	Number	ppb	%	%	%	%
Alkanes	15	66.3	37.8	79.0	66.7	89.9
Aromatics	35	38.8	98.9	99.2	98.8	99.5
Benzene-sulfonamides	3	0.95	96.2	96.6	96.2	99.9
Biphenyls	7	0.43	85.5	96.3	97.5	98.7
Chloro-benzenes	2	0.15	98.0	99.3	100.0	100.0
Ethers	12	83.7	46.1	50.7	69.5	99.0
Naphtalenes	10	2.14	98.2	98.4	98.2	98.8
Organic phosphates	11	31.7	95.3	97.9	97.8	98.8
PAHs	6	0.57	81.5	88.9	92.7	97.4
Phenols	6	410	96.7	84.8	98.2	99.2
Phthalates	11	13.4	18.6	47.1	28.1	41.7
Thiophenes	8	4.21	9.5	48.7	56.9	81.9
Terpenes	24	67.5	79.4	95.0	96.4	99.4
PCBs	29	0.02	51.5	81.8	81.8	93.9

(after Thörneby *et al*., 2006)

While the test cell only accounted for a relatively small percentage removal, the fact that these compounds are almost completely eliminated through the treatment sequence is promising for other similar studies.

Conclusion to Vegetated Plane Systems

Treatment units VP 1 and VP 2 in this project can be compared to the irrigation of leachate to vegetated planes (engineered and non-engineered) presented above. Each unit contained a stratified sand, grit and gravel (fining up) media planted with a variety of salt tolerant grasses.

The units were operated in sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 (August 2008 to October 2010) with VP 1 switched in May 2010 to sequence Cell 7 – Cell 8 – VP 1. These sequences from here on shall be called Sequence A and Sequence B. Each bed had a surface area of $25m^2$ and irrigation rates were $96L/m^2/day$ ($960m^3/ha/day$) for sequence A and $24L/m^2/day$ ($240m^3/ha/day$) for sequence B.

Allowing for irrigation for six months of the year, the application rates for this project are in the region of those stated by Tyrell *et al*. (2002) for plot 2(D) and plot 2(E) (70 and $75L/m^2/day$ respectively) as well as plot 6(D) and plot 6(E) (24 and $23L/m^2/day$ respectively).

The total average ammonium load removal for sequence A was $0.84g/m^2/day$ (75% removal) with VP 1 and VP 2 accounting for $0.49g/m^2/day$ (44% removal) and $0.34g/m^2/day$ (55% removal) load removal respectively.

The influent concentration to each unit was low at 12mg/l and 7mg/l NH_4 respectively.

The average ammonium load removal for VP 1 in sequence B was $0.19g/m^2/day$ (95% removal) with a low influent concentration of 8mg/l.

Average COD load removal for sequence A was $3.3g/m^2/day$ (19% removal) with VP 1 and VP 2 accounting for $4g/m^2/day$ and $-1g/m^2/day$ load removal respectively.

Average COD load removal in sequence B for VP 1 was $3g/m^2/day$ (50% removal) (influent concentration of 239mg/l).

Average BOD_5 load removal for sequence A was $0.23g/m^2/day$ (44% removal) ($0.19g/m^2/day$ in VP 1 and $0.04g/m^2/day$ in VP 2) and for sequence B was $0.11g/m^2/day$ (79% removal).

Chloride loading to VP 1 and VP 2 for sequence A was 34g/m^2/day and 30g/m^2/day respectively (influent Cl conc. 380mg/l and 312mg/l respectively). The cumulative load removal for VP 1 and VP 2 was 1.14g/m^2/day (4.5g/m^2/day removal in VP 1 and -3.4g/m^2/day in VP 2)

Load removal in sequence B (VP 1) was 0.4gCl/m^2/day (4% removal) (influent conc. of 259mg/l).

Average nitrate loading (TON) to sequence A was 86g/m^2/day and 77g/m^2/day for VP 1 and VP 2 respectively. VP 1 recorded an average TON load removal of 9g/m^2/day whereas VP 2 displayed an increase in TON load of 12g/m^2/day.

Sequence B loading to VP 1 was 30gTON/m^2/day. There was no change in effluent load.

The mass balance calculation for N (total inorganic N) for sequence A revealed an average increase of 0.07gN/unit/day in the final effluent at VP 2.

VP 1 recorded an average N load removal of 2.3g/m^2/day whereas VP 2 displayed an increase in N load of 2.4g/m^2/day.

Sequence B revealed a reduction in N of 0.1gN/m^2/day in VP 1 effluent.

A comparison of parameter loading to vegetated treatment planes for ammonium, TON, total N, COD, chloride and electrical conductivity data for this project with selected referenced literature is presented in Table 9.33.

While hydraulic loadings for Sequences A and B (this project) and Plots 2(E) and 6(E) of Tyrell *et al.* (2002) are similar, the parameter mass loadings to Plots 2(E) and 6(E) are well in excess of this project. The exception being total N loadings, where N loading to the plots of Tyrell *et al.* (2002) were approximately 30% higher than loading to sequence A and B. However, N load removal in Plots 2(E) and 6(E) (97% and 79% removal respectively) by far out performed treatment efficiency in Sequences A and B (-0.05% and 1% removal respectively).

Ammonium mass loadings for the trials undertaken by Harrington and Maris (1986) are similar to this project. The ammonium load removal efficiency for Sequence A and B (75% and 95% respectively) are slightly higher than that reported by Harrington and Maris (1986) (66% NH_4 load removal), albeit at very low loading rates.

Regarding metals removal, influent leachate concentrations are broadly in line with those presented by Tyrell *et al*. (2002). However, due to the low sampling number and in many cases the high standard deviation of results about the mean concentration, interpretation of metals data in this project was limited.

Consequently, phosphate (as P) is the only parameter where it can be definitively stated that a significant reduction (with a low standard deviation) in concentration from influent to final effluent across the vegetated plane sequences occurred (average concentration reduced from 143µg/l in VF2 (influent) to 89µg/l in VP 1 and 80µg/l in VP 2.

Treatment units VP 1 and VP 2 performed reasonably well overall as polishing units. The removal rates were not in the range of those mentioned by Thörneby *et al*. (2006) or Tyrell *et al.* (2002) however, it should be noted that the majority of pollutant removal (in particular NH_4, BOD_5, SS) occurred in the units preceding the vegetated planes.

Nitrate uptake could be enhanced in the VP units through execution of an appropriate programme of grass mowing and biomass off-take.

It is possible that the VP units could operate to a higher standard if they were irrigated for 5 hours and rested for 19 hours, however, this application cycle remains to be tested on sand based vegetated planes

Table 9.33 Parameter Loadings to Sequence A (VP 1 & VP 2) and Sequence B (VP 1) as Compared with Loadings to Vegetated Treatment Planes in Referenced Literature

	Sequence A	Sequence B	Harrington & Maris, 1986	Plot 2(E)	Plot 6(E)	Thörneby *et al*., 2006
HLR ($l/m^2/day$)	96	24	5	75	23	No data
Parameter NH_4						
	Sequence A	Sequence B	Harrington & Maris, 1986	Plot 2(E)	Plot 6(E)	Thörneby *et al*., 2006
Influent Conc. (mg/l)	12	8	70	514	514	60
Effluent Conc. (mg/l)	3	1	25			0.1
Influent Load ($g/m^2/day$)	1.12	0.2	0.35	38.55	11.82	
Effluent Load ($g/m^2/day$)	0.28	0.01	0.13			
Load Removal ($g/m^2/day$)	0.84	0.19	0.23			
Load Removal (%)	75	95	66			
Parameter Total N						
	Sequence A	Sequence B	Harrington & Maris, 1986	Plot 2(E)	Plot 6(E)	Thörneby *et al*., 2006
Influent Load (g/m2/day)	20.3	6.9	No data	33.37	10.23	70mg/l
Effluent Load (g/m2/day)	20.4	6.8		1.00	2.97	8mg/l
Load Removal (g/m2/day)	-0.1	0.1		32.37	7.27	
Load Removal (%)	-0.5	1		97	71	
Parameter COD						
	Sequence A	Sequence B	Harrington & Maris, 1986	Plot 2(E)	Plot 6(E)	Thörneby *et al*., 2006
Influent Conc. (mg/l)	184	239	400	1930	1930	No data
Effluent Conc. (mg/l)	145	118	60			
Influent Load ($g/m^2/day$)	17	6	2.00	144.75	44.39	
Effluent Load ($g/m^2/day$)	14	3	0.30			
Load Removal ($g/m^2/day$)	3	3	1.70			
Load Removal (%)	19	50	85			
Parameter Chloride						
	Sequence A	Sequence B	Harrington & Maris, 1986	Plot 2(E)	Plot 6(E)	Thörneby *et al*., 2006
Influent Cl Conc. (mg/l)	380	259	No data	3611	3611	410
Effluent Cl Conc. (mg/l)	347	249				330
Influent Load ($g/m^2/day$)	34	10.4		270.83	83.05	
Effluent Load ($g/m^2/day$)	33	10				
Load Removal ($g/m^2/day$)	1	0.4				
Load Removal (%)	3	4				

Note: Sequence A (VP 1 & VP 2) and Sequence B (VP 1), this project; Plot 2(E) and Plot 6(E) after Tyrell *et al*., 2002

Constructed Wetlands for Leachate Treatment

Constructed wetlands have been identified as promising technologies for the treatment of landfill leachate (Kadlec and Knight, 1996). They have a small ecological footprint, utilise "low-tech" technology, and have an aesthetic value similar to that of natural wetlands (Nivala *et al*., 2007).

There are two basic types, vertical flow (VF) and horizontal flow (HF) systems. Whilst the application of wetland technology for treating landfill leachate is still developing, there are a number of good examples where both HF and VF systems have been applied as primary, secondary or polishing systems for leachate treatment.

Vertical Flow Constructed Wetlands

Vertical flow systems are far less commonly used; but a number of studies have been cited in the literature.

In the same paper describing the operation of a willow treatment plane planted on a landfill in Slovenia (Justin *et al*., 2009), a combined constructed wetland provided pre-treatment to this system.

The constructed wetland system covers 1000m^2 and consists of six interconnected beds with a horizontal and vertical subsurface water flow, planted with *Phragmites australis*. The influent raw leachate was characterised by high concentrations of COD, N and salinity indicators. Concentrations of xenobiotic organic compounds (HVLS – Hardly volatile lipophilic substances, TH – Total hydrocarbons, BTX – Benzene–Toluene–Xylene, AOX – Adsorbable organically bound halogens, VHHC – Highly volatile halogenated hydrocarbons and POS – Polar organic solvents) were low as were heavy metals (<1mg/l) with the exception of Cr, B, Fe and Mn.

The hydraulic loading of the wetland system was high and variable (3,000-70,000mm/year). Considering the CW was used as a pre-treatment system, it performed particularly well, removing an average of 40% - 60% of major pollutants, e.g. removal rates for SS, COD. BOD_5, Cl, NH_4, P (total) were 83%, 41%, 65%, 17%, 41% and 38% respectively. High metal removal rates were recorded for Al (55%), Cr (33.1%), Cu (17.6), Zn (33%), Ti (31%), As (34%) and B (35%).

Most interesting of all was the removal of xenobiotic organic compounds, where removal rates for AOX (halogens), VHHC (volatile halogenated hydrocarbons) and phenols were 12.7%, 45% and 61.7% respectively (Table 9.34).

Overall, the constructed wetland proved highly efficient in terms of pollutant removal and provided significant effluent reduction for irrigation to the willow plant system.

Table 9.34 Constructed Wetland Influent and Effluent with Removal Efficiencies

		Inflow		Outflow		
Parameter	Unit	Average	(Range)	Average	(Range)	Removal (%)
T	°C	18.07	(12.3–25)	12.24	(0.7–24.9)	
pH		8.03	(7.2–9.73)	7.93	(7.5–8.21)	
SS	mg/L	180	(6–1 160)	29.5	(4–98)	83.7
EC	mS/cm	8.9	(1.4–16.2)	6.7	(1.3–11.8)	24.7
DOC	mg/L	429	(183–1 047)	293	(128–761)	31.7
COD	mg/L	1 508	(200–4 040)	890	(185–2 300)	40.9
BOD_5	mg/L	193	(34–490)	66	(13–280)	65.5
NO_2^-	mg/L	9.7	(<0.5–30)	9.6	(0.3–103)	
NO_3^-	mg/L	159	(<0.1–540)	136	(<0.1–485)	
CN^-	mg/L		(<0.1–<0.1)		(<0.1–<0.1)	
F^-	mg/L		(<0.1–<0.1)		(<0.1–<0.1)	
Cl^-	mg/L	961	(132–1 994)	795	(128–2 227)	17.3
Br^-	mg/L	2.6	(<0.1–5)	2.7	(1.1–7.8)	
SO_4^{2-}	mg/L	170	(<0.1–340)	155	(34–292)	8.6
S^{2-}	mg/L		(<0.1–0.25)		(<0.1–<0.1)	
SO_3^{2-}	mg/L		(<0.1–<0.1)		(<0.1–<0.1)	
HPO_4^{2-}	mg/L	5.8	(<0.5–11.9)	2.6	(<0.5–4.7)	55.7
NH_4^+	mg/L	327	(46–992)	190	(44–466)	41.9
total N	mg/L	398	(151–760)	256	(73.4–560)	35.5
Na^+	mg/L	595	(46–1 310)	476	(69–1 360)	20
K^+	mg/L	594	(44–1 594)	504	(66–1 634)	15.2
Mg^{2+}	mg/L	62	(5.3–124)	50.5	(8–126)	18.5
Ca^{2+}	mg/L	53.6	(2–157)	48.8	(2.5–147)	8.9
total P	mg/L	2.37	(0.44–6.8)	1.46	(0.44–6.8)	38.4
HVLS	mg/L	4.5	(2–7)	4.5	(4–5)	
TH	mg/L		(<0.1–<0.1)		(<0.1–<0.1)	
BTX	mg/L		(<0.05–<0.05)		(<0.05–<0.05)	
AOX	mg/L	0.58	(0.25–1.2)	0.51	(0.32–1.4)	12.7
VHHC	mg/L		(< 0.005–0.01)		(<0.005–0.01)	45
POS	mg/L		(<0.05–<0.05)		(<0.05–<0.05)	
Phenols	mg/L	0.05	(0.02–0.11)	0.02	(0.01–0.03)	61.7
ANS	mg/L	0.52	(0.45–0.59)	0.52	(0.46–0.57)	1
Pesticides	µg/L		(<0.05–<0.05)		(<0.05–<0.05)	

*T – Temperature, SS – Suspended Solids, EC – Electrical conductivity, DOC – Dissolved organic carbon, COD – Chemical oxygen demand, BOD_5 – Biochemical oxygen demand, HVLS – Hardly volatile lipophilic substances, TH – Total hydrocarbons, BTX – Benzene–Toluene–Xylene, AOX – Adsorbable organically bound halogens, VHHC – Highly volatile halogenated hydrocarbons, POS – Polar organic solvents, ANS – Anionic and non–ionic surfactants

(after Justin *et al.*, 2009)

Yalcuk *et al*. (2009) describes the operation of a pilot CW plant involving VF and HF systems using leachate from an open dumping area near Ankara, Turkey. The system involved the independent operation of two VF beds and one HF bed. Dimensions of the beds were 1000mm long, 500mm wide and 400mm deep. VF 1 was infilled with (top to bottom) 15cm of sand, 5cm of zeolite and 20cm of different grades of gravel. VF 2 was infilled with a 15cm layer of sand on top of 30cm of two different grades of gravel and the HF bed consisted of gravel (7–15mm). Each bed was planted with *Typha latifolia* at a density of 20 rhizomes per m^2.

It was anticipated that the addition of Zeolite (clinoptilolite) in VF 1 would improve removal mechanisms and provide sites for ion exchange, adsorption etc.

Each bed was fed intermittently at a rate of 10 litres/day (HRT was 11.8 days for the VF beds and 12.5 days for the HF bed) and effluent was not recirculated.

The mean influent leachate concentrations dosed to the system were as follows, NH_4 = 122mg/l, PO_4 = 2.87mg/l and COD = 211mg/l.

The study concentrated on NH_4, COD and P removal through the treatment sequence over the 123-day trial period. Maximum removal rates for COD were recorded in the last month of operation, 30% in VF1, 36% in VF2 and 61% in the HF bed.

Both vertical flow systems showed a significant amount of NH_4 removal of up to 71% on average, whereas maximum average NH_4 removal was 50% in the horizontal system. Maximum NH_4 removal occurred in July and August and thus exhibited a seasonal difference in removal efficiencies. Full ammonium removal was not accomplished at system end and average NH_4 effluent values for each unit were 46mg/l from VF 1, 62mg/l from VF 2 and 75mg/l from the HF bed. Interestingly, NO_3 effluent concentrations were low (3.4mg/l from VF 1, 2.6mg/l from VF 2 and 4.7mg/l from HF) suggesting nitrification and de-nitrification within the beds.

PO_4 removal was highly variable across the system, with reduction in VF 1 between 29% and 83%, VF 2 between 36% and 64% and HF between 26% and 61%. P removal increased with time during the operational period (maximum P removal in September) and then decreased again, which could be due to saturation of the sorption site.

Metals removal was mainly low (30% for Ni, Pb varied between 30% and 90%) and the final effluent showed higher concentrations of Cr and Zn. VF 1 containing zeolites removed marginally more metals than VF 2.

The system described by Yalcuk *et al*. (2009) displayed consistent removal capacities for the main wastewater parameters across each treatment unit and demonstrated the benefits and efficiencies of combined VF and HF reed bed systems.

In a laboratory experiment, Lavrova *et al*. (2010) described the operation of a vertical flow constructed wetland (VF-CW) reactor at different flow rates (40, 60 and 82 ml/min) and recirculation ratios (pumping time versus rest time (hours)) of 1:1, 1:2 and 1:3. The aim of this study was to evaluate the removal of organic matter (as COD and BOD_5), nutrients (nitrogen and phosphorus), metals and inorganic compounds.

The experimental set up consisted of a Plexiglass VF-CW, 123mm in diameter, 900mm in height filled with a 300mm base layer of 35–55mm round gravel with 500mm of 5-25mm gravel on top. The column was planted with *Phragmites australis* and operated continuously in a recirculation regime.

The characteristics of the leachate used in the trials are detailed in Table 9.35.

Table 9.35 Leachate Characteristics used in VF-CW Laboratory Trials

Parameter	Influent
COD, mg/l	2800
BOD_5, mg/l	204.2
Ammonia nitrogen (NH_4-N), mg/l	198.4
Nitrate nitrogen (NO_3-N), mg/l	1.9
Total phosphorus (TP), mg/l	5.5
pH	7.9
Salinity, ‰	2.5
Conductivity, $\mu S\ cm^{-1}$	4710
Total dissolved solids (TDS), mg/l	2460
Suspended solids (SS), mg/l	2720

(after Lavrova *et al*., 2010)

Results from the experimental set up showed BOD_5 and COD removal rates in excess of 90% when the reactor was operated continuously at the lower application rate (40ml/min) and at the pump to rest ratio of 1 hour to 3 hours.

Complete NH_4 removal was observed in the trials with a corresponding high NO_3 production. The concentration of NO_3 increased faster when the flow rate was lower thus the influence of the recirculation ratios was opposite. Little or no denitrification was observed throughout the experiment.

pH slightly decreased from 7.9 to 7.5, as did EC from 4.7 to 3.4 mS/cm. Ca, K and Na concentrations decreased by 21%, 31% and 8% respectively at the 40ml/minute application with the pump to rest ratio of 1:3.

The study indicated the importance of leachate application rate and rest periods when operating VF reed bed systems.

Conclusions to Vertical Flow Constructed Wetlands

Treatment units VF 1 and VF 2 in this project can be compared to the irrigation of leachate to vertical flow constructed wetlands presented above. Each unit contained a stratified sand, grit and gravel (fining up) media planted with *Phragmites* (VF 1) and *Typha* (VF 2).

The units were operated in separate sequences, Cell 10 - VF 1 – HF 1 and Cell 1 - VF 2 – HF 2 for phase 1 plant operations (November 2007 – March 2008).

In phases 3 and 4 plant operations they were operated in sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 (August to October 2010).

Each VF unit had a surface area of $25m^2$ and application rates to each VF unit were $96L/m^2/day$ during all phases.

Concentrating initially on dosing volumes, the application rates for this project are comparable to the midpoint HLR of Justin *et al*. (2009) (i.e. 100 $l/m^2/day$). The application volumes of Yalcuk *et al.* (2009) were approximately 20% of this project; whereas irrigation rates of Lavrova *et al*. (2010) were a multiple (up to 52 times) of this project.

Regarding treatment efficiency, VF 2 (planted with *Typha* this project) outperformed VF 1 during phase 2 operations, producing mean load reductions for NH_4, COD and SS of

17g/m^2/day (85% reduction), 1g/m^2/day (6% reduction) and 1.1g/m^2/day (69% reduction) respectively. The chloride load was reduced by 3g/m^2/day (10% reduction) whereas Fe and Mn removal was 0.16g/m^2/day (84% reduction) and -0.19g/m^2/day (-38% reduction) respectively. Effluent pH dropped from 7.5 to 6.9, most likely due to nitrification. Nitrate production was not recorded during phases 1 and 2 operations.

Phase 2 removal efficiencies for VF 2 are much lower when compared with those of Justin *et al*. (2009), with removal of 41%, 83% and 17% for COD, SS and Cl respectively. Metals removal was also higher in the study described by Justin *et al.* (2009), with removal rates of 33%, 18%, 32% and 35% recorded for Cr, Cu, Zn and B. The only parameter where VF 2 outperformed was NH_4; 41% removal versus 85% (this project). Interpretation of metal removal rates for VF 2 was limited due the low sampling number and high standard deviation of results.

Influent concentrations in the Slovenian study were also higher for most parameters.

There is, however, one caveat to the comparison of the two sets of results, as the data of Justin *et al.* (2009) only detail concentrations (inflow and outflow) and load removal at the final effluent from six interconnected VF and HF beds. A direct comparison of VF units between the studies is therefore not possible.

During phases 3 and 4 operations, VF 1 and VF 2 operated in sequence (VF 1 – VF 2) and results for all parameters were promising. Mean load removals for VF 1 and VF 2 were as follows; NH_4 8g/m^2/day (67% removal) and 3g/m^2/day (75% removal); COD 3g/m^2/day each (13% and 15% removal); SS 0.5g/m^2/day (36% removal) and 0.1g/m^2/day (13% removal); Cl no change in VF 1 and 2g/m^2/day in VF 2 (6% removal); Fe 0.07g/m^2/day (35% removal) and 0.04g/m^2/day (40% removal); Mn 0.02g/m^2/day (7% removal) and 0.03g/m^2/day (12% removal). Nitrate loads increased by 30g/m^2/day (58%) and 4g/m^2/day (5%) for VF 1 and VF 2 respectively. Results for total N (inorganic N) revealed a load increase in VF 1 of 1.9g/m^2/day and a slight reduction of 1.2g/m^2/day in VF 2.

The figures are slightly lower compared to phase 2, however VF 1 and VF 2 were operating as the 3rd and 4th treatment units in a sequence during phases 3 and 4

operations, and for many wastewater parameters (NH_4, COD, SS etc.), the majority of load removal took place in the primary and secondary treatment units.
Metals removal was variable at VF 2 effluent, albeit at very low influent concentrations.
Removal rates for metals / salts (with the exception of P) could not calculated with confidence due to the low sampling number and high standard deviation of the results.

Comparing phases 3 and 4 results to the other referenced material; removal rates from Yalcuk *et al.* (2009) for NH_4 and COD are lower than VF 1 and VF 2 (this project) (to avoid confusion VF units of Yalcuk *et al*. (2009) shall be referred to as YVF 1 and YVF 2). While influent concentrations to each system were similar, the irrigation rates to YVF 1 and YVF 2 were almost 80% lower than this project.
An interesting feature of the results presented by Yalcuk *et al*. (2009) is the low nitrate concentrations in YVF 1 and YVF 2 effluents (mean conc. of 3.4mg/l and 2.6mg/l) which suggests that a considerable level of denitrification occurred in these units. The fact that the YVF units remained water laden below the surface with a hydraulic retention time of 11 and 8 days respectively for YVF 1 and YVF 2, (as opposed to VF 1 and VF 2, which fully drained after each dosing episode) may have created the conditions for denitrifying bacteria at depth.

The results presented in the study by Lavrova *et al*. (2010) by far out-perform results in the literature mentioned previously and in this study. The results are impressive given that the equivalent irrigation rates in the different sequences (2.4 l/hr, 3.6 l/hr and 4.92 l/hr at 1:1, 1:2 and 1:3 dose:rest period) were a multiple of this project (13 – 52 times) when converted to $l/m^2/day$.
However, it should be noted that the study by Lavrova *et al*. (2010) was a laboratory scale column test where conditions can be controlled (temperature, light, humidity etc.) and the experiment was operated on a continuous circulation mode over 10 days.

The overall operation of the VF beds in this study performed moderately well when assessed against similar studies. An exact comparison with other studies is difficult due to the diversity in operating conditions and the dearth of data for vertical flow constructed

wetlands; however, it is felt that results from VF 1 and VF 2 were within acceptable limits.

A comparison of parameter concentrations and loadings to the VF reed beds for ammonium, total N, COD, chloride and electrical conductivity data during phases 3 and 4 operations for this project with selected referenced literature is presented in Table 9.36.

It would be interesting to assess the operation of the VF units in this study at longer application to rest periods to gauge the potential for increased treatment efficiencies.

Consideration should also be given to operating the units in continuous recirculation mode.

Although VF 2 (containing *Typha*) marginally outperformed VF 1 (containing *Phragmites*) in phase 2 operations (phases 3 and 4 differences were not directly comparable as the units operated in sequence), experience in this study has shown that *Typha* is prone to invasive species and excessive weed growth in VF reed beds. Therefore, it is recommended that *Phragmites* is considered as a first choice reed species when planning vertical flow reed beds/constructed wetlands as this species is easier to manage overall, and from a practical point of view requires much less labour to carry out weed clearance activities.

Table 9.36 Selected Parameter Loadings to VF 1 and VF 2 as Compared with Loadings to Vertical Flow Reed Beds in Referenced Literature

	VF 1	VF 2	JVF	YVF 1	YVF 2	LVF 1:1	LVF 1:2	LVF 1:3
HLR (l/m^2/day)	90	90	100	20	20	2436	1624	1218
Parameter NH_4	**VF 1**	**VF 2**	**JVF**	**YVF 1**	**YVF 2**	**LVF 1:1**	**LVF 1:2**	**LVF 1:3**
Influent Conc. (mg/l)	132	42	327	122	122	198	198	198
Effluent Conc. (mg/l)	42	12	190	46	62			
Influent Load (g/m^2/day)	12	4	32.70	2.44	2.44	482	322	241
Effluent Load (g/m^2/day)	4	1	19.00	0.92	1.24			
Load Removal	8	3	13.70	1.52	1.20			
Load Removal (%)	67	75	41.9	62.3	49.2			
Parameter Total N	**VF 1**	**VF 2**	**JVF**	**YVF 1**	**YVF 2**	**LVF 1:1**	**LVF 1:2**	**LVF 1:3**
Influent Conc. (mg/l)			398	No Data	No Data	154	154	154
Effluent Conc. (mg/l)			256					
Influent Load (g/m^2/day)	21.1	21.5	39.80			376	251	188
Effluent Load (g/m^2/day)	21.5	20.3	25.60					
Load Removal	-0.4	1.2	14.20					
Load Removal (%)	-1.9	5.6	35.7					
Parameter COD	**VF 1**	**VF 2**	**JVF**	**YVF 1**	**YVF 2**	**LVF 1:1**	**LVF 1:2**	**LVF 1:3**
Influent Conc. (mg/l)	244	212	1508	211	211	2800	2800	2800
Effluent Conc. (mg/l)	212	184	890	148	135			
Influent Load (g/m^2/day)	23	20	150.80	4.22	4.22	6,821	4,547	3,410
Effluent Load (g/m^2/day)	20	17	89.00	2.95	2.70			
Load Removal	3.00	3.00	61.80	1.27	1.52			
Load Removal (%)	13	15	41.0	30	36			
Parameter Chloride	**VF 1**	**VF 2**	**JVF**	**YVF 1**	**YVF 2**	**LVF 1:1**	**LVF 1:2**	**LVF 1:3**
Influent Cl Conc. (mg/l)	396	397	961	No Data	No Data	No Data	No Data	No Data
Effluent Cl Conc. (mg/l)	397	380	795					
Influent Load (g/m^2/day)	36	36	96.10					
Effluent Load (g/m^2/day)	36	34	79.50					
Load Removal	0.00	2.00	16.60					
Load Removal (%)	0	6	17.3					
Parameter EC	**VF 1**	**VF 2**	**JVF**	**YVF 1**	**YVF 2**	**LVF 1:1**	**LVF 1:2**	**LVF 1:3**
Influent EC (mS/cm)	No Data	No Data	8.9	No Data	No Data	4.71	4.71	4.71
Influent EC (mS/cm)			6.7					
EC Reduction			2.20					
Removal (%)			24.7					

Key

VF 1 and VF 2, Phases 3 & 4, this project

JVF, Midpoint HLR 100L/m^2/day, calculated from Justin *et al*., 2009

YVF 1 and YVF 2, calculated fromYalcuk *et al.*, 2009

LVF 1:1 = 40ml/min flow rate at rest to irrigation ratio 1:1

LVF 1:2 = 40ml/min flow rate at rest to irrigation ratio 1:2 } (calculated from Lavrova *et al*., 2010)

LVF 1:3 = 40ml/min flow rate at rest to irrigation ratio 1:3

Blank cells = no data

Horizontal Flow Constructed Wetlands

There are two general types Horizontal Flow Constructed Wetlands, Surface Flow (SF) and Sub-Surface Flow (SSF) systems.

Surface Flow (SF) systems consist of shallow basins in soil or any other media that will support plant roots. A SF CW generally has a soil base, emergent vegetation, and a column of free-standing water exposed to the atmosphere. The wastewater moves through the system above the substrate at low velocities in a quiescent manner.

Sub-Surface Flow (SSF) systems are essentially horizontal trickling filters containing emergent vegetation set in a media of crushed rock or sand and gravel. The water line is usually set at or just below the media level.

HF systems are more widely used for wastewater treatment than VF systems and are ideal for passive treatment, especially in remote areas where sites may be abandoned, unoccupied and without power.

Five examples are presented below where landfill leachate has been treated using horizontal flow systems; two examples are from pilot plants, two from active sites and one from a closed landfill site.

Nivala *et al.* (2007) describe the construction and operation of a pilot-scale subsurface-flow constructed wetland at the Jones County Municipal Landfill, Anamosa, Iowa (USA) to demonstrate the use of constructed wetlands as a viable low-cost treatment option for leachate generated at small, rural landfills.

The treatment wetland consisted of a lined cell, 15.5m long by 6m wide, planted with 100 potted stiff goldenrod (*Solidago rigada*) set in a media of 150mm composted yard waste above 300mm of pea gravel. Leachate was applied using a submersible pump, at a rate of 4mm/day (approximately $0.4m^3$/cell/day).

The bed was actively aerated using a lattice of perforated pipes placed on the liner base prior to infill with gravel and compost. However, the original aeration was replaced 18 months into the operation of the pilot plant due to problems with clogging of media and aeration lines. The revamped aeration system included a pre-treatment aeration chamber for the removal of solids and precipitation of excess dissolved iron. The original aeration lines in the CW were also replaced. This caused considerable disruption to the stiff

goldenrod and encouraged the establishment of invasive species such as curly dock (*Rumex crispus*), bull thistle (*Cirsium vulgare*), stinging nettle (*Urtica dioica*), willow (*Salix sp.*), cannabis (*Cannabis sativa*) and cattail (*Typha latifolia*).

The leachate was characterised by high concentrations of COD (781mg/l) and moderate – low concentrations of ammonium (212mg/l), TSS (186mg/l), BOD_5 (116mg/l), nitrate (2mg/l) and iron (21mg/l).

Two sets of results were presented in the paper relating to periods of bed aeration and non-aeration (see Tables 9.37 and 9.38). Non-aerated bed results reveal BOD_5 removal efficiency between 75% and 81%, COD removal of zero to 53%, NH_4 removal of 14% to 43% and effluent concentrations for nitrate were below detection limits. Effluent pH ranged from 7.4 to 7.9.

Table 9.37 Mean Effluent Concentrations from CW during the period of no aeration at Jones County Landfill

No Aeration	Winter	Spring	Summer	Fall
	Jan–Mar	Apr–Jun	Jul–Sep	Oct–Dec
Q (m^3/d)	0.14	0.17	0.29	0.18
T_{air} (°C)	−0.8	15.1	21.4	7.3
T_{water} (°C)	1.7	12.0	19.6	10.1
$BOD_{5\ in}$ (mg/L)	308	171	85	89
$BOD_{5\ out}$ (mg/L)	59	36	21	22
BOD Efficiency	*81%*	*79%*	*76%*	*75%*
COD_{in} (mg/L)	1108	626	525	606
COD_{out} (mg/L)	525	674	513	525
COD Efficiency	*53%*	*0%*	*2%*	*13%*
NH_4–N_{in} (mg/L)	176	93	139	173
NH_4–N_{in} (mg/L)	105	80	80	118
NH_4–N Efficiency	*40%*	*14%*	*43%*	*32%*
NO_3–N_{in} (mg/L)	0.4	0.4	0.1	0.0
NO_3–N_{out} (mg/L)	0.0	0.0	0.0	0.0
pH_{in}	–	7.9	7.8	7.8
pH_{out}	–	7.9	7.8	7.4

(after Nivala *et al.*, 2007)

Results during aeration of the bed revealed BOD_5 removal efficiency between 88% and 97%, COD removal of 35% to 60%, NH_4 removal of 93% to 98% and effluent concentrations for nitrate ranged from 21-75mg/l. Effluent pH ranged from 7.7 to 7.9.

The results reveal that aeration greatly improved the efficiency of the system with the exception of COD where a significant portion was not readily biodegradable and simply passed through the system (mean effluent COD was 395mg/l).

Table 9.38 Mean Effluent Concentrations from CW during the period of aeration at Jones County Landfill

Aeration	Winter	Spring	Summer	Fall
	Jan–Mar	Apr–Jun	Jul–Sep	Oct–Dec
Q (m^3/d)	0.27	0.20	0.43	0.53
T_{air} (°C)	−2.0	13.6	20.9	5.6
T_{water} (°C)	1.8	11.5	19.5	10.0
$BOD_{5\ in}$ (mg/L)	97	110	177	41
$BOD_{5\ out}$ (mg/L)	12	5.0	5.5	4.7
BOD Efficiency	*88%*	*95%*	*97%*	*89%*
COD_{in} (mg/L)	734	773	873	628
COD_{out} (mg/L)	414	406	350	409
COD Efficiency	*44%*	*48%*	*60%*	*35%*
NH_4–N_{in} (mg/L)	195	175	253	190
NH_4–N_{in} (mg/L)	14	6.8	4.3	13
NH_4–N Efficiency	*93%*	*96%*	*98%*	*93%*
NO_3–N_{in} (mg/L)	6.9	13.7	0.3	2.3
NO_3–N_{out} (mg/L)	75	50	21	51
pH_{in}	8.0	8.0	7.8	8.2
pH_{out}	7.7	7.7	7.7	7.9

(after Nivala *et al.*, 2007)

Removal efficiencies during periods of no aeration were inconsistent and poor for BOD_5, COD, and NH_4.

Notable NO_3 formation was only observed when the wetland system was aerated, however this was overcome by applying a cyclic aeration scheme (12 h on/12 h off) and almost total nitrogen removal was established by the third season of operation.

In a microcosm test involving vetiver grass, Lin *et al.* (2003) describe the operation of a pilot scale constructed wetland to treat landfill leachate from Likeng landfill site near Guangzhou, China.

Vetiver grass (*Vetiveria zizanioides*) is commonly used for prevention of soil erosion in many countries around the world; however, it has more recently been used to treat wastewater effluents from a variety of sources.

In the study described by Lin *et al*. (2003), vetiver grass was planted in a mixture of seven different media types in small-scale constructed wetlands measuring 0.46m long x 0.30m wide x 0.32m deep.

The experimental design and media utilised in the pilot scale plant is outlined in Table 9.39.

Table 9.39 Experimental Design and Substrate of CW planted with Vetiver Grass

Treatment	Substrates	Plant
Batch 1	50%coal refuse +50% sawdust	vetiver
Batch 2	50%fly ash+50% sawdust	vetiver
Batch 3	50%cinder+ 50%sawdust	vetiver
Batch 4	50%soil+ 50%sawdust	vetiver
Batch 5	50%gravel + 50% sawdust	vetiver
Batch 6	80%gravel + 20% sawdust	vetiver
Batch 7	100% gravel	vetiver
Batch 8	100% gravel	without plant

(after Lin *et al.*, 2003)

Batches 1-5 were set up to test the pollutant removal performance of five different substrates and batches 5 and 7 were established to test the effect of nitrate removal efficiency with the addition of carbon.

Landfill leachate (with mean COD conc. 1291mg/l, mean NH_4 conc. 383mg/l) was fed into the wetland system daily for 35 days with a HRT of 5 days. Following on from this, landfill leachate (with mean COD conc. 1465 mg/l, mean NH_4 conc. 711mg/l) was added to the system (daily) at a HRT of 10 days for a period of 40 days.

The characteristics of the applied leachate at HRT 5 and 10 days respectively are outlined in Table 9.40.

Table 9.40 Leachate Characteristics applied to Vetiver Grass CW Batch Plant

HRT		pH	EC mS cm^{-1}	mg L^{-1}						
				COD	TKN	NH_4^+-N	NO_3^--N	TP	TSP	TSS
5 days	Min. value	6.64	6.53	841	91	26	6.6	1.95	0.88	527
	Max. value	8.71	8.70	1553	619	561	76	4.50	2.05	2313
	Mean value	7.43	8.01	1291	433	383	28	3.55	1.17	1164
10days	Min. value	6.42	7.40	1271	572	544	31	2.03	0.16	250
	Max. value	8.57	10.00	1668	910	851	90	4.38	1.22	1383
	Mean value	7.49	8.82	1465	752	711	56	2.85	0.66	788

(after Lin *et al.*, 2003)

The following parameters were determined for influent and effluent; pH, electrical conductibility (EC), COD, TKN, ammonium, nitrate, total phosphorus, total soluble phosphorus (TSP) and total suspended solids (TSS).

Selected results from the pilot CW plant for pollutant removal efficiencies in the different substrates at varying HRTs are detailed in Tables 9.41 and 9.42.

Table 9.41 Selected Results for Pollutant Removal Efficiencies from Pilot CW Plant

Items		COD RE(%)	NH_4^+-N RE(%)	TKN RE(%)	NO_3^--N RE(%)	TP RE(%)	TSP RE(%)	TSS RE(%)
HRT =5d	Batch 1	70.40a ±1.07	74.06a ±0.55	72.91a ±3.59	77.21a ±9.16	90.47a ±0.43	91.62a ±1.08	66.29a ±2.55
	Batch 2	45.86c ±1.04	46.50d ±1.11	48.87d ±0.59	-6.89c ±17.91	51.18cd ±2.51	44.37b ±3.55	39.92b ±6.13
	Batch 3	73.37a ±1.34	63.37b ±0.10	64.34b ±3.14	80.27a ±2.67	75.43ab ±1.33	47.36b ±5.90	63.90a ±7.35
	Batch 4	60.88b ±0.58	61.27bc ±1.39	59.89bc ±1.41	68.57ab ±7.09	45.07d ±12.24	14.17c ±12.10	60.08a ±0.51
	Batch 5	64.34b ±1.39	57.65c ±1.81	57.97c ±1.87	63.20b ±2.57	74.73bc ±1.36	35.39b ±6.87	57.96a ±6.27
HRT =10d	Batch 1	52.16c ±0.31	68.13a ±1.41	65.00a ±0.98	84.82a ±4.64	81.62a ±2.37	26.44a ±8.54	44.02b ±9.46
	Batch 2	32.95d ±1.70	47.07b ±1.87	46.47b ±1.15	42.09b ±7.10	41.72c ±4.04	-5.00a ±3.78	9.87c ±7.86
	Batch 3	65.76a ±5.19	69.24a ±4.05	66.97a ±3.24	93.65a ±1.95	43.62bc ±8.01	-308.46b ±42.33	59.62a ±3.90
	Batch 4	50.62c ±1.09	68.50a ±1.96	65.49a ±1.17	83.37a ±0.73	-127.32d ±50.54	-1713.77c ±310.24	44.81b ±8.22
	Batch 5	59.78b ±0.63	67.35a ±2.76	64.31a ±1.57	91.40a ±2.46	39.92c ±3.78	-280.90db ±52.49	46.27ab ±2.50

Note: Mean±sd(n=3), Treatments with different letters are significantly different (P<0.05), same letters are not significantly different (P>0.05), according to LSD test, RE: Removal Efficiency

(after Lin *et al.*, 2003)

Table 9.42 Selected Results for Pollutant Removal Efficiencies in Control (Batch 8) and Batch 7 (Gravel Substrate) in Pilot CW Plant

Items		COD RE (%)	NH_4^+-N RE (%)	TKN RE (%)	NO_3^--N RE (%)	TP RE (%)	TSP RE (%)	TSS RE (%)
HRT= 5 days	Batch 7	68.43* ±1.03	66.81** ±1.17	70.26** ±1.76	32.98** ±11.67	82.29** ±0.44	55.34* ±3.63	69.10 ±4.30
	Batch 8	59.34* ±1.86	53.88** ±0.76	54.54** ±1.30	-71.82** ±30.06	64.85** ±1.02	-1.68* ±5.23	67.49 ±2.24
	Balance	9.09	12.93	15.72	104.8	17.44	57.02	1.61
HRT = 10 days	Batch 7	46.17 ±7.58	61.80 ±5.06	62.33 ±4.67	38.13 ±5.39	63.12 ±2.71	-51.86 ±32.60	35.58 ±5.02
	Batch 8	48.43 ±4.21	61.36 ±2.69	62.24 ±3.48	22.25 ±1.20	58.12 ±5.56	-59.78 ±24.58	29.88 ±4.63
	Balance	-2.26	0.44	0.09	15.88	5.00	7.92	5.70

Note: Mean±sd (n=3); * significant (P<0.05), ** greatly significant (P<0.01), all tested by ANOVA; RE: Removal Efficiency

(after Lin *et al.*, 2003)

Results revealed that different substrates had different effects on the removal efficiency of pollutants. The cinder substrate treatment (Batch 3) showed the best performance in removing COD, NO_3 and TSS (73%, 80% and 75% removal respectively, at a HRT of 5 days; and 66%, 94% and 60% removal respectively, at a HRT of 10 days). It also performed well in removing NH_4, TP and TSP (63%, 75% and 47% removal at a HRT of 5 days; and 69%, 44% and -309% (an exception) removal at a HRT of 10 days).

The coal refuse treatment (Batch 1) performed best in removing NH_4, TP and TSP (74%, 90% and 92% removal at a HRT of 5 days), and achieved removal efficiencies for COD, NO_3 and TSS of 70%, 77% and 66% at a HRT of 5 days.

The fly ash treatment (Batch 2) and the soil-based batch (Batch 4) performed poorly whereas the gravel medium was about average in terms of treatment efficiency.

Vetiver grass functioning and growth was hindered at the higher NH_4 and COD (711mg/l and 1464mg/l) concentrations whereas its capacity for pollutant removal at the lower NH4 and COD concentrations (383mg/l and 1291mg/l) remained high.

In conclusion, Lin *et al.* (2003) demonstrated that a vetiver grass constructed wetlands have great potential in treating highly concentrated landfill leachate and that the coal/sawdust and cinder/sawdust substrate outperformed typical gravel based HF systems

It was also established that ammonium concentrations above 383mg/l caused phytotoxic shock and stress to the plants. The addition of sawdust to the substrate greatly enhanced nitrate removal from the wastewater.

The construction and operation of a demonstration-scale treatment wetland for treating landfill leachate at NQSWF landfill near the city of Rochester, New York (USA) is described by Eckhardt *et al*. (1999).

The HF system consists of two parallel sets of lined beds split into two components, a surface flow (SF) pre-treatment wetland followed by a sub-surface flow gravel and reed wetland. The dimensions of the beds were; SF 18m x 3.5m x 0.3m (length, width, depth) (area 63m^2); SSF 17.1m x 6.1m x 0.6m (area 104m^2). The SF beds were planted with *Phragmites australis* in 150mm soil substrate (although they were invaded by *Typha latifolia* shortly after establishment) and the SSF beds were also planted with *Phragmites australis* in 600mm pea gravel substrate. To enable further explanation of the operation of this particular system, only one of the parallel systems shall be described from this point forward.

The flow to the SF bed was 600 litres per day (effluent from SF drained to SSF) and the HRT was 32 days (SF) and 42 days (SSF) respectively (SF HLR = 9.5L/m^2/day; SSF HLR = 5.8L/m^2/day).

The median leachate influent and effluent concentrations for the system over the 410-day monitoring period are set out in Table 9.43.

Table 9.43 Median Leachate Concentrations for Inflow and Effluent from SF and SSF CW at NQSWF Landfill Site, Rochester, New York

Parameter	**Inflow**	**SF Outflow**	**SSF Outflow**
Ammonium (mg/l)	296	171	23
NH4 as (N) (mg/l)	230	133	18
TON (as N) (mg/l)	<0.05	<0.05	<0.05
EC (mS/cm)	4.74	3.9	0.97
Cl (mg/l)	490	510	160
Total P (mg/l)	1.9	1.5	0.18
BOD_5 (mg/l)	70	27	10
TOC (mg/l)	160	120	33
Ca (Total) (mg/l)	180	70	77
Mg (mg/l)	160	150	50
K (mg/l)	269	196	64
Na (mg/l)	410	430	130
Cd (µg/l)	<1	<1	<1
Cr (µg/l)	13	9	<5
Cu (µg/l)	30	<10	<10
Fe (mg/l)	51	15	1.3
Pb (µg/l)	13	<5	<5
Ni (µg/l)	65	60	30
Zn (µg/l)	227	80	25
Phenol (mg/l)	56	19	3
Benzene (µg/l)	5.5	0.6	<0.5
Toluene (µg/l)	22	1.3	<0.5
Xylene (µg/l)	45	2	1

(after Eckhardt *et al*., 1999)

Data from the field study demonstrated load reductions for selected constituents ranged between 40–100%. The highest removal efficiencies recorded in the final effluent were for metals, TP, phenol, VOCs, BOD_5 and ammonium (as N), all of which exceeded 90% removal. Removal was slightly lower for Mg, Ca, Na and Cl at 80%.

Reductions in concentrations differed between the SF and SSF beds. Effluent concentrations in SF and SSF for EC, ammonium, BOD_5, Cl, Na and K were 3.9 and 0.968 mS/cm (EC), 133 and 18mg/l (NH_4), 27 and 10mg/l (BOD_5), 510 and 160mg/l (Cl),

430 and 130mg/l (Na) and 169 and 64mg/l (K). There was very little change in effluent concentrations for nitrate and when detected remained below 10mg/l.

Metals removal for SF and SSF were recorded as; 61% and -10% for Ca, 6% and 33% for Mg, 30% and 45% for Cr, 66% and no change for Cu, 70% and 91% for Fe, 62% and no change for Pb, 8% and 50% for Ni and 65% and 69% for Zn. There was no change in effluent concentrations for Cd.

Phenols and VOCs (toluene, xylene, ethlybenzene and benzene) were all reduced by over 90% in the final effluent.

The majority of parameter removal occurred in SSF (except for BOD_5 and Ca), which proved highly efficient in pollutant load removal. The low nitrate concentration in the wastewater stream indicated simultaneous nitrification and denitrification/N uptake in biomass was occurring across the system.

Total load reductions (over the 410 days of operation) for selected parameters in the combined SF – SSF CW are detailed in Table 9.44.

Table 9.44 Total Load Reductions for Selected Parameters in the SF – SSF CW at NQSWF Landfill Site, Rochester, New York

Parameter	**Inflow**	**SSF Outflow**	**% Reduction**
Ammonium (kg)	68	6	88
NH4 as (N) (kg)	53	4.8	91
TON (as N) (kg)	0.035	0.216	
Cl (kg)	125	28	78
Total P (kg)	5.9	0.042	99
BOD_5 (kg)	51	2.4	95

(after Eckhardt *et al*., 1999)

Final effluent from the wetlands complied with New York State discharge limits with the exception of ammonium, phenol, magnesium, nickel, sodium and iron. These parameters (with the exception of phenol) were only marginally above discharge consent limits and it is likely that with some minor adjustments to the system; e.g. increase in HRT, pre-aeration and biomass harvesting, the effluent could meet the required standard.

A full-scale hybrid wetland system for leachate treatment at Perdido Landfill near Pensacola, Florida (USA) is described by DeBusk (1999). The system consists of a primary treatment pond (L1), a series of ten surface flow wetlands (W1 – W10) and a final detention pond for treated leachate (SF). The wetland cells each measure 91m x 11m (410mm deep) and were planted with a variety of emergent macrophytes. The species contained in the cells were as follows; W1, W2 and W3 contained *Typha* and *Juncus effusus* (soft rush), W4 and W5 contained *Juncus effusus* and *Phragmites australis* and W6 to W10 contained *Zizania aquatica* (wild rice), *Scirpus sp.* (rush), *Pontederia cordata* (pickerelweed), *Hydrocotyle umbellata* (pennywort), *Sagittaria lancifolia* (duck potato), *Sagittaria latifolia* (common arrowhead) *and Iris virginica* (blue flag iris).

The L1 pond was actively aerated and contained *Eichhornia crassipes* (water hyacinth). Leachate was pumped from L1 and flowed by gravity to the outlet at SF. The HRT for the wetland system (W1 – W10) was 9.3 days, approximately 1 day per cell (HLR of 473L/m^2/day).

The leachate at the landfill site was characterised by high levels of dissolved and suspended solids (3414mg/l), high concentrations of iron (460 mg/l) and high and often variable concentrations of analytes (EC 6.44mS/cm). The other main parameter concentrations were in the moderate range for landfill sites (see Table 9.45).

Table 9.45 Mean Leachate Concentrations for Selected Parameters at Perdido Landfill Site, Pensacola, Florida

Parameter	**Mean Concentration (mg/l)**
Ammonia	398
TON	0.15
TKN	460
BOD_5	209
EC (mS/cm)	6.64
pH (pH units)	7.02
Total P	2.1
Fe	294
Mn	1.81
Cd (µg/l)	17

Note: All data in mg/l unless indicated otherwise

(after DeBusk, 1999)

Analysis of the results revealed significant load removal and reduction for all measured parameters across the system. The majority of pollutant removal occurred in L1 (aerated pond) prior to dosing to the wetland cells (W1 – W10).

The system removed pollutants to such a level that discharge limits for groundwater recharge were achieved. A summary of the influent and effluent concentrations and loadings for the aerated pond – wetland system is outlined in Tables 9.46 and 9.47.

Table 9.46 Influent and Effluent Concentrations for the Aerated Pond and Wetland System at Perdido Landfill Site

	Parameter Concentration (mg/l)						
Unit	BOD_5	NH_4	NO_3	TKN	Fe	Mn	Cl
L0	209	398	0.1	460	294	1.74	958
L1	37	4.5	8.9	12.4	8.2	0.18	210
S1	16	2.4	9.5	8.6	2.8	0.16	175
W1	11	2.5	7.2	7.8	1.2	0.09	184
W3	10	1.5	5	5.8	1.1	0.1	N.D.
W5	17	1.3	2.1	4.9	0.7	0.11	170
W7	8	1.2	1.8	4.4	1.4	0.14	N.D.
W9	8	0.8	0.8	4.1	1.6	0.10	146
SF	8	0.3	4	4.3	0.8	0.08	140
System Removal (%)	96	99.9		99	99.7	95	85

Key
L0 = Leachate Source (influent)
L1 = Primary Treatment Pond
W1 – W9 = Wetland Cells
SF = Wetland Outflow Detention Pond
N.D. Not Detected

(after DeBusk, 1999)

Table 9.47 Influent and Effluent Loadings for the Wetland System at Perdido Landfill Site

	Parameter Loading ($g/m^2/day$)						
Unit	BOD_5	NH_4	NO_3	TKN	Fe	Mn	Cl
Influent	7.57	1.14	4.49	4.07	1.32	0.08	82.78
W1	5.20	1.18	3.41	3.69	0.57	0.04	87.03
W3	4.73	0.71	2.37	2.74	0.52	0.05	0.00
W5	8.04	0.61	0.99	2.32	0.33	0.05	80.41
W7	3.78	0.57	0.85	2.08	0.66	0.07	0.00
W9	3.78	0.38	0.38	1.94	0.76	0.05	69.06
Final Effluent	3.78	0.14	1.89	2.03	0.38	0.04	66.22

HLR = $473 L/m^2/day$

(calculated from DeBusk, 1999)

However, a problem in the treatment system occurred early on during plant operations, when the water hyacinths in L1 were lost due to cold weather. This resulted in a sharp decline in denitrification in L1 and caused a rise in nitrate concentration in the influent to the wetlands. Whilst denitrification was achieved within the wetlands, nitrate concentrations in the final effluent occasionally exceeded 20mg/l.
Overall, the treatment system described, supports the use of constructed wetlands for full-scale leachate treatment operations and stresses the importance of a primary facultative pond (particularly actively aerated ponds) for pre-treatment prior to discharge to SF beds.

In the final paper discussed under horizontal flow reed beds, Robinson *et al*. (1999) describes the planning, construction and operation of a gravel-based, lined surface flow wetland to treat leachate from an old disused landfill site that was causing minor but persistent pollution of a nearby stream. The site in question was Monument Hill Landfill Site in Wiltshire (UK) and the SF reed bed was sized at 1800m^2 (600mm deep) to cater for a through flow of 180 to 220m^3 per day of groundwater-diluted leachate (HLR of 100 to 122 l/m^2/day). The reed bed was planted with 20,000, 9cm pot grown *Phragmites australis* plants, and leachate was discharged to the system via a baffled settlement tank at the front end to encourage iron settlement.

The characteristics of the dilute leachate prior to discharge to the reed bed was as follows; pH 6.9, BOD_5 <2mg/l, NH_4 19.6mg/l, iron 12.2mg/l, SS 42mg/l, Cl 77mg/l and mecoprop 10.5µg/l. Reed bed operations commenced in July 1996 and the effect on effluent concentrations was significant and consistent, with NH_4 reduced by up to 50%, to 11.8mg/l, mecoprop concentrations dropped to 2.7µg/l, BOD_5 remained below 2mg/l, iron reduced to <0.6mg/l and SS to 3mg/l. Chloride remained constant throughout.
Results from analysis of samples taken from different locations at Monument Hill, in September 1996 are presented in Table 9.48. Calculated loadings to the system are presented in Table 9.49.

Table 9.48 Selected Parameter Concentrations from different locations at Monument Hill

Determinand	New Culvert	Old Culvert	After Settling Tank	Reed Bed Effluent	Agreed Downstream Sampling Point
pH value	8.0	6.8	6.9	7.4	7.6
BOD_5	<2	<2	<2	<2	<2
ammoniacal-N	<0.3	19.4	19.6	11.8	1.8
iron	<0.6	16.9	12.2	<0.6	0.7
suspended solids	19	42	42	3	16
chloride	23	78	77	76	32
mecoprop µg/l	<0.1	9.4	10.5	2.68	0.44

Note: All results in mg/l, except mecoprop in µg/l, and pH value in pH units

Key
New Culvert - installed as a by-pass for stream flow around the landfill site
Old Culvert - source of leachate pollution to stream
Settling Tank - leachate from Old Culvert diverted to settling tank for iron precipitation
Reed Bed Effluent - samples taken from discharge point from reed bed
Downstream Sampling Point – Stream sampling point 80m downstream of Reed bed discharge
System Operation: Old Culvert → Settling Tank → Reed Bed → Stream

(after Robinson *et al*., 1999)

Table 9.49 Reed Bed Loadings at Monument Hill

	Parameter Concentration (mg/l)				
Unit	**NH_4**	**Iron**	**SS**	**Cl**	**Mecoprop** (µg/l)
Influent	2.18	1.35	4.66	8.55	1.17
Effluent	1.31	0.07	0.33	8.44	0.30
HLR = 111L/m^2/day Note: all results in mg/l unless indicated otherwise					

(calculated from Robinson *et al*., 1999)

Overall, the system proved highly successful in treating the targeted pollutants of concern and provided a low cost, low technological solution to a problem of persistent pollution in a stream. The treatment system since inception has consistently achieved effluent quality requirements and has provided a template for application at other old, often abandoned landfill sites.

Conclusions to Horizontal Flow Constructed Wetlands

Treatment units HF 1 and HF 2 in this project can be compared to the irrigation of leachate to horizontal flow constructed wetlands presented above.

HF 1 contained a subsoil medium planted with *Sparganium sp.* (Bur Reed) and HF 2 contained a gravel medium also planted with *Sparganium sp.*

The units were designed as sub-surface flow beds and operated in separate sequences; Cell 10 - VF 1 – HF 1 and Cell 1 - VF 2 – HF 2; for phase 2 plant operations (November 2007 – March 2008).

In phase 3 and 4 plant operations HF 2 was operated in sequence; Cell 9 – Cell 10 – VF 1 – VF 2 – HF 2 (August 2008 to May 2009) (HF 1 was switched off due to operational difficulties).

Each HF unit had a surface area of $25m^2$ and application rates to each reed bed were $96L/m^2$/day for phase 2 and $90L/m^2$/day for phases 3 and 4 (HRT of 4.7 days for HF 1 and 5.75 days for HF 2).

Focussing initially on dosing volumes, the application rates for this project are within range of those cited by Lin *et al.* (2003) (5 day HRT, $64L/m^2$/day HLR) and Robinson *et al*. (1999) (HLR of 100 to $122L/m^2$/day).

The hydraulic loading rates in the study by Nivala *et al.* (2007) of $4L/m^2$/day and Eckhardt *et al*. (1999) of $9.5L/m^2$/day and $5.8L/m^2$/day were considerably lower than this project whereas the HLR of the treatment wetland described by Debusk (1999); $473L/m^2$/day; was almost 5 times this project.

The HLR of Robinson *et al*. (1999), of 100 to $122L/m^2$/day best approximates this project.

Regarding treatment efficiency, results for phase 2 operations for HF 1 and HF 2 were highly erratic and mean load removal and mean concentrations very often do not tally. Overall, HF 2 marginally outperformed HF 1. Results for selected parameter influent and effluent concentrations and loadings to HF 1 and HF 2 are presented in Table 9.50.

Table 9.50 Parameter Concentrations and Loadings for HF 1 and HF 2 during Phase 2 Operations

Phase 2 Operations - HF 1 and HF 2						
Unit	**HF 1**	**HF 2**		Unit	**HF 1**	**HF 2**
CW Type	SSF	SSF		CW Type	SSF	SSF
HLR ($l/m^2/day$)	96	96		HLR ($l/m^2/day$)	96	96
Parameter NH_4	HF 1	HF 2		**Parameter Chloride**	HF 1	HF 2
Influent Conc. (mg/l)	95	31		Influent Conc. (mg/l)	281	269
Effluent Conc. (mg/l)	98	35		Effluent Conc. (mg/l)	299	254
Influent Load ($g/m^2/day$)	9.1	3		Influent Load ($g/m^2/day$)	27	25.8
Effluent Load ($g/m^2/day$)	9.5	3.3		Effluent Load ($g/m^2/day$)	28.7	24.3
Load Removal	-0.4	-0.3		Load Removal	-1.7	1.5
Load Removal (%)	-4	-10		Load Removal (%)	-6	6
Parameter BOD	**HF 1**	**HF 2**		**Parameter Fe**	**HF 1**	**HF 2**
Influent Conc. (mg/l)	40	20		Influent Conc. (mg/l)	0.26	0.31
Effluent Conc. (mg/l)	34	12		Effluent Conc. (mg/l)	0.1	0.13
Influent Load ($g/m^2/day$)	5	2		Influent Load ($g/m^2/day$)	0.02	0.03
Effluent Load ($g/m^2/day$)	4	1		Effluent Load ($g/m^2/day$)	0.01	0.01
Load Removal	1	1		Load Removal	0.01	0.02
Load Removal (%)	20	50		Load Removal (%)	50.0	66.7
Parameter COD	**HF 1**	**HF 2**		**Parameter Mn**	**HF 1**	**HF 2**
Influent Conc. (mg/l)	181	168		Influent Conc. (mg/l)	2.98	3.48
Effluent Conc. (mg/l)	158	145		Effluent Conc. (mg/l)	2.45	2.71
Influent Load ($g/m^2/day$)	17	16		Influent Load ($g/m^2/day$)	0.29	0.33
Effluent Load ($g/m^2/day$)	15	14		Effluent Load ($g/m^2/day$)	0.23	0.26
Load Removal	2.00	2.00		Load Removal	0.06	0.07
Load Removal (%)	12	13		Load Removal (%)	21	21
Parameter SS	**HF 1**	**HF 2**		**pH**	**HF 1**	**HF 2**
Influent Cl Conc. (mg/l)	7	6		Influent (pH units)	6.9	6.9
Effluent Cl Conc. (mg/l)	16	4		Effluent (pH units)	7.3	7.2
Influent Load ($g/m^2/day$)	0.7	0.6		**Key**		
Effluent Load ($g/m^2/day$)	1.6	0.4		HF 1 = *Sparganium* in subsoil medium		
Load Removal	-0.90	0.20		HF 2 = *Sparganium* in gravel medium		
Load Removal (%)	-129	33				

Results for Phases 3 and 4 plant operations for HF 2 fared slightly better with load reductions of 3% for COD, 8% for Nitrate (as TON), 4.4% for total (inorganic) N and 74% for Mn. Effluent loads for ammonium and suspended solids increased by 100% and 14% respectively.

Results for selected parameter influent and effluent concentrations and loadings to HF 2 are presented in Table 9.51.

Table 9.51 Parameter Concentrations and Loadings for HF 2 during Phases 3 and 4 Operations

Phases 3 and 4 Operations - HF 2					
Unit	**HF 2**	Unit	**HF 2**	Unit	**HF 2**
CW Type	SSF	CW Type	SSF	CW Type	SSF
HLR ($l/m^2/day$)	90	HLR ($l/m^2/day$)	90	HLR ($l/m^2/day$)	90
Parameter NH_4	HF 2	**Parameter TON**	HF 2	**Parameter Chloride**	HF 2
Influent Conc. (mg/l)	12	Influent Conc. (mg/l)	967	Influent Conc. (mg/l)	380
Effluent Conc. (mg/l)	21	Effluent Conc. (mg/l)	823	Effluent Conc. (mg/l)	389
Influent Load ($g/m^2/day$)	1	Influent Load ($g/m^2/day$)	86	Influent Load ($g/m^2/day$)	34
Effluent Load ($g/m^2/day$)	2	Effluent Load ($g/m^2/day$)	79	Effluent Load ($g/m^2/day$)	37
Load Removal	-1	Load Removal	7	Load Removal	-3
Load Removal (%)	-100	Load Removal (%)	8	Load Removal (%)	-9
Parameter BOD	HF 2	**Parameter Total N**	HF 2	**Parameter Fe**	HF 2
Influent Conc. (mg/l)	6	Influent Conc. (mg/l)		Influent Conc. (mg/l)	0.6
Effluent Conc. (mg/l)	5	Effluent Conc. (mg/l)		Effluent Conc. (mg/l)	0.5
Influent Load ($g/m^2/day$)	0.5	Influent Load ($g/m^2/day$)	20.3	Influent Load ($g/m^2/day$)	0.05
Effluent Load ($g/m^2/day$)	0.5	Effluent Load ($g/m^2/day$)	19.4	Effluent Load ($g/m^2/day$)	0.05
Load Removal	0	Load Removal	0.9	Load Removal	0
Load Removal (%)	0	Load Removal (%)	4.4	Load Removal (%)	0
Parameter COD	HF 2	**Parameter SS**	HF 2	**Parameter Mn**	HF 2
Influent Conc. (mg/l)	174	Influent Cl Conc. (mg/l)	8	Influent Conc. (mg/l)	2.36
Effluent Conc. (mg/l)	134	Effluent Cl Conc. (mg/l)	8	Effluent Conc. (mg/l)	0.62
Influent Load ($g/m^2/day$)	17.3	Influent Load ($g/m^2/day$)	0.7	Influent Load ($g/m^2/day$)	0.23
Effluent Load ($g/m^2/day$)	16.7	Effluent Load ($g/m^2/day$)	0.8	Effluent Load ($g/m^2/day$)	0.06
Load Removal	0.60	Load Removal	-0.10	Load Removal	0.17
Load Removal (%)	3	Load Removal (%)	-14	Load Removal (%)	74

Key

HF 2 = *Sparganium* in gravel medium

Operational Period: August 2008 – January 2009

The overall performance of the HF reed beds in this project was relatively poor when assessed against similar studies.

The positive load removals in HF 2 for COD, nitrate and N in phases 3 and 4 are still below removal rates cited in the referenced literature despite the fact that with the exception of COD, chloride and nitrate, all other parameter concentrations entering the reed bed were relatively low.

A comparison of parameter concentrations and loadings to HF 2 reed bed for ammonium, total N, COD and chloride during phases 3 and 4 operations for this project with selected referenced literature is presented in Table 9.52.

Table 9.52 Selected Parameter Loadings to HF 2 (Phases 3 and 4) as Compared with Loadings to Horizontal Flow Reed Beds in Referenced Literature

Unit	HF 2	JC Aerated	JC Non Aerated	Batch 1	Batch 4	Batch 7	NY 1	NY 2	MH
CW Type	SSF	SSF	SSF	SSF	SSF	SSF	SF	SSF	SF
HLR ($l/m^2/day$)	90	3.8	2.1	64	64	64	9.5	5.8	111
Parameter NH_4	HF 2	JC Aerated	JC Non Aerated	Batch 1	Batch 4	Batch 7	NY 1	NY 2	MH
Influent Conc. (mg/l)	12	203	145	383	383	383	296	171	19.6
Effluent Conc. (mg/l)	21	10	96	130	149	126	171	23	11.8
Influent Load ($g/m^2/day$)	1	0.77	0.30	25	25	25	3	1	2
Effluent Load ($g/m^2/day$)	2	0.04	0.20	8	10	8	2	0	1
Load Removal	-1	0.73	0.10	16	15	16	1.19	0.86	0.87
Load Removal (%)	-100	95	34	74	61	67	42	87	40
Parameter Total N	HF 2	JC Aerated	JC Non Aerated	Batch 1	Batch 4	Batch 7	NY 1	NY 2	MH
Influent Conc. (mg/l)		159	113	304	304	304	230	133	No Data
Effluent Conc. (mg/l)		19	75	103	118	103	133	18	
Influent Load ($g/m^2/day$)	20.3	0.61	0.24	19.48	19.48	19.48	2.19	0.77	
Effluent Load ($g/m^2/day$)	19.4	0.07	0.16	6.58	7.56	6.56	1.26	0.10	
Load Removal	0.9	0.53	0.08	12.90	11.91	12.91	0.92	0.67	
Load Removal (%)	4.4	88.2	33.8	66.2	61.2	66.3	42.2	86.5	
Parameter COD	HF 2	JC Aerated	JC Non Aerated	Batch 1	Batch 4	Batch 7	NY 1	NY 2	MH
Influent Conc. (mg/l)	174	752	716	1291	1291	1291	No Data	No Data	No Data
Effluent Conc. (mg/l)	134	395	559	387.3	413.12	503.49			
Influent Load ($g/m^2/day$)	17.3	2.86	1.50	82.62	82.62	82.62			
Effluent Load ($g/m^2/day$)	16.7	1.50	1.17	24.79	26.44	32.22			
Load Removal	0.60	1.36	0.33	57.84	56.18	50.40			
Load Removal (%)	3	47	22	70.0	61	68			
Parameter Chloride	HF 2	JC Aerated	JC Non Aerated	Batch 1	Batch 4	Batch 7	NY 1	NY 2	MH
Influent Conc. (mg/l)	380	No Data	No Data	No Data	No Data	No Data	490	510	77
Effluent Conc. (mg/l)	389						510	160	76
Influent Load ($g/m^2/day$)	34						4.655	2.958	8.547
Effluent Load ($g/m^2/day$)	37						4.845	0.928	8.436
Load Removal	-3.00						-0.19	2.03	0.11
Load Removal (%)	-9						-4.1	68.6	1.3

Key

HF 2 = This Project

JC Aerated, JC Non Aerated = calculated from Nivala *et al.*, 2007

Batches 1, 4 and 7 = calculated from Lin *et al.*, 2003

NY 1 and NY 2 = calculated from Eckhardt *et al.*, 1999

MH = calculated from Robinson *et al.*, 1999

Blank Cells = No Data

The horizontal flow reed beds in this project (HF 1 and HF 2) did not function as intended. The likely reasons for the poor treatment efficiencies were as follows:

- Poor reed growth

  Neither bed experienced vigorous reed growth.

  It is possible that there were insufficient nutrients or feedstock in the influent (being at the end of the treatment sequence, most of the readily biodegradable organics were removed from the leachate by the time it flowed to each HF reed bed).

- Reed species unsuited to treatment of landfill leachate

  Despite exhaustive searches through the literature, no other reference was found where *Sparganium sp.* (Bur Reed) was used in constructed wetlands.

  Sparganium sp. may not be as salt tolerant as *Typha* and *Phragmites*

- Development of an algal mat compromised reed functioning

  An algal mat had developed on the surface of each bed (due to high nitrate concentration in the influent) early during the trials (August 2008).

  The algae would have limited oxygen transfer to the rhizosphere, lowered photosynthesis capability of the reeds, and led to stratification in the water column, creating oxygen depleted beds.

- Design error

  Each HF reed bed was designed to function as a sub-surface reed bed; however, due to a higher than expected silt content in the subsoil (HF 1), the influent simply did not percolate through the medium to the outflow mechanism.

  This resulted in consistent ponding and overtopping of HF 1 containment bunds.

  HF 1 should have been designed as a surface flow HF bed with the outlet 300mm above the level of the growing medium.

  The gravel based HF 2 bed functioned as designed, but there were occasional problems in maintaining a steady water level – sometimes it would flood, other times it would drain.

  It is possible that the seals between the liner and the outlet pipe were not 100% water tight (there may have been some ground movement or frost heave).

- Design error in outlet mechanism

  The outlet mechanism (pipe with flexible joint for raising and lowering water levels) was encased in a Ø 1.0 metre concrete ring. Unfortunately, this did not allow the beds to fully drain due to lack of space. The original design called for an outlet mechanism encased in a Ø 1.8 metre concrete ring, but due to an error in the materials order coupled with construction issues, an incorrectly sized concrete ring was emplaced.

The HF reed beds were ultimately switched off, due to continued poor treatment efficiencies and were converted to irrigated vertical flow vegetated plane units (VP 1 and VP 2).

De-nitrification Trials

The process of wastewater nitrification will result in an effluent containing high concentrations of nitrite-nitrogen plus nitrate-nitrogen. Nitrate release to waterways can result in eutrophication which can lead to a drop in dissolved oxygen concentrations, causing problems for aquatic life (fish kills etc.). It is therefore necessary to include a denitrification stage in the treatment process (Traut, 2007).

In the process of denitrification, nitrate, the form of nitrogen that results from the completion of the nitrification process, is converted to nitrogen gas, utilizing facultative heterotrophic bacteria. The process of denitrification occurs under anoxic conditions as follows:

NO_3 + Denitrifying Bacteria + Organic Carbon $\rightarrow$ Nitrogen Gas + Water + Alkalinity

There are two steps required to achieve complete denitrification, i.e. nitrate removal.

Step 1 - The nitrification process is reversed, and nitrate (NO_3) is converted back to nitrite (NO_2).

Step 2 - Nitrite is converted to nitric oxide (NO), then nitrous oxide (N_2O) and finally to nitrogen gas (N_2).

There are two main requirements for successful denitrification.

- Anoxic environment

Since facultative heterotrophs prefer to respire using dissolved oxygen (DO), the denitrifiers will continue to respire aerobically as long as DO is available. It is only when the DO is depleted that denitrifiers begin using nitrate for respiration, which commences the denitrification reaction.

- Sufficient amount of organic carbon

Without organic carbon as the food supply, facultative heterotrophs cannot continue to grow and multiply.

Organic carbon can be supplied to the denitrification phase of biological treatment using an exogenous source such as methanol, molasses, ethanol or an internal source, i.e. the influent wastewater with a high carbonaceous BOD (www.iittm.ac.in).

Denitrification is usually conducted at wastewater treatment plants using upflow or downflow denitrification reactors or a sequencing batch reactor (SBR). The carbon source typically used is methanol; however, a number of small-scale trial plants have been studied using other carbon sources.

In a pilot scale sequencing batch reactor Traut (2007) describes the denitrification of leachate from Vissershok landfill site near Cape Town in South Africa. Using a 160 litre reactor, the denitrification process involved an aeration cycle (16 hrs), effluent discharge (30 mins.), anoxic mixing (4 hrs), methanol dosing (4 hrs), leachate dosing (13 hrs) and sludge settlement (2 hrs).

Leachate was applied to the reactor at 9-13 l/day and methanol was dosed from stock bottles using a dosing pump (258ml–1234ml per week) to produce a reactor concentration of 15%-30%. The average methanol to nitrogen ratio was 4.80:1.

The mean HRT in the reactor was 16 days and a DO concentration of 0.5mg/l was maintained in the reactor.

Average parameter values for the influent leachate were as follows; alkalinity 12,283mg/l, NH_4 2335mg/l, COD 4650mg/l, chloride 3654mg/l, pH 7.6–8 and EC of 2904mS/cm.

The decanted effluent was tested each day for NH_4, NO_3, NO_2, pH, chloride, COD, EC, TSS (to assess sludge production) and temperature.

Results over the 35 week trial revealed a reduction in effluent COD from 4650mg/l to 1734mg/l (62%); NH_4 <0.1mg/l and NO_3 + NO_2 <0.6mg/l. TSS increased from 2124mg/l to 8844mg/l. The high TSS was attributed to excess methanol dosage due to a dosing pump malfunction.

The trial described by Traut (2007) performed extremely well, however to attain discharge consent, a further ponding stage would be required to lower the TSS and COD effluent concentration.

In a laboratory scale SBR experiment, Fernández-Nava *et al*. (2010) describe the use of three different carbon sources to achieve denitrification. The three sources were waste products from various industrial processes; Carbon Source 1 (CS1) was wastewater produced in the production of sweets; Carbon Source 2 (CS2) was a saccharose rich residue from the production of soft drinks, and Carbon Source 3 (CS3) was a lactic acid-rich residue from a dairy plant. Different COD-N ratios were investigated for each of the carbon sources tested and reaction kinetics were determined.

The reactor consisted of a 3 litre closed glass column equipped with mechanical stirrers to improve contact between the microorganisms and the synthetic wastewater. The Sequencing Batch Reactor system was operated as follows: loading period (40 min), anoxic reaction period (6–22 h), settling period (30 min) and unloading period (40 min). Sludge from a landfill leachate treatment plant was used as inoculum.

A synthetic wastewater was created to mimic a close approximation of wastewater from the steel industry. The synthetic wastewater was characterized as follows; pH 8.5, fluoride 5mg/l, nitrate 700mg/l, sulphate 200mg/l, calcium 150mg/l and chloride 177mg/l.

Following an acclimatization period, the reactor was dosed with the three different carbon sources.

CS1 contained 14% total solids (in weight) and was rich in sugars (53.6–57% glucose and 32.1–46.4% saccharose as a % dry matter weight) It had a COD of 155g/l.

CS2 was a saccharose-rich residue (98–99% saccharose dry matter) with a high organic matter content (850g COD/l).

CS3 was a lactic acid-rich residue with water content of 71.5% and an organic matter content of 370g COD/l. It also contained ammonium and phosphorus.

An external addition of phosphorus was required to achieve an N/P ratio of 10 in the reactor.

Following several cycles and variations of inputs, the optimum COD/N ratio to achieve denitrification with each carbon source was arrived at.

The optimum COD/N for CS1 was 6.5. Maximum denitrification was achieved after 6 hours. A biomass concentration of 4.4g/l in the reactor produced a nitrate-free effluent with 90mg/l organic matter concentration (COD).

CS2 had a faster reaction (4 hours) at COD/N of 5.5 (biomass concentration of 5.8g/l). Effluent COD was 163mg/l and was nitrate free.

Optimum reaction time for CS3 was 6 hours at COD/N of 4.6 (biomass concentration of 5.8g/l). Effluent COD was 257mg/l and nitrate values of 0.4mg/l were recorded.

The trial experiments were highly successful and the denitrification rates obtained when using the three carbon sources tested were found to be higher than those obtained in previous studies using methanol as a carbon source.

CS1 and CS2 performed best in the trials producing an effluent free of nitrate.

In conclusion, Fernández-Nava *et al*. (2010) stated that the main drawback in employing sugar rich carbon sources on a large scale would be the higher sludge production, which would extend reactor purge time and increase management costs.

Lee *et al.* (1996) described a study to determine the denitrification activity of bacteria selectively enriched from activated sludge with four different carbon sources. The four carbon sources selected were acetate, methanol, crude syrup and hydrolysed starch.

The paper details the experimental results of all four carbon sources, but only the laboratory column test and results for the crude syrup shall be discussed here as this most closely resembles the carbon source used in denitrification trials in this project.

The experiment involved a reactor column of 500ml, inoculated with 10ml activated sludge from a nearby wastewater treatment works and dosed with a synthetic wastewater with the following characteristics; 3.25g/lKNO_3, 190mg/lNH_4Cl, 520mg/lK_2HPO_4., pH of 7. The carbon source was added to the reactor to sustain a COD concentration of 1.4g/l and a continuous flow was maintained to give a HRT of 24 hours.

Nitrate, nitrite, ammonium, COD and dry matter in the reactor effluent were determined regularly during the 120-day experiment.

Optimum conditions were achieved after 65 days of operation resulting in a 65% reduction in nitrate and an 84% reduction in COD. Effluent concentrations for NH_4, NO_2 and NO_3 were 12mg/l, 6.3mg/l and 164mg/l respectively. The mass balance was, 231mg/day in → 73.3mg/day out for NO_3 and 25mg/day in → 4.85mg/l out for NH_4.

The denitrification yield for crude syrup was 0.26g N/g COD.

Lee *et al.* (1996) concluded that the use of crude syrup as a carbon source for denitrification was questionable on a large scale due to the higher sludge production and lower denitrification yield. Instead, methanol and acetic acid provided higher rates of denitrification at much lower sludge production rates.

Denitrification phase II trials for this project were in operation from September 2009 to October 2010. The denitrification units consisted of four $1m^3$ reactors set in sequence, connected to VP 2 (grass plane unit).

The sequence of treatment units was as follows:

Cell 9 - Cell 10 - VF 1 - VF 2 – (VP 1) - VP 2 – N1 – N2 – N3 – N4.

Units N1 – N4 were $1m^3$ plastic tanks (IBCs) with an operating volume of 800 litres per unit.

Reactor N1 was dosed with a carbon source (Sorbitol®) at a rate of 520 ml/hour (12.48 l/day, 121.5gCOD/l concentration in the feedstock tank) to achieve a COD concentration of 632mg/l in the vessel (excluding influent COD in treated leachate). Sorbitol is a sugar substitute used in the pharmaceutical industry for the production of sugar free tablets and has a COD of 121.5g/l at a dilution of 1:10.

P was also added to the system (dosed to N1) to achieve a steady state concentration of 5mg/l (P) in the vessel.

Treated leachate was applied to N1 via gravity feed from VP 2 at a constant flow totalling 2400 l/day giving a residence time of approximately 8 hours per unit.

A fall between each succeeding denitrification unit was engineered so that flow from N1 to N4 was also by gravity.

The average nitrate (TON) influent concentration to N1 was 953mg/l, effluent concentrations from the units were, 767mg/l from N1, 759mg/l from N2, 699mg/l from N3 and 725mg/l from N4.

Average nitrate (TON) load removal for each unit was, 445g/unit/day (23% removal) for N1 (2287g/unit/day influent, 1757g/unit/day effluent), 20g/unit/day (1% removal) for N2, 144g/unit/day (7% removal) for N3 (1822g/unit/day influent, 1678g/unit/day effluent), and -61g/unit/day (3% increase) for N4 (1678g/unit/day influent, 1739g/unit/day

effluent). Cumulative nitrate load removal at sequence end was 548g/unit/day representing a 24% nitrate (TON) load removal from the system.

Unfortunately, due to a lack of monitoring data for COD concentrations in N1 to N4, the ratio of COD/N was not be calculated for much of the denitrification trial, except for the period July to October 2010.

The results revealed a COD/N of 2.6 for N1, 1.6 for N2, 1.5 for N3 and 1.5 for N4.

Analysis of the data reveals that the majority of nitrate removal occurred in reactor N1 where the COD/N ratio was highest. It terms of COD removal, 62% of the COD load was removed in N1 effluent with a small percentage COD load removal in the subsequent units; 1% in N2, 13% in N3 and 3% in N4 (data for July to October 2010 only).

It is obvious when comparing the data from this project to the cited examples that the denitrification trials were unsuccessful and the units N1 to N4 did not function as intended. The likely reasons for the poor denitrification rates are as follows:

- COD/N ratio of 2.6 was too low; it should have been between 6.5 and 5.5 as per C1 and C2 carbon source quoted by Fernández-Nava *et al*. (2010).
- Poor initial process controls regarding the dosing pump and exact quantification of COD application rates to N1 resulted in excess COD dosing during the initial denitrification phase.
- The system should have been operated on a batch control basis, beginning with a fill → carbon dosing and anoxic phase → settlement → decant and ending with a sludge removal phase.

  The continuous stream of treated leachate to N1 resulted in a poorly functioning reactor due to high flow variability between dosing events. Consequently excess biomass was produced (as COD was added at a relatively constant rate) resulting in regular clogging of influent and effluent lines to/from the units.
- There was no set routine for sludge removal, instead influent and effluent lines to/from the reactors were cleared on an ad-hoc basis.

Despite these setbacks, the use of Sorbitol as a carbon source should not be discounted for future denitrification trials for landfill leachate.

The sugar substitute is relatively easy to handle, is non-toxic and does not require any special delivery or storage conditions (other than storage of the powered material in dry conditions). It also mixes well in cold water unlike many other sugar substitutes that require higher temperatures in the dosing tank to maintain the sugars in solution.

The issue of cost may however prohibit large-scale use of Sorbitol for denitrification purposes; at a cost of €1.20 - €1.60 per kg of COD; it will have to be competitive against the industry standard, typically methanol costing €1.30 - €1.50 per kg of COD, although prices can fluctuate due to market volatility.

9.3 Final Comment on Leachate Characteristics

The leachate at Kinsale Road Landfill Site can be characterised as relatively low to moderate strength when compared to other methanogenic and acetogenic leachates.

The leachate stream tends to be relatively stable and does not fluctuate wildly. Typical mean parameter values for key wastewater constituents are 323mg/l for NH_4; 20mg/l for BOD_5; 279mg/l for COD; 30mg/l for suspended solids; 404mg/l for chloride and 83mg/l for nitrate (as TON). pH tended to be neutral, ranging from 7.07 – 7.81.

Heavy metal concentrations in the raw leachate was low, usually below drinking water standards except for iron and manganese with mean concentrations of 8mg/l and 3.1mg/l respectively (potassium and sodium revealed mean concentrations of 194mg/l and 307mg/l respectively).

Results from analysis of 138 compounds contained within the List I and II catalogue (VOC, SVOC, PAH, PCB) revealed extremely low concentration levels for all substances in the leachate. Concentration values were either below the drinking water standard, detected but not quantifiable (i.e. detected but under range) or not detected (i.e. <LOD).

Toxicity tests carried out on the leachate revealed toxicity values of 5.1 – 5.6 (Toxic Units) placing the leachate in the 'slightly toxic' range. Further determination of toxicity through the treatment units revealed that toxicity values were attributable to ammonium concentration in the leachate (given the low heavy metals count and absence of List I and II substances).

The pathogen count was not considered to be particularly high. The range of values for total coliforms and *E. coli* in the raw leachate was 5.74×10^3 - 3.77×10^4 MPN/100ml (TC) and 135 – 1782 MPN/100ml (*E. coli*) respectively.

There is a multitude of reasons for the relatively moderate strength leachate:

- Leachate has filtered through up to 25m of waste and many particles and pollutants have become entrained in the waste body during the passage through the heterogeneous waste and soil layers
- This stratification has provided a large surface area for sorption of metals as well as sediment straining and has created the conditions for chemical complexation, immobilisation, precipitation and oxidation through microbial processes. These

processes are probably occurring simultaneously in alternating zones, within waste of differing ages throughout the waste body

- The strength of the leachate was also reduced through biogeochemical reactions within the waste body and at the clay/gravel interface zone at the base of the landfill
- When pH is close to neutral, slightly reducing conditions tend to persist which leads to biogeochemical equilibrium within the landfill, thus providing permanent storage inside the landfill body (Modin, 2012)
- The low concentrations of List I and List II substances within the leachate stream could be attributed to the fact that (a) the substances were simply never landfilled at the facility; (b) the substances were landfilled but remained *in situ* and have never found their way into the leachate stream or (c) have become immobilised through similar processes as mentioned for metals and salts. However, given the age of the landfill and the fact that it was in operation long before the current waste licensing regime (a) is improbable and a more credible explanation lies with a combination of (b) and (c)
- It was assumed prior to analysis that the leachate from the active area (raw active) would be much more potent in terms of pollutants. However, with the exception of high values for ammonium, BOD_5, COD and chloride, determination of metals and List I and II substances revealed extremely low concentrations or concentrations below detection limits. On reflection, the likely reason for the low parameter values is that their absence was due to compliance with the conditions of the waste licence, whereby landfilling of hazardous materials or of waste containing hazardous components (waste electrical items, batteries, herbicides, pesticides etc.) was prohibited
- Low counts for TC and *E. coli* can be attributed to leachate straining through absorbent layers (i.e. timber chippings used for daily waste cover), and multiple flow paths for leachate percolation providing prolonged contact time and development of a biomat in micro-aerobic zones
- Groundwater intrusion at the base of the landfill has further diluted the leachate.

9.4 Comment on the Effects of Weather on the Treatment Plant

The effects of weather on treatment were not specifically measured during the course of this project. Quantification of the effect of weather (temperature, pressure, rainfall, evapotranspiration) on the treatment processes would require the installation of an onsite meteorological station equipped with a rain gauge, temperature probe and anemometer. Weather data referred to in the text relate to the recordings from Cork Airport meteorological station, approximately 4km from the facility.

In general, the climate in the Cork area is quite mild and the region does not experience a large temperature range. With the exception of very cold weather experienced during January 2009 and November 2009 – January 2010, the typical average temperature range is 5°C - 16°C. During the cold spells mentioned above, the trial plant was turned off to prevent damage to infrastructure due to freezing temperatures (particularly at night) (freeze – thaw action on pipes and pump sumps etc.).

The cold temperatures experienced in 2009/2010 were exceptional, and it has been shown that the trial treatment plant is capable of operating all year round during a 'normal' annual weather cycle, e.g. phase 5 plant operations involving bacteriological testing in the treatment units operated from October to December 2011.

Optimum temperatures for aerobic processes for wastewater treatment are 10°C – 30°C and the climate in the Cork city area seems to suit such systems. In addition, it was noted that the treatment media in many of the units (specifically compost and timber chippings and VF reed beds) did not tend to freeze as the media seemed to have a temperature buffering capacity preventing surface frost.

Nevertheless, for future projects of a similar nature, insulation of all pipes and tanks to prevent damage during periods of low temperature should be considered.

9.5 Up-scaled Trial Treatment Plant

A draft format of an up-scaled treatment plant for treatment of leachate at Kinsale Road Landfill Site has been developed. The design has been produced based on the treatment performance of the trial plant and entails the use of multiple natural treatment systems, including an aerated gravel bed, compost and timber chip beds, vertical flow constructed wetlands, facultative ponds, a vertical flow vegetated plane and a package plant denitrification unit.

The calculations for the surface area required for treatment are based on the maximum annual leachate production at the facility over the last ten years, i.e. the year 2006, when 122,627m^3 of leachate was pre-treated and discharged to the sewer. This figure is 23% higher than the 2012 leachate production volume of 99,172m^3, therefore a plant design based on the 2006 figure will afford flexibility in the event of an increase in leachate production volumes in the future.

It should be noted, that the facility was still operating as an active landfill site in 2006, and since then, the facility has closed (2009) and the main area of the landfill site has been fully capped and restored with an impermeable liner. Therefore, it is expected that leachate production at the facility will significantly decline into the future.

The application rate is taken directly from the results achieved in the trial plant.

The flow sequence between units (1 – 11) and application rates (based on leachate production of 336m^3/day) are:

1 Leachate Collection Pond

▼ Controlled Gravity Flow

2 Aerated Gravel Bed (100m^3) = HRT of 0.3 days

▼ Pumped

3 Coarse Grade Compost and Timber Chip Beds (1:1 mix) (HLR = 945 litres/m^2/day)

▼ Pumped

4 Coarse Grade Compost and Timber Chip (1:1 mix) Beds (HLR = 945 litres/m^2/day)

▼ Pumped

5 Vertical Flow Constructed Wetlands (HLR= 96 litres/m^2/day)

▼ Pumped

6 Vertical Flow Constructed Wetlands (HLR = 96 litres/m^2/day)

▼ Pumped

7 Vertical Flow Vegetated Grass Plane (HLR = 50 litres/m^2/day)

▼ Controlled Gravity Flow

8 Settling Pond with Water Hyacinth/*Lemna minor* (400m^3) = HRT of 1.19 days

▼ Pumped

9 De-nitrification Package Plant (ASTRASAND, up-flow continuous backwash filter or other)

▼ Pumped

10 Re-aeration Tank/Pond (size to be determined)

▼ Controlled Gravity Flow/Pumped

11 Final Settling Pond (400m^3) = HRT of 1.19 days

▼ Controlled Gravity Flow/Pumped

12 Discharge to Tramore River

The detail of each unit is presented in Table 9.53 and the plant layout is outlined in Figure 9.7.

Table 9.53 Unit Detail for Full-Scale Leachate Treatment Plant at Kinsale Road Landfill Site

Number	Unit Name	Size	Quantity	Detail	Comments
1	Leachate Collection Pond	Capacity 3500m^3	1	Lined, covered pond	Already on site
2	Aerated Gravel Bed	Capacity 100m^3 (10 x 10 x 1m)	1	Lined, open top with pea gravel or larger washed gravels 0.50m freeboard	Actively aerated from the base with downflow flushing mechanism to facilitate solids removal during overhaul
3 & 4	Compost and Timber Chip Bed	Surface Area 361m^2 Dimensions 19 x 19 x 1m	2	Lined bed with Coarse Grade Compost and Timber Chip (1:1) 0.50m freeboard	Surface Irrigation Pipes Units can be operated in series or in parallel
5 & 6	Vertical Flow Reed Bed	Surface Area 3481m^2 Dimensions 59 x 59 x 1m	2	Lined bed planted with *Phragmites sp*. in media of stratified sand, grit, gravel (2 sizes) fining up 0.50m freeboard	Surface Irrigation Pipes Units can be operated in series or in parallel
7	Vertical Flow Vegetated Grass Plane	Surface Area 6724m^2 Dimensions 82 x 82 x 1m	1	Lined bed seeded with salt tolerant grass in media of stratified sand, grit, gravel (2 sizes) fining up 0.50m freeboard	Surface Irrigation Pipes Unit to be operated during grass growing season (up to 9 months) Regular grass mowing and biomass off-take to facilitate nutrient removal
8	Settling Pond	Capacity 400m^3 Dimensions 20 x 20 x 1m	1	Lined pond with floating reed species Water Hyacinth and *Lemna minor* (duckweed) 0.50m freeboard	Controlled flow in / out via weir Reed species to facilitate nitrate uptake
9	De-Nitrifying Unit(s)	To be determined	1?	ASTRASAND package plant	Continuous upflow denite system (SIEMENS Water Technology)
10	Re-aeration tank / pond	To be determined	1	Re-aeration of effluent will be required	
11	Final Settling Pond	Capacity 400m^3 Dimensions 20 x 20 x 1m	1	Allow for settling out of any remaining solids prior to discharge to river 0.50m freeboard	

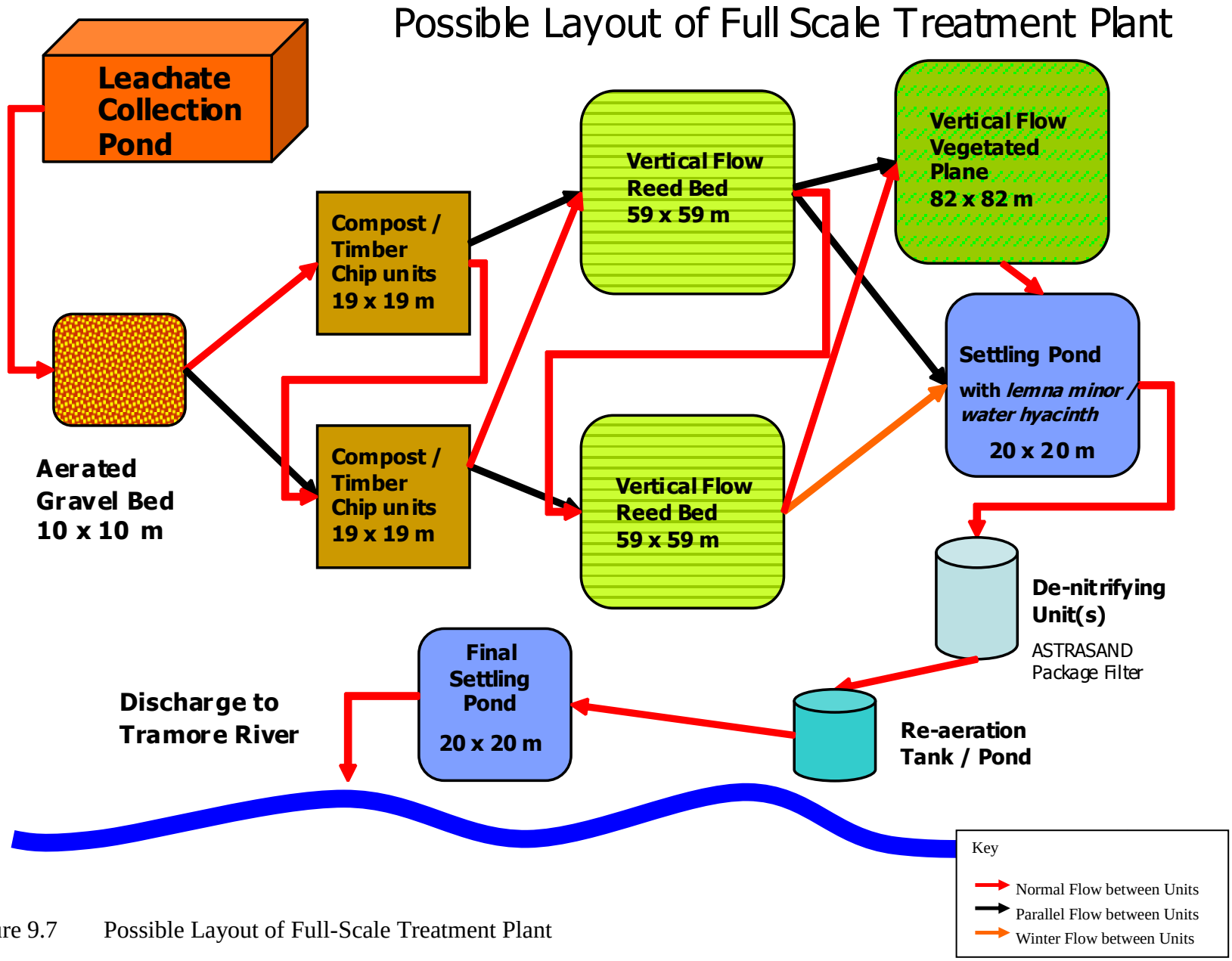


Figure 9.7 Possible Layout of Full-Scale Treatment Plant

Explanation of Key

→ Normal Flow between Units

→ Parallel Flow between Units - can be operated during periods of low leachate production or low pollutant concentrations

→ Winter Flow between Units – when vegetative plane is inactive during winter, the unit can be by-passed

Denitrification in the up-scaled plant will be facilitated by the settling pond with Water Hyacinth and *Lemna minor*.

It is expected that a denitrification reactor will also be required in the event of failure of the Water Hyacinth and during the winter months.

The denitrifying unit (unit 9) chosen (on a preliminary basis) is an off the shelf package plant, ASTRASAND, continuous up-flow denitrification filter.

Figure 9.8 shows the typical operation of a continuous backwash filter (CBF) and the operating process is as follows (Freed *et al*., 2006):

- Secondary effluent is transported into the filter by means of an Influent Pipe (1).
- The water enters the Filter Bed (4) through the Feed Pipe (2) and the Distributors (3).
- The influent flows in an upward direction where solid particles are trapped within the sand filter medium and purified filtrate (10) is discharged from the top of the filter through the Effluent Pipe (5).
- The filter bed is continuously moving downward as the water flows up. Sand circulation is accomplished using an airlift to force the dirty medium (6) from the bottom of the bed upward through a central airlift pipeline (7).
- The Sand Washer (9) is positioned around the top of the airlift pipe. The sand particles fall through the washer and the intense scouring action within the airlift wash-box separates most of the contaminating biomass from the sand filter medium, discharging dirty water from the top of the filter (8) and depositing washed, clean sand back to the top of the filter bed.

Continuous backwash filters (CBF) have been successfully employed for many years to remove solids and nitrate from secondary effluent. Reactors can be sized according to influent load and required effluent standard.

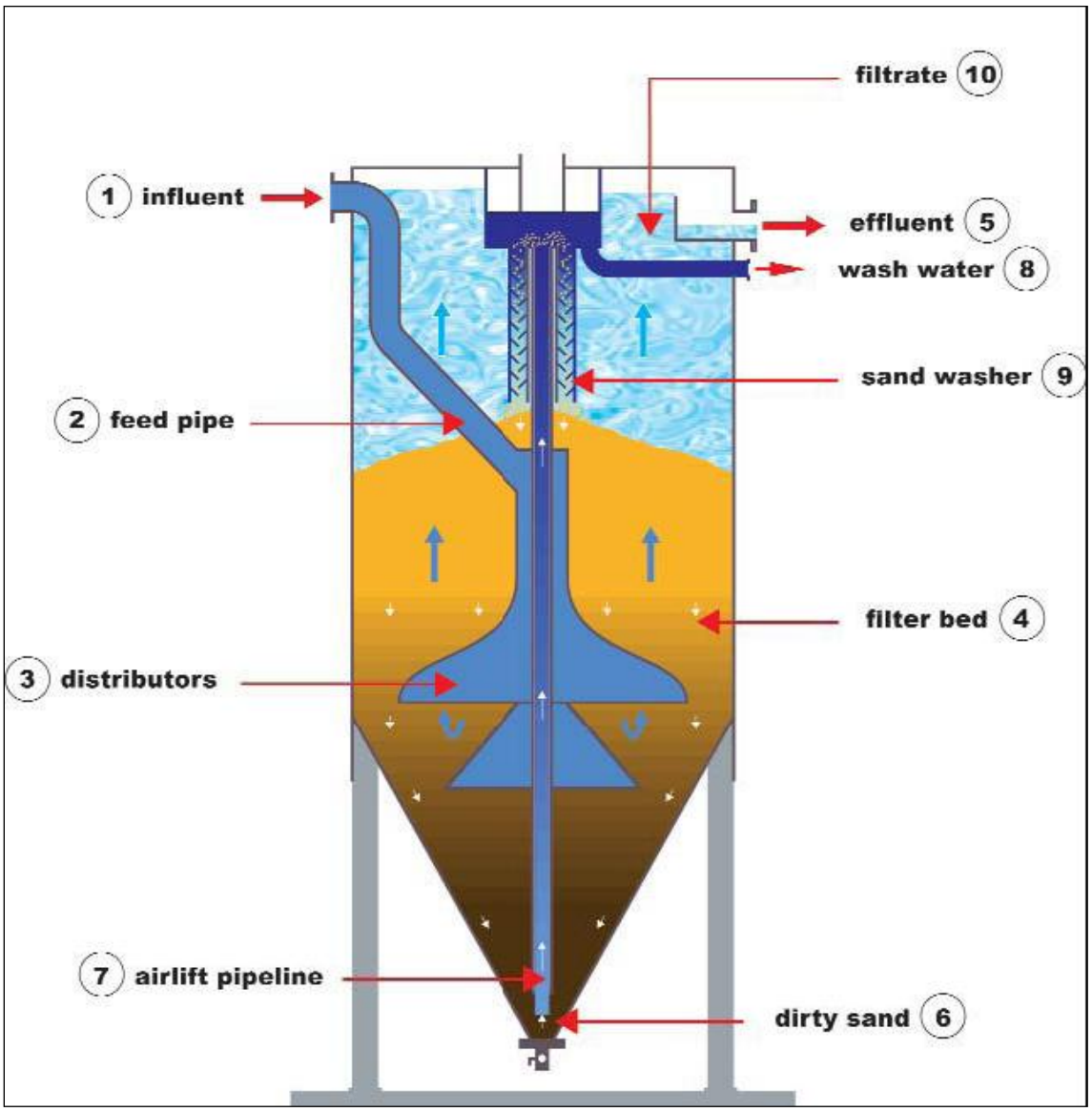


Figure 9.8 Layout of the ASTRASAND Denite System (after Freed *et al*., 2006)

CHAPTER 10

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Introduction

The leachate treatment trials using natural systems at Kinsale Road Landfill Site operated successfully and relatively smoothly for a period of 42 months between August 2007 and December 2011.

During this period, several key points have been demonstrated that would enable the design of a full-scale, on-site leachate treatment plant to be constructed with confidence.

The main objectives of the leachate treatment trials were met by addressing the various aspects of leachate treatment as outlined below.

10.2 Leachate Characteristics

- Leachate at Kinsale Road Landfill Site can be characterised as relatively low to moderate strength when compared to other methanogenic and acetogenic leachates
- Ammonium, BOD_5, COD, suspended solids and chloride concentrations are below previously studied methanogenic leachates
- Heavy metals and List I and II substances are present in extremely low concentrations, at or below drinking water standards or not detected
- Ground water dilution and to a lesser extent, rainfall infiltration as well as filtration through the alternating layers within the waste body are significant in moderating the potency of the leachate.

10.3 System Design

- Rotating sprinklers (ROTOFRAME) were effective at effluent dispersal, but were prone to seizing up due to the buildup of iron plaque
- The fixed sprinklers (consisting of a modified plastic end cap glued over a Ø 25mm non-flexible HDPE pipe with 16 no. Ø 3.5mm holes drilled evenly around the circumference of the end cap), whilst not as efficient at dispersing effluent, did not seize and required less maintenance

- The effluent distribution system for the HF reed beds (consisting of modified gutter pipe, blanked at each end, with a series of ∅ 7.5mm holes drilled every 200mm along its length) was very effective at evenly distributing effluent across the bed. The system was suspended from a number of U shaped threaded bars (attached to a rolled steel joist (RSJ, I-beam) which allowed for adjustments to maintain a level pipe
- Effluent distribution in the VF reed beds and VP units was effected via three ∅ 25mm pipe laterals, each with five evenly spaced 3mm orifices along each lateral. Each spray jet was directed onto a concrete paving slab (200mm x 200mm), to avoid pitting of the upper sand layer. This system proved highly successful in distributing the effluent across the beds
- Pond liner (HDPE) material, available at garden centres, is adequate for lining reed beds and other similar treatment units for trial studies. This will result in large cost savings in construction as specialist installation is not required, unlike LLDPE for landfill lining and capping
- Concrete rings, typically used in the construction of access chambers to sewers, are suitable for construction of receptacles for trial treatment plants. The concrete receptacles will require sealing at the base and along joints to remain watertight.

10.4 Design Improvements

- Accurate flow measurements would assist in modelling flow between successive treatment units and allow for calculation of evapotranspiration rates
- Header tank fill rate should be controlled by a level sensor. The existing arrangement whereby the operator sets the auto pump fill rate could lead to overtopping and scouring around the base of the tank
- Sediment strainers should be placed at the inlet and outlet from the gravel trap at the head of the system. This will result in cleaner effluent entering the pump sumps and reduce maintenance time. Active aeration of gravel beds should also be considered
- Sediment strainers should be placed on inlet pipes to pump sumps receiving treated effluent. This should help prevent clogging of pump sump filters with small amounts of treatment media.

10.5 Trial Plant Construction

- The use of locally available, off the shelf items was key to saving costs in construction and maintenance of the trial plant
- Pumps, pipework and fittings could all be maintained, repaired and refitted as required by the operator without specialist knowledge
- All media utilised in the treatment units (subsoil, compost, timber chippings, reeds), with the exception of sand and gravel, were available free of charge on site
- Vertical flow reed beds were planted with mature *Typha* and *Phragmites* reeds available on site. Over 50% of the *Typha* reeds died in the first season and required replanting. Mature *Typha* plants are difficult to uproot and transplant. Consideration should be given to planting *Typha* seedlings when constructing reed beds/constructed wetlands.

10.6 Trial Plant Operation and Unit Performance

- The operation of the trial plant on a phased basis assisted in project planning and provided a route map for future sequencing of treatment units
- The majority of pollutant removal occurred in the primary and secondary treatment units.

10.7 Treatment Units Providing Effective Treatment

10.7.1 Vertical Flow Reed Beds

- Vertical flow reed beds containing *Phragmites* (VF 1) and *Typha* (VF 2) in a media of stratified sand, grit and gravel (fining up) operated efficiently as secondary treatment and polishing units at areal loading rates of 96 $l/m^2/day$. Removal rates achieved for NH_4, Total (inorganic) N, BOD_5, COD and Suspended Solids were $17g/m^2/day$ (85% removal), $1.2g/m^2/day$ (6% removal), $1.3g/m^2/day$ (53% removal), $3g/m^2/day$ (3% removal) and $1.1g/m^2/day$ (69% removal) respectively
- Metals removal was variable in the effluent from the VF reed beds; albeit at very low influent concentrations (typically below drinking water limits). Average removal rates for Cd, Cr, Fe, Pb, P, Ni and K were 71%, 28%, 84%, 43%, 42%, 8% and 3% respectively. However due to the low sampling number and high standard deviation

of the average concentration, the results (with the exception of P) could not be considered significant

- The use of VF reed beds as primary treatment units is inadvisable at NH_4 leachate concentrations above 300mg/l. Concentration levels above this can lead to toxic shock, plant stressing and poor treatment efficiencies
- VF 2 containing *Typha* marginally out performed VF 1 containing *Phragmites* during phase 1 operations. However, experience in this study has shown that beds containing *Typha* are prone to invasive species and excessive weed growth. Therefore, it is recommended that *Phragmites* is considered as a first choice reed species when planning vertical flow reed beds/constructed wetlands as this species is easier to manage overall, and from a practical point of view requires less time and labour to carry out weed clearance activities
- Overall, when assessed against similar studies; operation of the VF reed beds in this study performed moderately well for all parameters
- An exact comparison between this project and other studies is difficult due to the diversity in operating conditions and the dearth of data for vertical flow constructed wetlands.

10.7.2 Vertical Flow Irrigated Grass Planes

- Vertical flow irrigated planes planted with salt tolerant grass (VP 1) and (VP 2) in a media of stratified sand, grit and gravel (fining up) operated efficiently as polishing units (3^{rd}, 5^{th} and 6^{th} stage units) at areal loading rates of 96 l/m^2/day and 24 l/m^2/day
- Removal rates achieved for VP 1 (5^{th} stage treatment unit) for NH_4, Total (inorganic) N, BOD_5, COD, Chloride and Suspended Solids were 0.49g/m^2/day (44% removal), 2.3g/m^2/day (11% removal), 0.19g/m^2/day (35% removal), 4g/m^2/day (24% removal), 4.5g/m^2/day (3% removal) and 0.1g/m^2/day (13% removal) respectively at an application rate of 96 l/m^2/day
- Removal rates achieved for VP 1 (operating as a 3^{rd} stage treatment unit) for NH_4, Total (inorganic) N, BOD_5, COD, Chloride and Suspended Solids were 0.19g/m^2/day (95% removal), 0.1g/m^2/day (1% removal), 0.11g/m^2/day (79% removal), 3g/m^2/day

(50% removal), 0.4g/m^2/day (4% removal) and 0.2g/m^2/day (66% removal) respectively at an application rate of 24 l/m^2/day

- Irrigation rates in this study were significantly higher than in other cited examples
- There was one exception where irrigation in a similar type study was 75 l/m^2/day
- Treatment efficiency in the vertical flow irrigated grass planes in this study could possibly be enhanced if they were irrigated for 5 hours and rested for 19 hours.

10.7.3 Cells Containing Coarse Grade Compost

- Coarse grade compost performed well as a medium for primary effluent treatment during this study at an areal loading rate of 945 l/m^2/day
- Load removal rates achieved for NH_4, Suspended Solids, COD and Iron were 130g/m^2/day (36% removal), 15g/m^2/day (33% removal), 33g/m^2/day (10% removal) and 4.21g/m^2/day (54% removal) respectively (primary treatment)
- Poor load removal rates were recorded for BOD_5 (3g/m^2/day, 5% removal), Chloride (8g/m^2/day, 2% removal) and Mn (0.29g/m^2/day (10% removal) (primary treatment)
- Coarse grade compost utilised as a medium for secondary effluent treatment revealed load removal rates for NH_4, Total (inorganic) N and COD of 39g/m^2/day (29% removal), 23g/m^2/day (11% removal) and 25g/m^2/day (11% removal) respectively
- Coarse grade compost required replacement after 20 months of operation due to breakdown and further humification of the treatment medium
- Results achieved in this study for NH_4, Total N and COD load removal in units containing coarse grade compost are favourable when compared to other similar studies
- Results achieved in this study for BOD_5 load removal in units containing coarse grade compost are below results attained in other similar studies involving peat filters.

10.7.4 Cells Containing Coarse Grade Compost and Timber Chip Mix

- Coarse grade compost and timber chip at a 1:1 ratio compositional mix performed well as a media for primary effluent treatment during this study at areal loading rates of 945 $l/m^2/day$
- Load removal rates achieved for NH_4, COD, suspended solids, Chloride and Iron were $66g/m^2/day$ (23% removal), $9g/m^2/day$ (4% removal), $2g/m^2/day$ (7% removal), $5.4g/m^2/day$ (1% removal) and $4g/m^2/day$ (52% removal) respectively (primary treatment)
- Poor load removal rates were recorded for BOD_5 ($-8g/m^2/day$, -42% removal), Mn ($0.2g/m^2/day$, 7% removal) and Total N ($-2g/m^2/day$, -1% removal) (primary treatment)
- Results achieved in this study for NH_4 treatment in units containing coarse grade compost and timber chippings are favourable when compared to other similar studies.

10.7.5 Cells Containing Timber Chippings

- Timber chip performed well as a medium for primary effluent treatment during this study at areal loading rates of 945 $l/m^2/day$
- Load removal rates achieved for NH_4, COD, Suspended Solids, Iron and Manganese were $162g/m^2/day$ (55% removal), $29g/m^2/day$ (11% removal), $18.8g/m^2/day$ (61% removal), $7.02g/m^2/day$ (64% removal) and $0.8g/m^2/day$ (25% removal) respectively
- Poor load removal rates were recorded for BOD_5 (no change) and Chloride ($7.6g/m^2/day$, 2% removal)
- Results for Total N showed a decrease in effluent load of $10g/m^2/day$ (4% N removal)
- Timber chip medium performance at an application rate of 98 $l/m^2/day$ for primary treatment revealed load removal for NH_4, COD, Suspended Solids, Iron and Manganese of $23g/m^2/day$ (71% removal), $6.9g/m^2/day$ (24% removal), $2.2g/m^2/day$ (71% removal), $0.64g/m^2/day$ (82% removal) and $0.14g/m^2/day$ (50% removal) respectively
- Results for Total N showed a decrease in effluent load of $1g/m^2/day$ (3% N removal)

10.7.6 Cell Containing Stratified Sand, Grit, Gravel (fining up)

- Stratified Sand, Grit and Gravel performed well as a media for secondary effluent treatment during this study at areal loading rates of 98 l/m^2/day
- Load removal rates achieved for NH_4, Total N, BOD_5, Iron and Manganese were 6g/m^2/day (66% removal), 3g/m^2/day (12% removal), 1.3g/m^2/day (50% removal), 0.04g/m^2/day (29% removal) and 0.07g/m^2/day (50% removal) respectively
- Poor load removal rates were recorded for COD (-2.16g/m^2/day, -10% removal), Suspended Solids (-0.5g/m^2/day, -55% removal) and Chloride (-0.2g/m^2/day, -1% removal)
- Results achieved in this study for NH_4 and Total N load removal in the unit containing stratified sand, grit and gravel are favourable when compared to other similar studies
- Results for BOD_5, Suspended Solids and pathogen removal in this unit are less favourable than other similar studies; however, the increased treatment efficiency cited in the literature occurred at hydraulic loading rates of 33% - 50% of this study
- Performance of the treatment unit containing stratified sand, grit and gravel in this study could be improved by lowering the HLR by 50%; this may facilitate further pathogen and BOD_5 removal.

10.8 Treatment Sequences Providing Effective Treatment

10.8.1 Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP2

Cells 9 and 10 contained coarse grade compost and timber chip mix (area per unit 2.54m^2)

VF 1 and VF 2 were vertical flow reed beds (area per unit 25m^2)

VP 1 and VP 2 were vertical flow vegetated (grass) planes (area per unit 25m^2)

- This sequence recorded load removal in the final effluent of 99% for NH_4, 15% for Total N, 84% for BOD_5, 46% for COD, 63% for Suspended Solids, 9% for Chloride, 94% for Iron and 98% for Manganese at an irrigation rate of 2400L/unit/day (945L/m^2/day to Cells 9 and 10; 96L/m^2/day to VF and VP units).

10.8.2 Cell 3 – Cell 5

Cell 3 contained timber chippings (unit area 2.54m^2)

Cell 5 contained stratified sand, grit and gravel (fining up) (unit area 2.54m^2)

- This sequence recorded load removal in the final effluent of 90% for NH_4, 13% for Total N, 36% for BOD_5, 17% for COD, 56% for Suspended Solids, 2% for Chloride, 88% for Iron and 73% for Manganese at an irrigation rate of 240L/unit/day (9.4L/m^2/day).

10.8.3 Cell 7 – Cell 8

Both cells contained timber chippings (area per unit 2.54m^2)

- This sequence recorded load removal in the final effluent of 81% for NH_4, 8% for Total N, 13% for BOD_5, 19% for COD, 77% for Suspended Solids, 2.4% for Chloride, 82% for Iron and 62% for Manganese at an irrigation rate of 2400L/unit/day (945L/m^2/day).

10.8.4 Cell 7 – Cell 8 – VP 1

Cells 7 and 8 contained timber chippings (area per unit 2.54m^2)

VP 1 was a vertical flow vegetated (grass) plane (unit area 25m^2)

- This sequence recorded load removal in the final effluent of 99.9% for NH_4, 9.7% for Total N, 96% for BOD_5, 63% for COD, 74% for Suspended Solids, 5% for Chloride, 99.6% for Iron and 99.7% for Manganese at an irrigation rate of 600L/unit/day (236L/m^2/day to Cells 7 and 8; 24L/m^2/day to VP 1).

10.9 Non-Performing Units

- The use of fine grade compost should be avoided due to compaction of the medium and subsequent surface ponding of effluent
- Subsoil and mixed subsoil, sand and compost based units (Cell 7 and Cell 8 for phases 1 and 2 operations) did not provide effective treatment due to the high silt content, media compaction and subsequent surface ponding of effluent
- Stratified sand and fine grade compost performed poorly due to compaction of the compost layers as well as differential settling between layers

- Willow trees in a subsoil medium were prone to surface ponding resulting in low treatment efficiencies
    - Willow trees exhibited toxic shock associated with high chloride concentrations >844mg/l
    - Landfill leachate application to willow treatment plots at rates of 450 - 950 l/m^2/day and chloride concentrations of 844mg/l will cause phytotoxic shock, impair tree function and limit treatment potential
    - These application rates grossly overloaded the willow treatment units
    - Irrigation of leachate to willow systems at the levels detailed in this project is unsustainable as the trees will be susceptible to shock loading and insect or fungal attack
- Neither horizontal flow reed bed performed particularly well (HF 1 contained *Sparganium* in subsoil matrix and HF 2 contained *Sparganium* in pea gravel matrix) as regards pollutant removal
    - Poor reed growth was observed in each HF reed bed
    - It is possible that there was insufficient feed stock in the incoming treated leachate
    - The use of *Sparganium* as a wetland species for leachate treatment is as yet unproven
    - Experience from this study has shown that horizontal flow reed beds with subsoil matrix should not be operated as sub-surface flow (SSF) systems
- Phase 1 operations demonstrated the requirement for an upfront unit for iron and sediment removal. In the absence of a pre-treatment unit, an iron plaque will develop on the surface area of the treatment media and result in decreased permeability.

10.10 Removal of Key Wastewater Constituents

- Almost complete nitrification was achieved in the final effluent in sequences Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 and Cell 7 – Cell 8 – VP 1 (system removal rate was 713g/day (99% system removal) and 233g/day (99.9% removal system) respectively)
- Very little denitrification occurred in treatment units (denitrification in aerobically operated units was not expected)
- Nitrate removal (as TON) in HF 2 (horizontal flow reed bed in gravel matrix) of 7g/m^2/day (8% removal) was below expectations
- The highest Total N removal rate was recorded in the final effluent for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 (system removal rate was 88g/day; 15% system removal)
- The highest COD removal rate was recorded in the final effluent for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 (system removal rate was 302g/day; 46% system removal)
- The highest BOD_5 removal rate was recorded in the final effluent for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 (system removal rate was 40g/day; 84% system removal)
- The highest Suspended Solids removal rate was recorded in the final effluent for sequence Cell 1 – VF 2 – HF 2 during Phase 2 operations (system removal rate was 65g/day; 86% system removal)
- The highest Chloride removal rate was recorded in the final effluent for sequence Cell 1 – VF 2 – HF 2 during Phase 2 operations (system removal rate was 160g/day; 21% system removal)
- The highest Iron removal rate was recorded in the final effluent for sequence Cell 7 – Cell 8 (system removal rate was 22.66g/day; 82% system removal)
- The highest Manganese removal rate was recorded in the final effluent for sequence Cell 9 – Cell 10 – VF 1 – VF 2 – VP 1 – VP 2 (system removal rate was 17g/day; 98% system removal)
- Influent pH ranged from 7.07 – 7.88
- Effluent pH ranged from 6.8 – 8.01.

10.11 Removal of Metals

- Interpretation of metals and salts concentrations in the influent and effluent for treatment units operating in sequence was limited by the low sampling number and in many cases by the high standard deviation of results about the mean concentration Consequently, phosphate (as P) is the only parameter where it can be definitively stated that a significant reduction (with a low standard deviation) in concentration from influent to final effluent occurred across the three sequences
- Final mean effluent P concentrations from the units operating in sequence were as follows:
    - Cell 3 – Cell 5 = 140µg/l (below the mean influent concentration)
    - Cell 9 ↛ VP 2 = 80µg/l (below the mean influent concentration)
    - Cell 7 – 8 – VP 1 = 90µg/l (below the mean influent concentration)

10.12 Nitrate Uptake Trials

- A lush growth of the grass sown in the irrigated vegetated planes (VP 1 and VP 2) was noted
- A calculated mass balance for N load removal from the applied influent/effluent and total dry biomass harvested for the period June to October 2010 revealed a low level of plant uptake of N ranging from:
    - 1.3% to 2.5% N dry matter content (of harvested biomass) for VP 1 and VP 2 (sequence Cell 9 ↛ VP 2)
    - 0.125% to 0.35% N dry matter content (of harvested biomass) for VP 1 (sequence Cell 7 – Cell 8 – VP 1)
- Based on these results, plant growth and associated biomass off-take was not a significant route for N removal from the system under the operating conditions described.

10.13 Denitrification Trials

- The alternative carbon source used in the trial ‘‘Sorbitol’’ did show potential (denitrification rates of 37% were achieved for a limited period). However it requires trialling under conditions where the appropriate process controls are in place

- Sludge production in this study was excessive and resulted in blockages of pipes and constriction of flow through the units
- Future denitrification trials should be operated on a batch sequence as the continuous flow mode operated in this project resulted in highly variable flow inputs to units.

10.14 Toxicity Tests

- Toxic inhibition to the *Daphnia magna* battery test within the leachate and selected effluents from the treatment units was associated with ammonium concentration
- Raw leachate used in all treatability tests was classed as Slightly Toxic (3 – 10 Toxic Units (TU))
- The data suggest that acute toxicity classification for landfill leachate in this study will move from Non-toxic (< 3 Toxic Units (TU)) to slightly Toxic (3 – 10 TU) at a concentration point somewhere between 269mg/l and 295mg/l NH_4
- Except for leachate from the active area, the toxicity assay *Vibrio fischeri* did not exhibit a toxic response to the filtered raw leachate or the effluent from the treatment units, thus limiting interpretation
- It was demonstrated that the remaining COD component in the treated effluent was non-toxic and most likely consisted of humic and fulvic acids.

10.15 Pathogen Removal

- Almost total pathogen removal occurred in the final effluent of sequence Cell 9 – Cell 10 – VF 1 - VF 2 – VP 1 – VP 2. Removal for *E. coli* and total coliforms (TC) in this sequence was 99.6% (1 MPN/100ml *E. coli* remaining) and 90% respectively
- Cumulative removal of pathogens in sequence Cell 3 (timber chip medium) - Cell 5 (stratified sand, grit, gravel media) was 72% and 84% respectively for *E. coli* and 16% and 52% respectively for TC
- Cumulative removal of pathogens in sequence Cell 7 - Cell 8 (both containing a timber chip medium) was 91% and 98% respectively for *E. coli* and 49% and 62% respectively for TC
- *E. coli* and total coliforms removal in Cell 1 (Coarse Grade Compost) was 76% and 45% respectively.

10.16 Optimal Application Rates

The following application rates are recommended for treatment of moderate strength landfill leachate (at NH_4 concentration of 330mg/l) using similar systems as described in this project:

Unit Detail / Media Type	**Application Rate**
Timber Chip	Units can perform at 945 l/m^2/day Preferred application rates 95 - 236 l/m^2/day
Coarse Grade Compost	945 l/m^2/day
Coarse Grade Compost-Timber Chip Mix	945 l/m^2/day
Stratified Sand, Grit and Gravel (2 sizes), media fining up	50 - 94 l/m^2/day
Vertical Flow Reed Beds	96 l/m^2/day
Vegetated Plane (planted with salt tolerant grass)	25 – 50 l/m^2/day
Note all units to be surface irrigated via suitably sized pump	

10.17 Answers to Initial Questions

Finally, to answer the research questions posed on commencement of the project:

1. **Is it possible to treat landfill leachate using natural systems and achieve the required standard for discharge to an aquatic receiving environment, river catchment or other?**

   Yes, but denitrification using a package plant will be required as natural systems are unlikely to provide consistent nitrogen removal to the required standard.

   Facultative denitrification ponds containing water hyacinth/*Lemna minor* could be incorporated to provide partial uptake of nitrogen on a seasonal basis.

2. **What kind of natural systems and media are best suited to leachate treatment?**

   A combination of natural systems has shown to be the most efficient at pollutant removal. Primary and secondary treatment can be provided using a pump irrigated system, with media containing a combination of coarse grade compost and timber

chippings. The third and fourth sequence of treatment could include vertical flow reed beds planted with *Phragmites.* Final polishing, if deemed necessary can be effected by irrigation to vertical flow vegetated planes (planted with salt tolerant grass).

An upfront aerated gravel bed should be considered for removal of suspended solids and dissolved iron.

3. **Is it possible to construct a full-scale treatment plant on site to accommodate leachate generated at the facility?**

   Yes, using the processes detailed above coupled with a denitrification package plant to ensure consistent removal of nitrogen.

   Facultative denitrification ponds containing water hyacinth/*Lemna minor* could be incorporated to provide partial uptake of nitrogen on a seasonal basis.

   Facultative aerobic ponds will be required post denitrification to allow for settlement of solids prior to discharge to river.

   The surface area required for treatment is approximately 1.53 hectares with a small additional area of 150m^2 required for denitrification tanks.

10.18 Recommendations for Future Work

- Research into the removal of List I and II substances (including endocrine disrupting compounds) from landfill leachate using natural systems. This may involve seeding raw leachate with such compounds to assess treatability
- Further denitrification trials using Sorbitol as a carbon source with the appropriate process controls
- Quantification of nitrate and salts uptake utilising irrigated salt tolerant vegetated grass planes coupled with a regular mowing regime and biomass off-take
- The effect of increasing rest periods on treatment efficiency in irrigated grass planes dosed with leachate should be investigated (e.g. irrigated for 5 hours and rested for 19 hours)
- The possibility of increasing treatment efficiency in vertical flow reed beds operated with longer rest periods should be investigated

- Similar future projects should calculate a complete nitrogen balance across the system. Consideration should be given to the use of leachate spiked with ^{15}N isotope to trace the accumulation and degradation processes as N passes through the treatment system
- Multilevel samplers should be incorporated in the sampling regime to assess the existence of a secondary biomat at the drainage gravel/media interface
- An onsite meteorological station would assist in calculating the effects of weather, seasonal patterns in parameter removal and evapotranspiration rates.

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APPENDIX 1

Laboratory Results

Appendix 1 A Results from Internal Laboratory Testing

- Chemical and Biological Results by Month (August 2007 – October 2010)
- Bacteriological Results (October – December 2011)
  Statistical Analysis of Results
- Phases 1 and 2
- Phases 3 and 4
- Phase 5

Appendix 1 B Results from External Laboratory Testing

- List I and II Substances
- Toxicological Analysis

APPENDIX 1 A

Results from Internal Laboratory Testing

- Chemical and Biological Results by Month (August 2007 – October 2010)
- Bacteriological Results (October – December 2011)

Statistical Analysis of Results

- Phases 1 and 2
- Phases 3 and 4
- Phase 5

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) August 2007

	Frequency	RAW 1	RAW 2	RAW 3	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Empty	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)	10-Aug-07				2400	2400	2400	2400	480	2400	2400	2400			4800	4800	4800	4800
Irrigation Rate (l/unit/day)	24-Aug-07				2400	2400	2400	2400	480	1200	2400	1200			4800	4800	4800	4800
Irrigation Rate (l/m^2/day)					945	945	945	945	189	472 / 236	945	472 / 236			1890	1890	1890	1890
Temp (°C)		20.60	18.50		20.20		19.70		19.40		19.60				20.40	19.80	18.50	18.60
pH (pH Units)		7.81	7.32	7.46	7.24	7.37	7.12	7.33	7.32	7.54	7.47	7.61			7.07	7.64	7.21	7.27
Ammonium	Monthly	370	388	440	174	364	240	336	356	400	280	392			94	138	142	156
BOD_5	Monthly			36.20		60.20		95.55		63.27		42.97			65.27	51.60		
COD	Monthly	599	259	315	260	297	259	315	237	309	259	300			368	411	211	231
TOC	Monthly	87	116	94	94	90	76	87	83	92	78	93			59	60	70	72
Chloride	Monthly	398.50	442.41	513.31	428.23	479.28	445.25	592.72	484.95	524.66	416.89	527.49			378.60	360.20	375.77	432.49
Cond. (mS/cm)	Monthly	4.06	4.95	5.16	4.28	4.90	4.44	4.78	4.61	5.01	4.63	4.99			3.18	3.37	3.62	3.98
Sus.Sols	Monthly	45.20	48.03	62.26	12.12	10.00	3.10	10.08	12.67	44.26	27.94	19.83			11.60	9.60	6.89	5.00
Ratio BOD:COD	Monthly			0.115		0.203		0.303		0.205		0.143			0.177	0.126		
Iron	Monthly	5.00	4.96	9.71	1.12	2.04	0.40	1.92	0.96	8.22	3.06	2.91			0.25	0.50	0.12	0.18
Manganese	Monthly	3.00	2.95	3.15	2.63	2.21	3.03	2.27	2.73	4.27	2.56	4.86			4.40	2.80	5.10	1.62
Sulphate	Monthly	0.99	19.00	<5	3.60	<5	<1	<5	<1	<5	9.00	<5			0.45	0.38	<1	<1
Methane	Monthly	3.50	3.50				0.02		0.12						0.04	0.05	0.11	0.01

Colour Code	Sample Date
	23-Aug-07
	30-Aug-07
	29-Aug-07

Flow Sequence	Raw to all cells
	Raw - VF 1 - HF1
	Raw - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data

All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) September 2007

	Frequency	RAW 1	RAW 2	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Empty	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)				2400	2400	2400	2400	480	1200	2400	1200			4800	4800	4800	4800
Irrigation Rate (l/m^2/day)				945	945	945	945	189	472	945	472			192	192	192	192
Ammonium	Monthly	440	440	276	396	400	440	324	440	400	440			328	256	312	280
BOD_5	Monthly	41.05	31.20	65.90	40.15	28.80	36.32	21.15	37.10	80.10	36.50			38.30	40.05	24.02	52.15
COD	Monthly	324	337	328	308	331	327	283	324	355	326			319	329	283	307
TOC	Monthly	158	118	19	77	140	79	131	136	76	93			10	21	98	87
Chloride	Monthly	482.12	507.64	465.10	439.58	513.31	475.03	482.12	473.61	507.64	501.97			493.46	456.12	493.46	467.94
Cond. (mS/cm)	Monthly	4.95	5.40	4.50	4.76	4.94	4.97	4.70	5.13	5.17	5.27			4.61	4.40	4.74	4.42
Ph (pH Units)	Monthly	7.30	7.38	7.09	7.23	7.64	7.64	7.44	7.51	7.60	7.62			7.15	7.11	7.42	7.32
Sus.Sols	Monthly	50.80	44.64	33.20	10.80	13.30	19.58	5.10	59.60	50.00	52.20			9.27	5.20	4.30	6.50
Temp (°C)	Monthly	19.90	17.60	19.80	19.40	19.30	19.20	16.70	17.20	18.10	17.30			19.20	19.00	16.20	17.20
Ratio BOD:COD	Monthly	0.13	0.09	0.20	0.13	0.09	0.11	0.07	0.11	0.23	0.11			0.12	0.12	0.08	0.17
Iron	Monthly	9.20	9.43	5.00	2.56	3.28	2.64	0.29	13.40	8.03	9.93			1.35	1.49	1.71	0.40
Manganese	Monthly		0.93					2.68	2.06	0.81	2.02					2.66	1.18
Sulphate	Monthly	<5	<1		<5		<5	<1	4.70	2.30	<1					<1	<1
Methane	Monthly	6.30	5.60	1.20	0.19	4.00	4.30	0.01	5.00	1.50	4.80			0.36	0.23	0.20	0.04

Colour Code	Sample Date
	26-Sep-07
	03-Oct-07

Flow Sequence	Raw to all cells
	Raw - VF 1 - HF1
	Raw - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) October 2007

	Frequency	RAW 1	RAW 2	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Empty	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)				2400	2400	2400	2400	480	1200	2400	1200			2400	2400	2400	2400
Irrigation Rate ($l/m^2/day$)				945	945	945	945	189	472	945	472			96	96	96	96
Ammonium	Monthly	322	330	284	268	346	396	328	356	268	352			304	232	247	220
BOD_5	Monthly	128.00	29.20	63.70	60.20	129.00	130.00	25.70	40.10	26.10	34.70			88.50	72.32	8.30	21.12
COD	Monthly	455	278	344	308	478	481	300	324	274	302			446	396	274	251
TOC	Monthly	81	33	22	30	26	85	30	39	14	29			28	21	10	10
Chloride	Monthly	408.38	348.82	414.05	428.23	425.40	462.26	385.69	436.74	419.72	405.54			411.22	416.89	422.56	382.86
Cond. (mS/cm)	Monthly	4.45	4.22	4.28	4.26	4.49	4.74	4.27	4.45	4.05	4.42			4.42	4.13	3.72	3.68
pH (pH Units)	Monthly	7.37	7.22	7.50	7.29	7.84	7.81	7.66	7.52	7.53	7.64			7.25	7.08	7.91	7.32
Sus.Sols	Monthly	48.40	36.84	53.76	24.56	54.86	34.25	39.88	75.65	29.76	52.40			29.61	16.16	19.56	6.42
Temp (°C)	Monthly	15.00	15.40	12.50	13.50	12.50	13.70	14.50	14.40	14.70	14.30			12.80	13.00	15.70	14.40
Ratio BOD:COD	Monthly	0.28	0.11	0.19	0.20	0.27	0.27	0.09	0.12	0.10	0.11			0.20	0.18	0.03	0.08
Iron	Monthly	10.60	6.94	5.23	3.11	9.30	3.76	6.10	10.40	5.04	9.20			4.71	1.27	0.36	0.29
Manganese	Monthly	3.50	3.07	3.21	3.01	4.10	4.00	4.30	5.60	3.50	4.90			7.00	6.50	2.02	6.40
Sulphate	Monthly																
Methane	Monthly	6.60	9.20	0.20	0.10	1.00	2.40	3.50	5.30	3.80	6.00			0.30	0.10	0.20	0.20

Colour Code	Sample Date
	25-Oct-07
	31-Oct-07

Flow Sequence	Raw to all cells
	Raw - VF 1 - HF1
	Raw - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) November 2007

	Frequency	RAW 1	RAW 2	RAW 3	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					2400	2400	2400	2400	OFF	1200	2400	OFF		2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					945	945	945	945	OFF	472	945	OFF		945	96	96	96	96
Ammonium	Monthly	440	248	240	324	370	352	348	NA	256	224	NA		264	152	84	160	84
BOD_5	Monthly	13.30	23.60	22.20	44.30	44.03	62.00	44.60	NA	50.00	61.80	NA		53.00	90.00	42.67	52.90	24.95
COD	Monthly	263	198	193	266	268	253	255	NA	212	211	NA		264	309	234	242	179
TOC	Monthly	49	13	12	37	91	21	65	NA	UR	UR	NA		15	13	5	9	3
Chloride	Monthly	428.23	272.25	277.92	431.07	422.56	442.41	439.58	NA	314.79	311.96	NA		326.14	386.68	357.33	360.17	323.30
Cond. (mS/cm)	Monthly	4.36	3.13	3.12	4.29	4.38	4.43	4.34	NA	3.37	3.25	NA		3.25	3.39	2.95	3.05	2.63
pH (pH Units)	Monthly	7.29	7.36	7.50	7.82	7.65	7.75	7.64	NA	7.77	7.73	NA		7.56	6.98	6.90	7.46	7.29
Sus.Sols	Monthly	37.50	31.87	27.58	38.37	49.06	20.55	46.33	NA	39.06	30.08	NA		37.50	16.86	12.50	18.35	6.91
Temp (°C)	Monthly	14.00	14.20	14.50	12.10	12.00	11.90	12.20	NA	12.50	12.00	NA		12.90	12.00	11.80	11.10	11.80
Ratio BOD:COD	Monthly	0.05	0.12	0.12	0.17	0.16	0.25	0.17		0.24	0.29			0.20	0.29	0.18	0.22	0.14
Iron	Monthly	2.44	2.37	1.81	1.70	0.30	0.40	0.43	NA	2.36	1.04	NA		0.77	0.38	0.42	0.15	0.19
Iron	Monthly		1.38															
Manganese	Monthly	2.21	2.11	2.26	1.64	2.61	3.22	3.21	NA	2.50	2.08	NA		1.28	3.80	4.80	3.06	3.60
Manganese	Monthly		1.48	1.64														
Sulphate	Monthly	84.00	72.00		5.00	5.00	5.00	5.00	NA	60.00	86.00	NA		75.00			5.00	5.00
Methane	Monthly	11.00			3.50	5.00	2.80	4.40							0.10	0.10		

Colour Code	Sample Date
	05-Dec-07
	05-Dec-07
	27-Nov-07
	28-Nov-07

Flow Sequence	Raw to all cells
	Raw - CELL 10 - VF 1 - HF1
	Raw - CELL 1 - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
NA / OFF = No Sample Taken (Under repair)
Raw 3 is another leachate sample taken from plant header tank to test accuracy of results
UR = Under range
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) January 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					2400	2400	OFF	2400	480	1200	2400	OFF		2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					945	945	OFF	945	189	472	945	OFF		945	96	96	96	96
Ammonium	Monthly	130	180	2	140	66		110	140	160	120			110	9	6	21	15
BOD_5	Monthly	13.00	23.80	9.90	25.45	16.35		32.30	38.80	37.90	28.60			19.25	14.02	5.05	26.25	4.10
COD	Monthly	122	153	121	133	107		111	184	123	280			105	99	114	75	116
TOC	Monthly	36	20		20	34		37	20	43	20			35	32	20	27	20
Chloride	Monthly	186.46	235.39	175.83	224.02	147.47		146.05	272.26	192.84	205.61			151.72	146.05	155.98	126.20	144.63
Cond. (mS/cm)	Monthly	2.46	2.60	2.22	2.59	2.01		2.20	2.75	2.65	2.55			2.16	1.65	1.60	1.60	1.52
pH (pH Units)	Monthly	7.07	7.23	7.36	7.34	6.91		7.52	7.32	7.63	7.38			7.41	6.75	6.89	7.16	7.12
Sus.Sols	Monthly	62.40	18.40	13.60	10.40	9.20		14.00	11.20	33.20	10.40			9.60	4.40	5.20	9.20	6.80
Temp (°C)	Monthly	10.20	8.80	9.60	8.20	8.60		8.30	8.20	8.20	8.10			8.30	8.90	9.90	8.70	8.70
Ratio BOD:COD	Monthly	0.11	0.16	0.08	0.19	0.15		0.29	0.21	0.31	0.10			0.18	0.14	0.04	0.35	0.04
Iron	Monthly		1.99	3.04		0.69		1.16						2.38	0.54			
Iron	Monthly	3.48	5.56	1.92	3.22	0.82		1.33	1.02	2.25	1.22			0.40	0.14	0.43	0.05	0.07
Manganese	Monthly		3.40	0.28		2.91		3.06						1.38	2.10			
Manganese	Monthly	2.54	2.44	2.82	2.60	2.94		2.62	2.83	3.40	2.62			1.97	2.41	2.64	2.48	2.01
Sulphate	Monthly	43.00	11.30	27.40		25.20		25.60		5.00				5.00	32.80		23.50	
Methane	Monthly	4.20	4.20		0.10						0.10				0.00		0.00	

Colour Code	Sample Date
	07-Jan-08
	16-Jan-08

Flow Sequence	
	Raw to all cells
	Raw - CELL 10 - VF 1 - HF1
	Raw - CELL 1 - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
NA / OFF = No Sample Taken (Under repair)
Raw C is another leachate sample taken from plant header tank to test accuracy of results
Raw C Ammonium value of 2mg/l is most likely a lab error
TOC values for 7 Jan were all under range at 20mg/l
Sulphate Values <5 mg/l (represented as 5 in table to allow for calculations)
Heavy rain in January & at time of sampling
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) February 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					2400	2400	OFF	2400	OFF	1200	2400	OFF		2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					945	945	OFF	945	OFF	472	945	OFF		945	96	96	96	96
Ammonium	Monthly	260	368		192	100		359			208			347	208	21	129	32
BOD_5	Monthly	32.10	27.30		30.45	48.10		47.20			29.20			29.10	39.30	9.00	39.50	11.20
COD	Monthly	182	240		161	137		218			176			211	200	131	179	120
TOC	Monthly	46	46		41	37		40			40			41	37	33	33	32
Chloride	Monthly	275.09	459.43		286.43	224.04		416.80			300.61			340.32	334.64	232.55	365.84	266.58
Cond. (mS/cm)	Monthly	3.02	4.15		2.66	2.40		3.97			2.88			3.96	3.25	2.03	2.81	2.00
pH (pH Units)	Monthly	7.53	7.24		7.29	6.80		7.51			7.36			7.56	7.04	6.90	7.48	7.11
Sus.Sols	Monthly	44.40	42.00		7.60	6.00		18.00			23.60			9.20	3.60	1.60	33.60	2.00
Temp (°C)	Monthly	17.60	15.90		20.20	20.10		13.40						14.40	14.40	20.20	14.40	20.10
Ratio BOD:COD	Monthly	0.18	0.11		0.19	0.35		0.22			0.17			0.14	0.20	0.07	0.22	0.09
Iron	Monthly	7.40	5.35	5.17	1.01	0.42					2.53					0.08		0.12
Manganese	Monthly	3.17	2.68	1.82	3.30	3.46		2.02			2.90			2.45	2.73	2.99	1.80	2.53
Manganese	Monthly	3.70	3.90	3.80	3.30	3.46					2.90							2.53
Sulphate	Monthly	1.50	5.00		0.70	1.61		5.00			0.88			5.00	5.00	3.94	5.00	3.87
Methane	Monthly	4.20	4.20		0.10						0.10				0.00		0.00	

Colour Code	Sample Date
	13-Feb-08
	19-Feb-08

Flow Sequence	
	Raw to all cells
	Raw - CELL 10 - VF 1 - HF1
	Raw - CELL 1 - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
NA / OFF = No Sample Taken (Under repair)
Raw C is another leachate sample taken from plant header tank to test accuracy of results
Cell 6 - no sample due to clogging
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) March 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					2400	2400	2400	2400	OFF	1200	2400	1200		2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					945	945	945	945	OFF	472	945	472		945	96	96	96	96
Ammonium	Monthly	240	270		186	156	244	170		150	220	238		162	10	14	84	10
BOD_5	Monthly	15.30	13.00		26.30	62.70	25.65	40.20		14.30	21.70	12.30		24.00	15.20	23.70	18.60	8.60
COD	Monthly	134	227		145	228	206	145		160	132	208		124	117	193	135	164
TOC	Monthly	80			51	52	67	55		45	69	71		64	51	48	51	48
Chloride	Monthly	343	448		260	405	425	272		343	320	399		297	258	330	345	280
Cond. (mS/cm)	Monthly	2.97	4.12		2.89	3.59	3.97	2.75		3.10	2.94	3.93		2.80	2.26	2.80	2.59	2.44
pH (pH Units)	Monthly	7.30	7.24		7.43	7.10	7.82	7.35		7.35	7.55	7.63		7.24	6.76	6.92	7.22	7.13
Sus.Sols	Monthly	26.40	32.00		11.20	6.00	7.20	4.80		11.60	14.40	11.20		5.20	2.80	4.00	4.40	2.00
Temp (°C)	Monthly	10.80	14.90		7.90	13.90	14.50	8.20		14.30	8.00	14.60		9.10	9.30	12.70	9.00	13.80
Ratio BOD:COD	Monthly	0.11	0.06		0.18	0.28	0.12	0.28		0.09	0.16	0.06		0.19	0.13	0.12	0.14	0.05

Colour Code	Sample Date
	20-Mar-08
	26-Mar-08
	19-Mar-08

Flow Sequence	Raw to all cells
	Raw - CELL 10 - VF 1 - HF1
	Raw - CELL 1 - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
NA / OFF = No Sample Taken (Under repair)
All data in mg/l unless indicated otherwise

RESULTS for Metals & Salts - LEACHATE - CELLS / REED BEDS (mg/l) March 2008

	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium	Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Empty	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)				2400	2400	2400	2400	OFF	1200	2400	1200		2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)				945	945	945	945	OFF	472	945	472		945	96	96	96	96
Boron																	
Cadmium	0.001			0.001	0.001	0.001	0.001		0.001	0.001	0.001		0.001	0.001	0.001	0.001	0.001
Chromium	0.007			0.006	0.006	0.003	0.005		0.003	0.005	0.005		0.005	0.004	0.005	0.003	0.003
Copper	0.049			0.015	0.013	0.023	0.015		0.026	0.019	0.021		0.049	0.033	0.044	0.033	0.025
Iron	1.200		0.828	0.634	0.585	0.227	0.195		0.083	0.938	0.480		0.313	0.136	0.310	0.065	0.102
Lead	0.001		0.000	0.000	0.001	0.000	0.000		0.000	0.000	0.000		0.002	0.001	0.001	0.001	0.000
Magnesium																	
Manganese	2.03		2.54	1.90	2.46	0.15	2.77		2.28	1.34	0.21		1.34	2.43	3.02	0.41	2.59
Mercury																	
Nickel																	
Phosphate (P)																	
Potassium	205.00		198.00	179.00	197.00	195.00	186.50		157.00	202.50	200.00		191.50	181.00	186.50	162.50	163.50
Sodium	246		286	225	257	184	225		174	219	253		224	283	239	203	252
Sulphate																	
Zinc	0.026		0.022	0.017	0.033	0.008	0.029		0.016	0.011	0.011		0.065	0.038	0.079	0.019	0.012
Alk																	

Colour Code	Sample Date
	20-Mar-08
	26-Mar-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 10 - VF1 - HF1
Raw - Cell 1 - VF2 - HF2

Note: Blank Cells = no data
NA / OFF = No Sample Taken (Under repair)
Results for Cadmium all <0.001mg/l
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) April 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Stratified compost/ sand	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					3576	3576	2400	2400	480	1200	2400	1200	3864	3168	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					1408	1408	945	945	189	472	945	472	1521	1247	96	96	96	96
Ammonium	Monthly	360	384		324	275	352	324	216	160	372	380	292	270	13	55	16	62
BOD_5	Monthly	33.05	28.40		27.30	70.89	19.90	70.50	71.10	6.90	29.00	18.60	29.02	76.05	46.00	44.90	12.10	27.80
COD	Monthly	281	305		278	292	326	297	306	172	270	278	347	336	280	271	266	272
TOC	Monthly																	
Chloride	Monthly	411	454		428	437	445	440	440	329	454	451	434	423	408	403	386	437
Cond. (mS/cm)	Monthly	4.65	4.91		4.56	4.21	4.90	4.61	4.28	3.18	4.83	4.94	4.46	4.21	3.40	3.45	3.11	3.65
pH (pH Units)	Monthly	7.18	7.15		7.60	7.12	7.52	7.35	7.11	7.69	7.54	7.56	7.73	7.28	6.63	7.23	7.36	7.16
Sus.Sols	Monthly	48.00	38.40		30.50	10.00	11.20	4.80	4.00	4.40	26.80	9.60	33.20	17.00	5.60	4.80	5.60	1.20
Temp (°C)	Monthly	12.30	15.60		10.40	10.90	15.50	13.40	14.50	17.20	14.10	15.00	11.30	11.20	10.80	10.90	10.80	13.00
Ratio BOD:COD	Monthly	0.12	0.09		0.10	0.24	0.06	0.24	0.23	0.04	0.11	0.07	0.08	0.23	0.16	0.17	0.05	0.10
Iron	Monthly	16.70	13.40	14.00	7.00	3.09	2.46	1.70	1.11	0.24	5.56	2.48	2.64	0.91	0.56	1.18	0.15	0.42
Manganese	Monthly	3.69	3.33	3.93	3.30	2.96	4.05	2.76	4.86	5.50	3.25	5.10	1.80	1.65	5.21	3.10	1.31	3.35

Colour Code	Sample Date
	16-Apr-08
	23-Apr-08

Flow Sequence	Raw to all cells
	Raw - CELL 10 - VF 1 - HF1
	Raw - CELL 1 - VF 2 - HF 2

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
NA / OFF = No Sample Taken (Under repair)
Noted that VF 1 and VF 2 were not filling to required volume - increased dosing volume to Cells 1, 2, 9 and 10 - loss in volume between units likely due to evapo-transpiration
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) May 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)	14-May-08				3576	3576	2400	1800	480	1200	2400	1200	3876	3180	2400	1800	2400	1800
Irrigation Rate (l/m^2/day)	14-May-08				1408	1408	945	709	189	472	945	472	1526	1252	945	709	945	709
Irrigation Rate (l/unit/day)	21-May-08				3576	3576	2400	1800	240	1200	1200	1200	2400	2400	2400	1800	2400	1800
Irrigation Rate (l/m^2/day)	21-May-08				1408	1408	945	709	94	472	472	472	945	945	945	709	945	709
Ammonium	Monthly	365	392		356	284	380	217	124	348	400	384	277	260	14	27	25	15
BOD_5	Monthly	22.90	22.60		18.10	45.90	40.30	46.20	12.55	28.45	57.90	17.68	20.80	30.70	17.20	11.80	3.20	11.68
COD	Monthly	228	252		210	247	312	221	214	261	242	254	204	202	214	183	254	205
TOC	Monthly	83			80	78		76	72	80	78	82	86	77	72	39	75	71
Chloride	Monthly	431	447		423	444	489	428	496	503	482	475	440	496	434	462	454	418
Cond. (mS/cm)	Monthly	4.61	4.47		4.51	4.19	4.28	3.82	3.99	4.78	4.69	4.81	4.24	4.09	3.17	3.24	3.41	3.13
pH (pH Units)	Monthly	7.19	7.60		7.72	7.57	8.18	7.48	7.52	7.84	7.97	7.90	7.52	7.79	7.14	6.64	7.53	7.51
Sus.Sols	Monthly	41.00	31.50		21.00	8.00	13.00	3.50	4.00	44.00	58.00	44.50	11.50	5.00	9.50	4.00	5.00	3.00
Temp (°C)	Monthly	18.10	14.50		17.70	20.90	13.90	21.00	13.60	13.20	13.30	13.90	19.40	20.10	19.90	20.30	13.90	14.70
Ratio BOD:COD	Monthly	0.10	0.09		0.09	0.19	0.13	0.21	0.06	0.11	0.24	0.07	0.10	0.15	0.08	0.06	0.01	0.06
Iron	Monthly	10.75		10.90	4.93	1.61		0.54	0.50	3.42	4.14	2.10	2.44	1.60	1.66	1.17	0.25	0.91
Manganese	Monthly	3.50		3.60	2.35	2.23		2.27	6.40	3.09	2.83	4.75	2.10	1.81	4.00	4.40	2.87	3.16
Sulphate	Monthly	<5	<5		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Methane	Monthly	14.00	6.60		0.70	0.10	0.10	0.00	0.00	0.80	0.20	0.20	0.20	0.10	0.00	0.00	0.20	0.02

Colour Code	Sample Date
	14-May-08
	21-May-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 2 - Cell 4 - VF2 - HF2
Raw - Cell 9 - Cell 10 - VF1 - HF1

Note: Blank Cells = no data
Cell 3 contents (Stratified Compost - Sand - Compost - Sand) dug out & replaced with Timber Chip - 13 May 08
Noted reduction in flow volume to pumps sump for Cell 4 and VF 2 (25% reduction). Perhaps due to evapo-transpiration in Cell 2 (Willow trees in Compost)
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) June 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					3060	3060	2400	2400	240	600	1200	600	2400	2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					1205	1205	945	945	94	236	472	236	945	945	96	96	96	96
Ammonium	Monthly	440	308		400	400	160	384	68	316	400	400	84	116	7	96	4	75
Nitrate	Monthly	30	23		36	33	640	41	1000	37	30	31	323	325	740	570	860	780
BOD_5	Monthly	27.85	35.30		53.30	36.80	41.30	85.20	15.20	89.10	81.45	98.25	104.48	105.05	26.15	13.45	8.60	20.40
COD	Monthly	293	208		292	295	240	291	258	236	256	275	457	402	289	292	191	240
TOC	Monthly		100		90	92	88	97	80	88	90	88	86	80	76	88	84	86
Chloride	Monthly	844	376		546	539	383	532	432	461	461	496	532	539	510	525	461	461
Cond. (mS/cm)	Monthly	5.34	3.80		5.22	5.09	3.38	4.87	3.40	4.25	4.26	4.64	4.19	4.22	3.86	3.88	3.09	3.18
pH (pH Units)	Monthly	7.19			7.68	7.82		7.81					7.05	7.64	6.53	7.25		
Sus.Sols	Monthly	34.50	28.00		36.00	23.50	9.00	6.50	4.50	18.00	63.50	46.50	7.50	5.50	6.00	3.00	11.00	5.00
Temp (°C)	Monthly	17.40	16.90		17.27	17.20	16.90	17.40	17.00	16.70	17.00	16.90	17.40	17.60	17.30	17.70	18.10	17.90
Ratio BOD:COD	Monthly	0.10	0.17		0.18	0.12	0.17	0.29	0.06	0.38	0.32	0.36	0.23	0.26	0.09	0.05	0.05	0.09
Iron	Monthly	11.55		16.85	10.50	5.95	3.15	1.54	1.24	3.69	17.45	10.85	1.43	0.76	0.99	0.82	0.30	0.39
Manganese	Monthly	3.07		3.89	2.89	2.97	1.60	2.12	5.90	3.05	4.24	4.34	2.83	2.28	3.52	0.03	2.80	2.97

Colour Code	Sample Date
	18-Jun-08
	25-Jun-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 2 - Cell 4 - VF2 - HF2
Raw - Cell 9 - Cell 10 - VF1 - HF1

Note: Blank Cells = no data
Reduction in flow volume to Cell 4 and VF 2 likely due to evapo-transpiration
Noted wilting and die back of leaves on willow trees in Cell 2 and Cell 6 (16 June 08)
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) July 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					3060	OFF	2400	2400	240	OFF	1200	600	2400	2400	2400	2400	2400	2400
Irrigation Rate (l/m^2/day)					1205	OFF	945	945	94	OFF	472	236	945	945	96	96	96	96
Ammonium	Monthly	237			234		112	210	114		216	190	56	42	0	41	1	20
Nitrate (TON)	Monthly	148			70		772	165	359		252	206	752	574	797	686	657	715
BOD_5	Monthly	17.00			13.60		21.10	79.10	21.30		8.30	18.70	61.90	40.40	1.50	33.30	3.00	5.70
COD	Monthly	207			189		177	196	174		198	169	220	218	147	201	145	183
TOC	Monthly	61			56		52	55	58		59	51	52	51	53	55	49	48
Chloride	Monthly	319			326		305	312	305		305	269	319	319	305	319	333	312
Cond. (mS/cm)	Monthly	3.37			3.23		2.83	3.03	2.70		2.97	2.80	2.57	2.44	2.22	2.37	2.06	2.16
pH (pH Units)	Monthly	7.21			7.78		7.08	7.98	7.12		7.46	7.60	6.83	7.28	7.50	6.90	6.88	7.04
Sus.Sols	Monthly	27.50			25.00		5.00	15.00	2.50		65.00	27.50	3.50	3.00	3.00	4.00	4.00	3.00
Temp (°C)	Monthly	19.80			18.70		19.10	22.50	19.40		19.60	19.00	20.20	18.70	18.50	18.70	19.70	19.40
Ratio BOD:COD	Monthly	0.08			0.07		0.12	0.40	0.12		0.04	0.11	0.28	0.19	0.01	0.17	0.02	0.03
Iron	Monthly	2.52			0.86		0.55	0.83	1.19		2.25	2.06	0.57	0.23	0.14	0.01	0.01	0.19
Manganese	Monthly	2.23			1.36		1.61	1.38	5.90		3.85	2.11	2.08	1.79	0.81	1.92	1.37	2.98

Colour Code	Sample Date
	17-Jul-08
NH_4, TON & TOC	16-Jul-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 4 - VF2 - HF 2
Raw - Cell 9 - Cell 10 - VF 1 - HF 1

Note: Blank Cells = no data
Cells 2 & 6 off - osmotic shock - poor treatment efficiencies
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) August 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					3060	OFF	240	2400	240	OFF	1200	600	2400	2400	2400	2400	2400	2400
Irrigation Rate ($l/m^2/day$)					1205	OFF	94	945	94	OFF	472	236	945	945	96	96	96	96
Ammonium	Monthly	249			248		7	234	2		245	244	76	75	1	0.4	2	28
Nitrate (TON)	Monthly	236			211		938	417	880		314	157	746	554	764	786	670	531
BOD_5	Monthly																	
COD	Monthly																	
TOC	Monthly	60			59		66	58	57		57	59	55	52	52	55	54	46
Chloride	Monthly																	
Cond. (mS/cm)	Monthly																	
pH (pH Units)	Monthly																	
Sus.Sols	Monthly																	
Temp (°C)	Monthly																	
Ratio BOD:COD	Monthly																	
Iron	Monthly																	
Manganese	Monthly																	
Sulphate	Monthly																	
Methane	Monthly																	

Colour Code	Sample Date
	08-Aug-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - HF 2
Raw - Cell 3 - Cell 5

Note: Blank Cells = no data
NH_4, TON & TOC only samples taken for August 08
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) September 2008

	Frequency	RAW 1	RAW 2	RAW 3	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					3060	OFF	240	2400	240	240	1200	600	2400	2400	2400	2400	OFF	2400
Irrigation Rate (l/m^2/day)					1205	OFF	94	945	94	94	472	236	945	945	96	96	OFF	96
Ammonium	Monthly	230			215		13	194	0.4		215	228	134	71	2	0.4		1
Nitrate (TON)	Monthly	149			322		806	112	734		124	198	533	335	635	635		531
BOD_5	Monthly	15.70	18.60		25.70		8.00	25.30	3.50		8.30	72.60	13.30	5.80	3.00	0.70		0.70
COD	Monthly	184	294		251		134	213	122		162	205	152	122	110	107		98
TOC	Monthly	326			352		157	332	125		355	325	254	135	118	104		84
Chloride	Monthly	277	468		425		266	355	241		305	241	298	291	312	284		255
Cond. (mS/cm)	Monthly	3.06	4.14		3.98		2.29	3.71	2.15		2.95	2.82	2.56	2.27	2.01	1.98		1.81
pH (pH Units)	Monthly	7.16	7.23		7.72		6.80	7.76	7.61		7.72	8.01	7.23	7.74	7.44	7.91		7.65
Sus.Sols	Monthly	27.75	34.00		30.00		1.50	13.00	2.90		12.35	5.50	5.30	3.50	11.05	6.05		6.00
Temp (°C)	Monthly	16.90	16.90		15.70		17.10	15.70	16.20		16.10	16.40	16.60	16.70	17.00	16.40		16.80
Ratio BOD:COD	Monthly	0.09			0.10		0.06	0.12	0.03		0.05	0.35	0.09	0.05	0.03	0.01		0.01
Iron	Monthly	8.05			7.85		0.69	3.44	0.38	5.50	8.30	2.29		0.35	1.00	0.17		0.90
Manganese	Monthly	2.98			3.18		0.52	2.31	0.31	2.67	3.98	2.62		2.42	1.28	0.29		0.27
Sulphate	Monthly																	
Methane	Monthly	9.80	20.00	13.00	3.00		0.10	0.40	0.00	0.60		0.30	0.20	0.01	0.00	0.00		0.00

Colour Code	Sample Date
	18-Sep-08
	24-Sep-08
Methane	24-Sep-08
Methane	01-Oct-08
Methane	08-Oct-08

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - HF 2
Raw - Cell 3 - Cell 5

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Note: Blank Cells = no data
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE and CELLS / REED BEDS (mg/l) October 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)
Irrigation Rate (l/unit/day)					1200	480	240	1200	240	240	OFF	OFF	2400	2400	2400	2400	OFF	240
Irrigation Rate (l/m^2/day)					472	189	94	472	94	94	OFF	OFF	945	945	96	96	OFF	10
Ammonium	Monthly	279			298	NO FLOW	23	259	1	214			163	99	10	1		2
Nitrate (TON)	Monthly	87			153		1207	368	37	554			459	756	1050	1013		934
BOD_5	Monthly	13.28	20.07		24.62		49.37	37.92	1.20	50.70			54.48	66.48	9.83	1.20		0.40
COD	Monthly	216	228		193		155	193	149	299			276	190	187	128		164
TOC	Monthly	437			525		108	459	95	436			402	240	122	70		81
Chloride	Monthly	390	383		404		383	447	411	418			397	390	390	418		411
Cond. (mS/cm)	Monthly	3.67	3.17		3.30		2.50	3.36	2.50	3.45			3.25	3.01	2.69	2.63		2.58
pH (pH Units)	Monthly	7.40	7.24		7.50		6.96	7.55	7.37	7.40			6.91	7.54	6.70	7.20		7.37
Sus.Sols	Monthly	18.30	31.00		134.50		2.50	2.00	1.00	12.75			13.55	4.60	3.60	23.75		9.20
Temp (°C)	Monthly	14.00	11.50		9.10		9.60	8.60	9.10	12.50			11.80	11.90	12.30	12.20		12.80
Ratio BOD:COD	Monthly	0.06	0.09		0.13		0.32	0.20	0.01	0.17			0.20	0.35	0.05	0.01		0.00
Iron	Monthly	4.92	4.10	1.01	6.15		1.02	0.76	0.42	3.54			2.42	1.14	0.58	0.31		0.31
Manganese	Monthly	2.43	2.21	3.26	2.59		0.72	1.86	0.52	2.47			2.87	2.38	2.18	1.45		1.11
Sulphate	Monthly	<5	<5		<5		<5	<5	<5	<5			<5	<5	<5	<5		<5

Colour Code	Sample Date
	22-Oct-08
	29-Oct-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2
Raw - Cell 3 - Cell 5 - HF2

Note: Blank Cells = no data
No flow from Cell 2
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) December 2008

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2	N1	N2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)					1200	480	240	1200	240	240	OFF	OFF	2400	2400	2400	2400	OFF	240	2400	2400
Irrigation Rate (l/m^2/day)					472	189	94	472	94	94	OFF	OFF	945	945	96	96	OFF	10		
Ammonium	Monthly	283			260	NO FLOW	135	203	31	244			160	142	86	39		33	28	27
Nitrate (TON)	Monthly	83			219		649	479	1195	347			740	975	1091	1228		1170	975	992
BOD_5	Monthly	24.90	10.90		19.70		22.50	14.80	15.00	14.60			59.30	72.60	46.35	19.75		13.55	10.5	11.6
COD	Monthly	240	239		277		248	221	159	223			261	254	264	232		204	206	219
TOC	Monthly	475			397		103	344	83	397			256	190	162	95		105	140	150
Chloride	Monthly	454	454		418		418	425	418	404			425	418	415	418		415	383	383
Cond. (mS/cm)	Monthly	3.35	2.60		2.50		2.40	2.10	2.00	2.50			2.78	2.67	2.61	2.56		2.32	2.18	2.32
pH (pH Units)	Monthly	7.15	7.40		7.27		7.52	7.32	6.50	7.34			6.95	7.53	7.06	7.11		7.42	7.48	7.56
Sus.Sols	Monthly	22.50	19.00		9.50		6.50	3.50	3.00	10.50			59.30	72.60	46.35	19.75		13.55	10.5	11.6
Temp (°C)	Monthly	14.90	10.70		10.10		10.00	9.80	9.50	9.00			12.20	12.30	13.20	14.30		13.20	13	13.5
Ratio BOD:COD	Monthly	0.10	0.05		0.07		0.09	0.07	0.09	0.07			0.23	0.29	0.18	0.09		0.07	0.05	0.05
Iron	Monthly	7.50		5.68	3.59		1.73	0.59	0.68	3.68			2.16	1.34	0.78	0.55		0.36	0.33	0.35
Manganese	Monthly	3.10		3.28	3.14		0.35	2.70	1.10	2.78			2.77	1.42	1.42	1.31		0.49	0.45	0.50

Colour Code	Sample Date
	10-Dec-08
	18-Dec-08

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - N1 - N2
Raw - Cell 3 - Cell 5 - HF2

Note: Blank Cells = no data
No flow from Cell 2
No data for Nov 09
Added de-nitrifying tanks - N 1 and N 2
Lemna minor (Duckweed) placed in HF 2
All data in mg/l unless indicated otherwise

Results for Metals & Salts - LEACHATE - CELLS / REED BEDS (mg/l) December 2008

	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2	N 1	N 2
Medium	Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)				1200	480	240	1200	240	240	OFF	OFF	2400	2400	2400	2400	OFF	240	2400	2400
Irrigation Rate (l/m^2/day)				472	189	94	472	94	94	OFF	OFF	945	945	96	96	OFF	10		
Boron																			
Cadmium	0.000		0.000	0.000	NO FLOW	0.000	0.000	0.000	0.000			0.000	0.000	0.000	0.000		0.000	0.000	0.000
Chromium	0.005		0.005	0.005		0.004	0.004	0.003	0.005			0.004	0.003	0.003	0.003		0.003	0.002	0.002
Copper	0.006		0.015	0.026		0.034	0.009	0.041	0.014			0.011	0.010	0.024	0.025		0.021	0.018	0.026
Iron	7.50		5.68	3.59		1.73	0.59	0.68	3.68			2.16	1.34	0.78	0.55		0.36	0.33	0.35
Lead	0.001		0.001	0.001		0.004	0.001	0.001	0.001			0.001	0.002	0.001	0.001		0.000	0.000	0.000
Magnesium	68.55		68.92	58.88		63.44	67.57	65.25	62.16			65.64	57.21	62.71	59.48				
Manganese	3.10		3.28	3.14		0.35	2.70	1.10	2.78			2.77	1.42	1.42	1.31		0.49	0.45	0.50
Mercury																			
Nickel	0.032		0.028	0.055		0.047	0.043	0.046	0.045			0.044	0.033	0.005	0.005		0.005	0.005	0.005
Phosphate (P)																			
Potassium	188.0		174.0	155.5		164.5	155.5	157.0	164.0			187.0	181.0	188.0	173.0				
Sodium	284.0		284.0	206.0		230.5	214.0	212.5	250.5			284.0	242.0	298.0	291.0				
Sulphate																			
Zinc	0.033		0.051	0.039		0.143	0.046	0.099	0.036			0.072	0.057	0.083	0.120		0.058	0.057	0.061

Colour Code	Sample Date
	10-Dec-08

Unit	Area
Cells	2.54m^2
Reed Beds	25m^2

Flow Sequence
Raw to all cells
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - N1 - N2
Raw - Cell 3 - Cell 5 - HF2

Note: Blank Cells = no data
No flow from Cell 2
Added de-nitrifying tanks - N 1 and N 2
Lemna minor (Duckweed) placed in HF 2
Weather has been very cold for last 2 weeks ~ 0 - 4 *C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) January 2009

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2	N1	N2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)					600	600	240	600	240	240	OFF	OFF	2400	2400	2400	2400	OFF	2400	2400	2400
Irrigation Rate (l/m^2/day)					236	236	94	236	94	94	OFF	OFF	945	945	96	96	OFF	96		
Ammonium	Monthly	382			328	No Flow	134	227	20	244			226	188	122	17		41	42	44
Nitrate (TON)	Monthly	116			281		1120	802	1418	347			860	918	1161	860		951	996	1009
BOD_5	Monthly	20.40	10.00		9.90		41.25	23.97	11.75	35.25			79.60	82.80	58.20	4.70		6.25	56.6	56.3
COD	Monthly	420	156		128		247	244	314	109			342	325	296	150		230	324	331
TOC	Monthly	78			78		67	71	63	71			83	74	72	42		58	81	85
Chloride	Monthly	588	275		306		581	335	574	261			574	588	574	425		475	468	482
Cond. (mS/cm)	Monthly	4.78	2.28		2.51		3.98	2.74	3.51	2.25			4.19	4.10	3.88	2.26		3.04	3.06	3.11
pH (pH Units)	Monthly	7.21	7.09		7.51		7.10	6.91	6.45	7.65			7.43	7.52	7.15	7.12		7.27	7.31	7.34
Sus.Sols	Monthly	32.00	80.00		9.50		4.50	1.50	3.50	10.50			13.00	9.50	5.00	4.50		4.00	21.5	30.5
Temp (°C)	Monthly	15.40	10.70		8.40		14.30	8.20	14.90	9.70			14.20	13.40	14.60	15.90		16.90	15.6	16.2
Ratio BOD:COD	Monthly	0.05	0.06		0.08		0.17	0.10	0.04	0.32			0.23	0.25	0.20	0.03		0.03	0.17	0.17

Colour Code	Sample Date
	14-Jan-09
	22-Jan-09

Unit	Area
Cells	2.54m^2
Reed Beds	25m^2

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - HF 2 - N 1 - N 2
Raw - Cell 3 - Cel 5
Raw - Cell 2
Raw - Cell 6

Note: Blank Cells = no data
No flow from Cell 2
Weather has been very cold for last 2 weeks ~ 0 - 4 *C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) February 2009

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2	N1	N2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)					600	1200	480	600	480	240	OFF	OFF	1200	1200	1200	1200	OFF	OFF	1200	1200
Irrigation Rate (l/m^2/day)					236	472	189	236	189	94	OFF	OFF	472	472	48	48	OFF	OFF		
Ammonium	Monthly	382			358	No Flow	248	279	94	371			184	103	14	0			0	0
Nitrate (TON)	Monthly	304			99		539	143	1159	366			924	924	1153	1283			1525	980
BOD_5	Monthly	24.00	22.78		59.80		94.95	52.60	35.00	21.85			21.30	9.45	6.40	6.60			13.6	11
COD	Monthly	292	338		295		272	249	232	307			232	189	161	129			155	165
TOC	Monthly	83			81		72	71	71	79			72	67	56	51			111	107
Chloride	Monthly	436	496		440		425	408	440	461			397	404	404	347			340	326
Cond. (mS/cm)	Monthly	4.01	4.60		4.28		3.94	3.82	3.41	4.42			3.32	2.99	2.48	2.27			2.23	2.18
pH (pH Units)	Monthly	7.09	7.11		7.60		7.42	7.67	7.29	7.61			6.99	7.27	6.64	7.15			7.3	7.26
Sus.Sols	Monthly	54.50	43.15		25.85		9.75	4.55	3.40	15.00			6.00	2.00	1.00	1.50			2	3
Temp (°C)	Monthly	12.50	14.80		13.60		14.10	14.20	13.40	13.80			10.90	11.50	11.70	10.90			10.9	11.5
Ratio BOD:COD	Monthly	0.08	0.07		0.20		0.35	0.21	0.15	0.07			0.09	0.05	0.04	0.05			0.09	0.07

Colour Code	Sample Date
	17-Feb-09
	25-Feb-09
NH4, NO3 & TOC	27-Feb-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - N 1 - N 2
Raw - Cell 3 - Cel 5
Raw - Cell 2
Raw - Cell 6

Note: Blank Cells = no data
No flow from Cell 2
Weather has been very cold for last 2 weeks ~ 0 - 4 *C
Weather was quite mild ~ 10* C
Commenced Sugar Dosing - N1 - N2
HF 2 - off - problems with maintaining levels
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) March 2009

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2	N1	N2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)					600	2400	240	600	240	240	OFF	OFF	1200	1200	1200	1200	OFF	OFF	1200	1200
Irrigation Rate (l/m^2/day)					236	945	94	236	94	94	OFF	OFF	472	472	48	48	OFF	OFF		
Ammonium	Monthly	376			385	378	200	313	16	378			347	128	13	0			0	7
Nitrate	Monthly	198.00			55.98	60.00	927.00	235.00	1338.99	253.96			824.00	759.00	1026.00	1131.00			1389.00	1320.00
Nitrite	Monthly	0.003			0.03	2.00	34.00	44.00	0.01	0.04			19.00	4.00	9.00	4.00			12	19
TON	Monthly	198			56	62	961	279	1339	254			843	763	1035	1135			1401	1339
BOD_5	Monthly																			
COD	Monthly																			
TOC	Monthly	92			78	84	74	77	69	90			73	69	64	56			76	65
Chloride	Monthly	489			468	454	461	461	454	475			454	475	447	454			461	468
Cond. (mS/cm)	Monthly	4.55			4.66	4.60	3.99	4.26	3.39	4.57			3.79	3.65	3.25	3.19			3.16	3.14
pH (pH Units)	Monthly	7.35			7.71	7.68	7.50	7.61	6.68	7.53			7.67	7.40	6.67	7.56			6.91	6.96
Sus.Sols	Monthly																			
Temp (°C)	Monthly	17.80			16.30	16.50	16.70	15.90	15.80	14.50			15.30	15.10	14.00	13.00			14.3	14.8
Ratio BOD:COD	Monthly																			

Colour Code	Sample Date
	26-Mar-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - N 1 - N 2
Raw - Cell 3 - Cel 5
Raw - Cell 2
Raw - Cell 6

Note: Blank Cells = no data
Weather was quite mild ~ 10* C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) April 2009

	Frequency	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1	HF 2	N1	N2
Medium		Leachate	Leachate	Leachate	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Horizontal Flow Reed Bed (*Sparganium* in sub-soil)	Horizontal Flow Reed Bed (*Sparganium* in gravel)	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)					600	2400	240	600	240	240	OFF	OFF	1200	1200	1200	1200	OFF	OFF	1200	1200
Irrigation Rate (l/m^2/day)					236	945	94	236	94	94	OFF	OFF	472	472	48	48	OFF	OFF		
Ammonium	Monthly	263			292	263	112	324	0	263			137	65	4	2			4	4
Nitrate	Monthly	61.99			36.99	55.95	445.00	31.00	1034.00	124.00			122.00	417.00	773.00	734.00			756.00	868.00
Nitrite	Monthly	0.009			0.01	0.05	1.00	12.00	1.00	0.01			2.00	23.00	2.00	4.00				
TON	Monthly	62			37	56	446	43	1035	124			124	440	775	738			756	868
BOD_5	Monthly																			
COD	Monthly																			
TOC	Monthly	51			64	53	48	78	48	53			67	55	51	46			50	50
Chloride	Monthly																			
Cond. (mS/cm)	Monthly																			
pH (pH Units)	Monthly																			
Sus.Sols	Monthly																			
Temp (°C)	Monthly																			
Ratio BOD:COD	Monthly																			
Iron	Monthly																			
Manganese	Monthly																			
Sulphate	Monthly																			
Methane	Monthly																			

Colour Code	Sample Date
	22-Apr-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - N 1 - N 2
Raw - Cell 3 - Cel 5
Raw - Cell 2
Raw - Cell 6

Note: Blank Cells = no data
Weather was quite mild ~ 10* C
All data in mg/l unless indicated otherwise

REULTS for LEACHATE - CELLS / REED BEDS (mg/l) May 2009

	Frequency	RAW 1	RAW 2	RAW C	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2
Medium		Leachate	Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Sub-soil	Mixed sand / subsoil / compost	Compost (coarse) & Timber Chip	Compost - coarse	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2
Irrigation Rate (l/unit/day)						600	OFF	240	600	240	OFF	OFF	OFF	2400	2400	2400	2400	2400	2400	OFF	OFF
Irrigation Rate (l/m^2/day)						236	OFF	94	236	94	OFF	OFF	OFF	945	945	96	96	96	96	OFF	OFF
Ammonium	Monthly	297			347	295		95	247	7				187	185	65	14	14	7		
Nitrate	Monthly	0			0	37		760	0	1032				381	396	819	887	949	834		
Nitrite	Monthly	0.013			0.01	0.00		3.00	18.00	3.00				41.00	26.00	37.00	12.00	12.00	9.00		
TON	Monthly	0			0	37		763	0	1035				422	422	856	899	961	843		
BOD_5	Monthly	11.10			610.00	6.80		39.40	9.60	5.20				33.50	18.30	19.00	3.35	OR	5.20		
COD	Monthly	236			979	259		206		184				237	241	233	184	153	141		
TOC	Monthly	63			214	64		56	69	53				60	61	61	57	48	42		
Chloride	Monthly	372			596	408		431	394	414				366	374	380	366	352	329		
Cond. (mS/cm)	Monthly	3.63			5.09	3.74		3.28	3.36	3.31				3.31	3.29	3.07	2.76	2.65	2.45		
pH (pH Units)	Monthly	7.63			7.63	7.72		7.41	7.84	6.74				7.35	7.68	6.98	6.99	7.67	7.49		
Sus.Sols	Monthly	27.50			276.88	15.50		8.00	5.50	9.00				10.50	8.00	4.50	11.00	10.50	5.50		
Temp (°C)	Monthly	24.10			24.40	24.00		24.00	24.20	24.10				24.00	24.10	24.10	24.20	24.20	24.30		
Ratio BOD:COD	Monthly	0.05			0.62	0.03		0.19		0.03				0.14	0.08	0.08	0.02		0.04		

Colour Code	Sample Date
	21-May-09

Unit	Area
Cells	2.54m^2
Reed Beds	25m^2

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
Raw - Cell 3 - Cel 5

Note: Blank Cells = no data
Weather was quite mild ~ 10* C
Raw Active is a sample taken from a well receiving leachate from the active tipping area, i.e. fresh leachate
HF 1 converted to VP 1 and HF 2 converted to VP 2 - (former reed beds now planted with grass)
OR = Sample conc. over range of meter setting
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) June 2009

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96	
Ammonium	Monthly	407		841	268		52	25	0		229	113	295	261	67	11	0	0	1
Nitrate	Monthly	0		0	211		1109	583	1126		578	1011	284	400	795	1138	1315	1137	29
Nitrite	Monthly	0.019		0.032	0.01		1.00		2.00		73.00	55.00	1.00	3.00	36.00	15.00	6.00	4.00	0.057
TON	Monthly	0		0	211		1110	583	1228		651	1066	285	403	831	1153	1321	1141	102
BOD_5	Monthly	24.95		224.00	16.00		20.90	36.80	2.15		49.50	51.40	23.90	30.60	29.40	31.20	1.00	1.00	2
COD	Monthly	345		1050	296		251		284		377	372	413	392	393	370	200	170	9
TOC	Monthly	93		413	67		66	57	54		74	71	72	83	85	83	70	67	1.3
Chloride	Monthly	474		1092	425		440	442	431		428	431	434	423	423	423	417	411	23
Cond. (mS/cm)	Monthly	4.67		10.19	3.80		3.41	3.11	3.16		4.09	3.69	4.18	3.96	3.33	3.13	3.07	3.03	368 µS/cm
pH (pH Units)	Monthly	7.31		7.40	7.37		6.97	7.09	7.05		7.18	7.46	7.45	7.90	7.06	6.96	7.14	7.60	7.6
Sus.Sols	Monthly	30.00		224.00	14.00		8.00	12.50	9.50		18.00	13.00	14.50	10.00	9.00	9.00	36.50	11.50	2
Temp (°C)	Monthly	24.20		24.20	24.20		24.30	24.30	24.00		24.20	24.30	24.20	24.20	24.20	24.10	24.10	24.10	24.1
Daphnia magna	Toxic Units	5.10		13.30	2.90		1.30						3.10					< 1	< 1
5 min EC 50 - *Vibrio fischeri*	Toxic Units	< 2.2		52.90	< 2.2		< 2.2						< 2.2					< 2.2	< 2.2
15 min EC 50 - *Vibrio fischeri*	Toxic Units	< 2.2		69.40	< 2.2		< 2.2						< 2.2					< 2.2	< 2.2
Ratio BOD:COD	Monthly	0.07		0.21	0.05		0.08		0.01		0.13	0.14	0.06	0.08	0.07	0.08	0.01	0.01	

Colour Code	Sample Date
	29-Jun-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was quite mild ~ 15* C - rain previous day (28/06/09 - may account for high nitrate level of 29mg/l in Tramore river)
Full suite of metals & salts tested
List I and List II Organics and toxicity test also carried out (*Daphnia magna & Vibrio fischeri)*
Media change in Cell 7 and 8 - (Cell 7 was Subsoil - now Timber Chip) (Cell 8 was Sand / Soil / Compost now Timber Chip)
Media change in Cell 10 - was Coarse Compost, now timber chip & coarse compost
Cells 2 & 6 are off
N1 and N2 removed
All data in mg/l unless indicated otherwise

RESULTS for Metals & Salts - LEACHATE - CELLS / REED BEDS / Tramore River (mg/l) June 2009

	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
Irrigation Rate (l/unit/day)				600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)				236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96	
Boron	1.36		< 0.02	1.39		1.14						1.26					1.00	0.14
Cadmium	0.002		0.001	0.002		0.001	0.001	0.001		0.001	0.002	0.002	0.001	0.006	0.001	0.006	0.010	0.000
Chromium	0.010		0.087	0.007		0.010	0.004	0.002		0.008	0.004	0.007	0.009	0.004	0.001	0.002	0.001	0.000
Copper	0.020		0.002	0.041		0.053	0.042	0.043		0.088	0.092	0.046	0.089	0.089	0.093	0.094	0.098	0.017
Iron	10.600		6.600	4.460		1.900	0.264	0.663		4.310	2.120	5.280	2.460	1.510	1.150	0.306	1.170	0.227
Lead	0.000		0.011	0.002		0.006	0.002	0.001		0.003	0.015	0.001	0.008	0.005	0.003	0.001	0.002	0.000
Magnesium	55.310		195.600	49.010		55.250	67.360	52.390		57.620	59.620	59.730	61.300	64.430	62.960	56.270	53.180	6.751
Manganese	2.940		2.700	2.900		2.790	3.760	1.190		2.490	1.690	3.030	1.480	1.770	2.380	0.485	0.148	0.090
Mercury	< 0.02		< 0.02	< 0.02		< 0.02						< 0.02					< 0.02	< 0.02
Nickel	0.153		0.040	0.141		0.045	0.048	0.043		0.047	0.049	0.048	0.049	0.050	0.054	0.056	0.059	0.007
Phosphate (P)	0.501		0.801	1.020		0.130	0.417	0.125			0.073	0.434	0.224	0.184	0.095	0.058	0.070	0.072
Potassium	195.0		547.0	177.0		182.0	150.0	18.1		206.0	201.0	206.0	213.0	217.0	217.0	208.0	197.0	2.5
Sodium	318.0		1060.0	350.5		332.0	904.0	470.5		461.5	436.5	433.5	418.5	419.5	427.0	421.5	380.5	14.2
Sulphate																		
Zinc	0.010		0.416	0.029		0.090	0.049	0.045		0.066	0.078	0.032	0.065	0.077	0.063	0.039	0.038	0.009
Alkalinity (g/l)	140		880	1100		280	560	130		700	360	1300	250	240	180	180	200	140
Calcium (g/l)	144		118	134		160	170	152		170	184	120	176	144	128	109	128	64

Colour Code	Sample Date
	29-Jun-09

Unit
Cells
Reed Beds

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was quite mild ~ 15* C - rain previous day (28/06/09 - may account for high nitrate level of 29 mg/l in Tramore river)
Full suite of metals & salts tested
List I and List II Organics and toxicity test also carried out (*Daphnia magna & Vibrio fischeri)*
Media change in Cell 7 and 8 - (Cell 7 was Subsoil - now Timber Chip) (Cell 8 was Sand / Soil / Compost now Timber Chip)
Media change in Cell 10 - was Coarse Compost, now timber chip & coarse compost
Cells 2 & 6 are off
N1 and N2 removed
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) July 2009

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate ($l/m^2/day$)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96	
Ammonium	Monthly	288		329	216		20	0	0		110	41	216	9	0	0	0	0	0
Nitrate	Monthly	0		0	62		849	392	805		514	751	36	732	610	838	729	686	22
Nitrite	Monthly	0.000		0	0		7	5	7		32	30	1	12	4	5	3	2	0
TON	Monthly	148		0	70		772	165	359		252	206	752	574	797	686	657	715	
BOD_5	Monthly	39.90			11.10		2.20	0.70	1.10		13.20	8.00	10.25	1.80	1.00	1.10	0.35	1.26	1.14
BOD_5	Monthly	22.00		51.00													0.43	0.45	
COD	Monthly	235		426	209		173	135	140		174	175	181	150	174	130	88	80	0
COD	Monthly	179		336													78	143	
TOC	Monthly	70		115	61		56	51	54		60	56	63	56	55	54	45	40	4
Chloride	Monthly	340		440	335		323	320	323		320	320	323	318	326	320	303	302	17
Cond. (mS/cm)	Monthly	3.60		4.50	3.17		2.65	2.57	2.56		3.00	2.74	3.28	2.59	2.53	2.51	2.39	2.31	365 µS/cm
Cond. (mS/cm)	Monthly	2.90		2.96													2.11	1.19	
pH (pH Units)	Monthly	7.15		7.57	7.58		7.07	7.19	7.39		7.04	7.23	7.47	7.28	7.34	7.65	7.77	6.90	6.97
Sus.Sols	Monthly	31.50		38.07	14.20		7.25	2.65	3.85		8.70	3.95	11.85	4.55	2.90	2.75	6.70	4.75	0.25
																		0.00	
Temp (°C)	Monthly	24.00		24.00	23.90		23.90	24.00	24.10		23.90	23.80	23.80	23.90	24.10	24.00	24.00	23.90	24
Ratio BOD:COD	Monthly	0.17		0.00	0.05		0.01	0.01	0.01		0.08	0.05	0.06	0.01	0.01	0.01	0.00	0.02	

Colour Code	Sample Date
	30-Jul-09
	06-Aug-09
	Anomalous reading - out of line with previous months

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was quite mild ~ 20* C, dry & sunny - rain previous day & night (28 July 09)
New sample taken for BOD, COD - measured due to inconclusive results in July sample
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) August 2009

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96	
Ammonium	Monthly	270		140	205		41	23	22		106	52	214	23	22	23	18	18	0.10
Nitrate	Monthly	124		93	50		924	657	1070		686	965	259	851	940	783	592	767	16.89
Nitrite	Monthly	0.180		0.004	0.01		0.34	6.00	4.00		39.00	15.00	4.00	5.00	2.00	4.00	2.00	2.00	0.106
TON	Monthly	124		93	50		924	663	1074		725	980	263	856	942	787	594	769	17
BOD_5	Monthly	13.60		23.50	9.50		4.55	1.20	0.90		21.40	10.05	14.25	5.35	1.35	0.72	1.17	0.88	1.67
COD	Monthly	212		202	210		145	118	129		197	179	136	127	117	103	78	68	3
TOC	Monthly	52		49	58		52	48	47		51	47	53	49	49	42	35	30	2
Chloride	Monthly	269		153	302		292	292	292		284	294	284	295	281	264	221	208	14
Cond. (mS/cm)	Monthly	3.14		2.05	2.91		2.54	2.27	2.38		2.70	2.53	3.01	2.36	2.40	2.12	1.80	1.74	362 µS/cm
pH (pH Units)	Monthly	7.44		7.52	7.54		7.19	7.24	7.49		6.99	7.56	7.54	7.65	7.83	7.86	7.89	7.95	7.81
Sus.Sols	Monthly	33.50		41.00	32.00		7.00	8.00	5.50		9.00	6.00	8.50	5.00	5.00	4.50	2.50	1.50	4.5
Temp (°C)	Monthly	23.00		23.40	23.30		23.30	24.90	24.70		23.50	23.30	23.30	23.60	23.50	23.40	23.40	23.40	23.2
Ratio BOD:COD	Monthly	0.06		0.12	0.05		0.03	0.01	0.01		0.11	0.06	0.10	0.04	0.01	0.01	0.02	0.01	

Colour Code	Sample Date
	27-Aug-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was quite mild ~ 20* C, wet & windy
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) September 2009

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400		
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96		
Ammonium	Monthly	163		481	131		12	1	1		59	16	138	3	1	1	0	0	0	0.00
Nitrate	Monthly																			
Nitrite	Monthly																			
TON	Monthly	79		0	114		580	518	660		422	526	124	536	541	565	531	570	560	33.00
BOD_5	Monthly																			
COD	Monthly																			
TOC	Monthly	65		163	63		44	38	42		43	43	46	42	46	43	77	1240	3480	4
Chloride	Monthly																			
Cond. (mS/cm)	Monthly																			
pH (pH Units)	Monthly																			
Sus.Sols	Monthly																			
Temp (°C)	Monthly																			
Ratio BOD:COD	Monthly																			

Colour Code	Sample Date
	18-Sep-09
	TOC value of 1240 mg/l is most likely due to a sampling error

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
BOD, COD, SS tests not carried out due to other work commitments
Weather was quite mild ~ 18* C
Denitrification tanks now number 4, i.e. N1 - N2 - N3 - N4 with sugar water (Sorbitol) dosed directly in to N1 from large $10m^3$ mixing tank via dosing pump
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS(mg/l) October 2009

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96					
Ammonium	Monthly	337		70	234		65	0	0		133	40	288	266	146	41	0	0	0	0	2	2	1.00
Nitrate	Monthly	0		6	120		919	756	1096		755	1010	190	170	455	719	600	524	588	592	549	626	21
Nitrite	Monthly	0.030		0.042	0.09		21.00	24.00	4.00		25.00	10.00	0.13	0.16	45.00	21.00	10.00	6.00	12.00	8.00	11.00	14.00	0.052
TON	Monthly	0		6	120		940	780	1100		780	1020	190	170	500	740	610	530	600	600	560	640	21.00
BOD_5	Monthly	21.50		16.90	17.95		10.60	9.95	7.25		14.55	9.60	26.45	2.61	19.90	10.40	1.69	7.85					2.47
COD	Monthly	235		119	191		197	131	138		212	196	229	298	204	186	105	101					14
TOC	Monthly	401		152	334		182	108	68		215	120	568	362	256	345	71	71	670	1200	1720	1140	18
Chloride	Monthly	369		94	360		383	335	377		383	386	386	391	383	332	261	250	250	247	244	264	14
Cond. (mS/cm)	Monthly	4.09		1.42	3.43		3.25	2.81	2.99		3.46	3.13	3.93	3.80	3.39	2.74	2.14	1.96					315 µS/cm
pH (pH Units)	Monthly	7.46		7.41	7.49		7.50	7.08	6.11		7.20	7.31	7.79	7.93	7.57	7.38	7.57	7.74			6.99		7.67
Sus.Sols	Monthly	16.5		1063.5	7.0		9.0	3.0	7.0		8.0	6.5	21.5	25.5	5.5	4.0	3.5	2.5	14.0	76.0			3.5
Temp (°C)	Monthly	16.10		15.80	15.10		13.70	14.50	13.90		14.50	14.20	14.30	14.00	15.40	15.60	15.60	16.40					15.5
Ratio BOD:COD	Monthly	0.09		0.14	0.09		0.05	0.08	0.05		0.07	0.05	0.12	0.01	0.10	0.06	0.02	0.08					
Methane	Monthly	0.40		1.25	0.26		0.00	0.00	0.00		0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.01					0.01

Colour Code	Sample Date
	23-Oct-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was DULL, OVERCAST & SHOWERY, HEAVY RAIN PREVIOUS NIGHT
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) December 2009

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96					
Ammonium	Monthly	264		95	184		41	0	0		111	41	194	165	46	10	2	2	3	3	2	2	1
Nitrate	Monthly	29		16	101		780	593	890		637	820	267	193	620	708	719	662	749	645	676	700	31
Nitrite	Monthly	5.00		0.015	17.00		7.00	8.00	9.00		2.00	11.00	12.00	5.00	12.00	11.00	6.00	1.00	7.00	6.00	6.00	7.00	0.02
TON	Monthly	34		16	118		787	601	899		639	831	279	198	632	719	725	663	756	651	682	707	31
BOD_5	Monthly	18.40		8.70	9.85		7.65	2.02	1.61		10.95	8.10	14.50	15.45	10.45	2.79	1.37	10.22				67.90	2.17
COD	Monthly	205		119	156		155	113	127		156	167	175	171	151	134	111	322				2204	29
TOC	Monthly	60		43	50		46	31	41		48	46	66	48	48	41	34	238	750	1038	864	666	4
Chloride	Monthly	286		99	261		272	267	267		275	267	271	272	261	244	238	227				214	14
Cond. (mS/cm)	Monthly	3.38		1.59	2.82		2.48	2.31	2.33		2.81	2.49	3.06	2.91	2.38	2.17	2.13	2.06				1.96	340 µS/cm
pH (pH Units)	Monthly	7.21		7.54	7.45		7.37	7.12	6.96		7.17	7.54	7.62	7.85	7.09	6.91	7.68	7.55				7.44	7.58
Sus.Sols	Monthly	33.0		17.0	6.5		5.0	4.0	9.0		20.0	7.0	22.5	12.5	4.5	4.0	3.5	12.1				10.5	3.5
Temp (°C)	Monthly	17.80		16.40	15.60		15.70	15.20	14.70		16.00	14.80	13.30	14.50	14.30	14.50	16.50	16.00				17.70	15.9
Ratio BOD:COD	Monthly	0.09		0.07	0.06		0.05	0.02	0.01		0.07	0.05	0.08	0.09	0.07	0.02	0.01	0.03				0.03	

Colour Code	Sample Date
	16-Dec-09

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
No samples taken in November 2009
Weather was DRY, SUNNY, VERY COLD ~ 0*C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) March 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96					
Ammonium	Monthly	390		241	328		120	230	64		212	114	325	309	207	73	25	5					1
Nitrate	Monthly	0		15	111		898	453	1075		546	923	119	124	362	738	940	938					23
Nitrite	Monthly	38		0.0001	23		0.05	53	1		19	0.05	0.21	0.44	84	145	67	49					0.029
TON	Monthly	0		15	134		898	506	1076		565	923	119	124	446	883	1007	987					23
BOD_5	Monthly	22.65		68.70	32.50		16.85	14.70	27.60		28.25	35.10	32.95	28.55	UR	UR	19.00	3.38					4.99
COD	Monthly	340		367	314		243	290	225		284	250	333	296	322	325	269	251					10
TOC	Monthly	550		480	470		203	360	128		500	180	450	430	201	87	350	136					19
Chloride	Monthly	444		251	447		440	441	440		442	437	444	450	442	434	421	425					50
Cond. (mS/cm)	Monthly	4.43		3.48	4.39		3.75	4.10	3.62		4.10	3.73	4.40	4.35	4.06	3.56	3.37	3.28					439 µS/cm
pH (pH Units)	Monthly	7.66		7.47	7.72		7.67	7.47	8.00		7.36	7.62	7.56	7.76	7.44	7.20	7.55	7.87					7.62
Sus.Sols	Monthly	44.5		42.5	14.0		8.0	4.0	6.5		12.5	9.5	22.0	15.0	9.0	6.5	22.5	5.0					21.5
Temp (°C)	Monthly	9.40		8.20	8.10		7.80	7.50	7.70		8.10	8.30	7.90	7.50	7.70	7.90	7.70	7.90					9.9
Phosphate (P)	Monthly	0.90		1.75	0.37		0.13	0.32	0.16		0.29	0.17	0.48	0.28	0.30	0.19	0.12	0.09					0.13
Ratio BOD:COD	Monthly	0.07		0.19	0.10		0.07	0.05	0.12		0.10	0.14	0.10	0.10			0.07	0.01					

Colour Code	Sample Date
	03-Mar-10

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
No samples taken in January (plant turned off for 3 weeks due to very cold temperatures - sub zero)
No samples taken in February due to other work commitments
Weather was MILD, WET, DRIZZLE ~ 8* C
UR = Under range
All data in mg/l unless indicated otherwise

Concentrations for Metals & Salts - LEACHATE - CELLS / REED BEDS / Tramore River (mg/l) March 2010

	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
Irrigation Rate (l/unit/day)				600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)				236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96	
Cadmium	0.000		0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chromium	0.011		0.021	0.000		0.000	0.000	0.000		0.000	0.001	0.000		0.002	0.001	0.000	0.000	0.002
Copper	0.025		0.048	0.097		0.087	0.080	0.091		0.202	0.074	0.111	0.066	0.078	0.099	0.101	0.097	0.057
Iron	12.550		7.650	3.570		1.880	0.606	1.220		3.990	2.150	5.660	2.870	1.620	0.952	0.418	0.192	0.729
Lead	0.000		0.003	0.005		0.001	0.000	0.000		0.001	0.002	0.012	0.001	0.001	0.000	0.000	0.001	0.002
Magnesium	59.025		62.200	55.800		46.750	55.050	54.325		55.500	52.900	54.550	54.875	54.850	52.350	57.200	59.550	5.829
Manganese	3.785		2.530	2.780		1.430	1.530	0.632		2.530	0.889	2.940	2.170	1.760	1.780	0.136	0.026	0.236
Nickel	0.045		0.043	0.036		0.036	0.035	0.033		0.032	0.031	0.035	0.026	0.046	0.045	0.042	0.038	0.004
Phosphate (P)	0.90		1.75	0.37		0.13	0.32	0.16		0.29	0.17	0.48	0.28	0.30	0.19	0.12	0.09	0.127
Potassium	171.0		111.8	164.8		175.5	177.8	165.8		171.0	184.0	183.8	174.3	172.8	145.5	175.0	171.5	2.66
Sodium	340.0		260.0	330.0		332.5	340.0	327.5		330.0	340.0	337.5	340.0	330.0	307.5	335.0	350.0	43.8
Zinc	0.016		0.091	0.056		0.071	0.049	0.049		0.311	0.048	0.116	0.060	0.063	0.072	0.035	0.032	0.057
Chloride	444		251	447		440	441	440		442	437	444	450	442	434	421	425	50

Colour Code	Sample Date
	03-Mar-10

Unit	Area
Cells	2.54m^2
Reed Beds	25m^2

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was MILD, WET, DRIZZLE ~ 8* C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) April 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96					
Ammonium	Monthly	260		70	224		41	58	22		110	31	235	110	5	6	2	1					1
Nitrate	Monthly	0		15	92		780	585	800		539	810	64	459	789	711	464	460					25
Nitrite	Monthly	4		0.006	12		14	20	18		7	23	20	7	10	3	7	6					0.009
TON	Monthly	0		15	104		794	605	818		546	833	84	466	799	714	471	466					25
BOD_5	Monthly	6.05		8.90	5.40		3.65	2.90	2.75		6.70	4.00	4.85	10.70	5.00	1.52	1.98	1.56					2.38
COD	Monthly	211		77	194		159	156	166		203	149	215	192	131	112	72	69					0
TOC	Monthly	57		30	60		57	51	55		52	53	48	44	44	43	30	44					3
Chloride	Monthly	269		18	298		287	280	287		294	287	294	287	252	230	151	145					71
Cond. (mS/cm)	Monthly	3.16		1.18	3.23		2.56	2.55	2.50		2.88	2.58	3.29	2.80	2.23	1.98	1.44	1.45					340 µS/cm
pH (pH Units)	Monthly	7.59		7.47	7.72		7.51	7.11	7.81		7.31	7.34	7.76	7.80	7.21	7.08	7.85	7.85					7.91
Sus.Sols	Monthly	26.5		5.5	13.0		6.0	3.5	39.0		9.0	4.5	10.5	9.0	5.5	5.0	3.5	3.5					26.5
Temp (°C)	Monthly	10.90		10.40	12.30		12.00	11.30	11.00		10.90	11.00	11.30	11.90	11.40	10.50	12.50	13.50					10.4
Ratio BOD:COD	Monthly	0.03		0.12	0.03		0.02	0.02	0.02		0.03	0.03	0.02	0.06	0.04	0.01	0.03	0.02					
Methane	Monthly	1.13		7.67	0.01		0.02	0.00	0.00		0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00					0.02

Colour Code	Sample Date
	07-Apr-10
	22-Apr-10

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was DRY, SUNNY, ~ 10*C - LIGHT RAIN PREVIOUS NIGHT
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) May 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	945	945	945	945	96	96	96	96					
Ammonium	Monthly	438		881	371		68	208	77		198	87	374	174	12	4	4	4				12	3
Nitrate	Monthly	19.88		74	39		1218	491	992		704	1071	24	710	1327	1246	1184	1119				679	28
Nitrite	Monthly	0.118		0.002	25		2	35	10		25	5	21	24	2	4	6	2				115	0.07
TON	Monthly	20		74	64		1220	526	1002		729	1076	45	734	1329	1250	1190	1121				794	28
BOD_5	Monthly	25.00		135.40	26.45		7.35	13.45	15.00		27.35	23.55	26.05	38.45	6.30	2.13	1.15	5.34					2.18
COD	Monthly	368		135	321		236	313	312		303	262	337	292	196	159	128	118				966	55
TOC	Monthly	216		726	183		82	178	71		123	68	372	110	57	56	44	40				204	3
Chloride	Monthly	476		476	468		457	459	465		464	457	468	457	442	448	445	413				357	14
Cond. (mS/cm)	Monthly	4.93		9.47	4.66		3.76	4.08	3.66		4.14	3.78	4.72	4.02	3.49	3.37	3.42	3.24				3.51	378 µS/cm
pH (pH Units)	Monthly	7.55		7.71	7.73		7.44	7.20	7.18		7.71	7.60	7.65	7.77	6.67	7.22	7.48	7.69				6.37	7.65
Sus.Sols	Monthly	46.5		148.0	11.0		12.0	13.0	13.0		17.5	9.5	18.0	11.0	10.0	10.5	16.0	7.0				21.0	218.0
Temp (°C)	Monthly	13.40		12.80	12.60		12.80	12.50	14.00		12.90	12.80	12.60	12.90	12.10	12.20	12.30	16.00				13.40	12.3
Ratio BOD:COD	Monthly	0.07		1.00	0.08		0.03	0.04	0.05		0.09	0.09	0.08	0.13	0.03	0.01	0.01	0.05					

Colur Code	Sample Date
	06-May-10

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8

Note: Blank Cells = no data
Weather was DRY, SUNNY, ~ 14* C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) June 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	600	600	2400	2400	2400	2400	600	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	236	236	945	945	96	96	24	96					
Ammonium	Monthly	418		1014	413		87	299	71		61	9	417	120	34	8	1	1	4			9	2
Nitrate	Monthly	13		204	8		1101	154	1022		1118	1367	35	846	1178	1270	1426	1308	856			808	25
Nitrite	Monthly	12		39	17		0.04	30	0.20		28	2	0.20	2	7	0.22	2	1	12			20	0.051
TON	Monthly	25		243	25		1101	184	1022		1146	1369	35	848	1185	1270	1428	1309	868			828	25
BOD_5	Monthly	26.65		122.40	20.35		17.20	37.65	33.95		17.35	4.75	24.45	26.55	10.20	1.89	1.02	1.11					2.44
COD	Monthly	333		1265	323		232	331	645		227	259	342	275	242	309	137	162	294			265	4
TOC	Monthly	540		1140	530		144	410	170		130	67	540	200	112	85	70	80	180			170	23.0
Chloride	Monthly	452		1089	459		454	451	457		444	451	457	450	464	465	476	465	474			464	17
Cond. (mS/cm)	Monthly	4.76		10.95	4.68		3.74	4.26	3.59		3.64	3.57	4.70	3.68	3.53	3.45	3.89	3.61	3.43			3.43	401 µS/cm
pH (pH Units)	Monthly	7.64		7.77	7.88		7.40	7.59	7.25		7.16	6.17	7.79	7.44	6.81	6.51	7.71	7.59	7.40			7.48	7.5
Sus.Sols	Monthly	24.00		48.50	52.50		12.50	9.50	19.00		18.00	14.50	36.00	14.00	10.00	6.50	9.50	8.50	11.50			13.00	1.5
Temp (°C)	Monthly	17.80		17.80	19.30		19.70	19.60	20.50		19.50	19.30	19.30	19.70	19.20	19.10	18.80	21.20	20.20			20.60	16
Ratio BOD:COD	Monthly	0.08		0.10	0.06		0.07	0.11	0.05		0.08	0.02	0.07	0.10	0.04	0.01	0.01	0.01					
Phosphate (P)	Monthly	0.40		0.50														0.10	9.00			10.00	

Colour Code	Sample Date
	17-Jun-10

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8 - VP 1

Note: Blank Cells = no data
Weather was dry, hot & cloudy ~ 20* C
Phosphate (P) was dosed in to Denitrification tank N 1
New flow sequence Raw - Cell 7 - Cell 8 - VP 1
New flow sequence Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2 - N1 - N2 - N3 - N4
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) July 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	600	600	2400	2400	2400	2400	600	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	236	236	945	945	96	96	24	96					
Ammonium	Monthly	218		77	257		27	243	24		45	4	233	140	58	6	1	2	5	1	5	6	2
Nitrate	Monthly	0		0	0		743	48	661		656	890	55	312	718	867	941	944	608	646	536	586	22
Nitrite	Monthly	10		11	28		11	41	23		28	3	0.002	0.04	6	1	1	3	2	9	5	9	3
TON	Monthly	10		11	28		754	89	684		684	893	55	312	724	868	942	947	610	655	541	595	25
BOD_5	Monthly	5.10			17.70		9.60	56.60	14.45		8.70	5.30	37.00	16.95	7.00	1.00	1.06	0.58					1
COD	Monthly	177		71	205		160	309	197		191	188	225	209	138	120	86	106	248	223	201	217	1
TOC	Monthly	301		256	365		74	384	82		105	57	474	210	128	53	63	58	120	115	120	126	27.0
Chloride	Monthly	241		96	284		269	312	269		281	312	258	261	320	301	315	312	289	298	281	306	14
Cond. (mS/cm)	Monthly	2.91		1.55	3.15		2.38	3.26	2.24		2.47	2.53	2.96	2.67	2.74	2.40	2.69	2.58	2.40	2.37	2.33	2.48	368 µS/cm
pH (pH Units)	Monthly	7.56		7.50	7.93		7.04	7.87	7.04		7.21	6.31	7.87	7.76	7.08	6.43	7.87	7.56	7.35	7.90	7.86	7.44	7.9
Sus.Sols	Monthly	14.50		10.00	20.00		7.00	14.50	9.00		11.50	7.50	28.50	20.00	6.50	5.00	4.00	3.50	70.91	36.00	30.00	34.00	1.5
Temp (°C)	Monthly	17.30		17.80	17.10		17.30	16.80	17.30		17.20	17.30	17.10	17.10	17.60	17.30	17.20	17.10	17.30	17.40	17.30	17.50	16.5
Ratio BOD:COD	Monthly	0.03		0.00	0.09		0.06	0.18	0.07		0.05	0.03	0.16	0.08	0.05	0.01	0.01	0.01					
Phosphate (P)	Monthly	0.20		0.40													0.03	0.05	6.50	6.20	6.80	7.30	0.07

Colour Code	Sample Date
	22-Jul-10

Unit	Area
Cells	2.54m^2
Reed Beds	25m^2

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8 - VP 1

Note: Blank Cells = no data
Weather was dry and overcast ~ 18* C - heavy rain over past two days (20 & 21 July 2010)
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) August 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	600	600	2400	2400	2400	2400	600	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	236	236	945	945	96	96	24	96					
Ammonium	Monthly	458		1380	305		53	85			62	4	420	26	3	0	0	0	0	0	1	6	2
Nitrate	Monthly	124		634	39		1400	1222			1295	1276	0	1172	1614	1628	1239	1508	1012	1066	922	864	32
Nitrite	Monthly	0.018		31	11		4	162	8		0.09	9	12	88	3	4	6	0.01	9	19	16	29	4
TON	Monthly	124		665	50		1404	1384			1295	1285	12	1260	1617	1632	1245	1508	1021	1085	938	893	36
BOD_5	Monthly	27.35			58.40		19.50	10.55	6.28		30.10	9.30	30.30	48.80	7.24	4.41		1.35				55.70	3.07
COD	Monthly	385		2014	318		260	313	390		281	273	372	364	230	191	125	125	285	315	264	251	13
TOC	Monthly	116		411	89		60	75	NA		74	82	103	85	68	68	44	22	58	60	64	66	3.0
Chloride	Monthly	522		1353	496		479	468	510		476	457	493	479	513	525	394	519	482	482	468	468	14
Cond. (mS/cm)	Monthly	5.21		13.63	4.22		4.03	4.07	4.62		3.84	3.51	4.96	3.74	3.88	4.03	3.16	4.05	3.63	3.63	3.56	3.48	384 µS/cm
pH (pH Units)	Monthly	7.33		7.67	7.50		7.63	7.16	7.77		7.24	7.67	6.26	7.71	7.07	7.18	8.18	7.51	6.99	7.35	7.22	7.12	7.74
Sus.Sols	Monthly	34.50		185.00	11.00		20.00	10.00	89.50		59.50	19.50	71.00	10.50	11.00	6.50	8.00	59.50	17.00	26.00	26.00	30.00	2.5
Temp (°C)	Monthly	18.70		19.00	18.80		18.90	18.90	18.80		19.40	19.20	19.10	19.20	19.10	18.90	19.10	20.30	17.90	18.10	18.50	19.70	17.2
Toxic Units - 48 h EC 50 to *Daphnia magna*	Toxic Units	5.60		40.00	5.40		1.40						7.90					<1				<1	<1
15 min EC 50 - *Vibrio fischeri*	Toxic Units	<2.2		52.60	<2.2		<2.2						<2.2					<2.2				<2.2	<2.2
Ratio BOD:COD	Monthly	0.07			0.18		0.08	0.03	0.02		0.11	0.03	0.08	0.13	0.03	0.02		0.01				0.22	
Methane	Monthly	1.560			0.020		0.015	0.000	0.000		0.010	0.000	0.220	0.045	0.000	0.000	0.000	0.000	0.000			0.000	0.010
Phosphate (P)	Monthly	0.60		3.70													0.06	0.03	4.20	4.10	4.60	4.40	0.06

Colour Code	Sample Date
	16-Aug-10
	26-Aug-10

Unit	Area
Cells	2.54m^2
Reed Beds	25m^2

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8 - VP 1

Note: Blank Cells = no data
Full suite of metals & salts tested
List I and List II Organics and toxicity test also carried out (*Daphnia magna & Vibrio fischeri)*
Weather was quite mild, dry, cloudy ~ 20* C
All data in mg/l unless indicated otherwise

RESULTS for Metals & Salts - LEACHATE - CELLS / REED BEDS / Tramore River (mg/l) August 2010

	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium	Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)				600	OFF	240	600	240	OFF	600	600	2400	2400	2400	2400	600	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)				236	OFF	94	236	94	OFF	236	236	945	945	96	96	24	96					
Boron	1.34		1.49	1.33		1.24	1.69			0.28	1.17	1.13	1.63	1.83	1.99	0.93	1.71	0.31			1.14	0.03
Cadmium	0.000		0.000	0.000		0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
Chromium	0.006		0.085	0.005		0.005	0.004	0.007		0.005	0.004	0.005	0.004	0.006	0.004	0.003	0.003	0.002	0.003	0.002	0.003	0.000
Copper	0.009		0.020	0.022		0.015	0.028	0.027		0.059	0.065	0.014	0.034	0.032	0.024	0.032	0.024	0.027	0.017	0.019	0.022	0.007
Iron	6.25		2.02	0.99		1.39	0.16	2.43		3.16	1.41	4.52	1.99	0.52	0.29	0.02	0.04	0.04	0.04	0.02	0.04	0.08
Lead	0.001		0.013	0.001		0.001	0.000	0.000		0.003	0.009	0.000	0.001	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.000
Magnesium	65.49		186.43	56.60		69.96	78.10	63.32		66.78	61.99	66.63	68.54	71.07	77.38	56.61	76.26	64.42	67.10	66.53	72.94	7.11
Manganese	2.71		1.08	1.40		3.11	5.00	1.00		6.60	0.47	2.28	7.81	7.79	6.98	0.01	0.02	0.02	0.02	0.06	0.09	0.02
Mercury	<0.02		0.160	<0.02		<0.02	<0.02			<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.040	<0.02			<0.02	<0.02
Nickel	0.019		0.131	0.048		0.056	0.064	0.072		0.075	0.079	0.081	0.082	0.076	0.080	0.074	0.081	0.085	0.086	0.078	0.092	0.102
Phosphate (P)																						
Potassium	224.5		282.0	257.0		210.5	175.5	226.5		232.5	226.5	223.0	205.0	199.0	214.0	177.5	214.0	227.0	211	211	201	7
Sodium	392.0		1030.0	372.0		375.5	363.0	361.5		365.5	336.5	347.5	340.0	367.0	386.0	275.5	336.5	402.0	369.5	366.5	382.0	12.6
Zinc	0.001		0.209	0.029		0.111	0.074	0.023		0.109	0.166	0.014	0.081	0.174	0.052	0.022	0.036	0.020	0.019	0.013	0.014	0.009
Chloride	522		1353	496		479	468	510		476	457	493	479	513	525	394	519	482	482	468	468	14

Colour Code	Sample Date
	16-Aug-10

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8 - VP 1

Note: Blank Cells = no data
Full suite of metals & salts tested
List I and List II Organics and toxicity test also carried out (*Daphnia magna & Vibrio fischeri)*
Weather was quite mild, dry, cloudy ~ 20* C
All data in mg/l unless indicated otherwise

RESULTS for LEACHATE - CELLS / REED BEDS (mg/l) October 2010

	Frequency	RAW 1	RAW 2	Raw Active	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	VP 1	VP 2	N1	N2	N3	N4	Tramore River
Medium		Leachate	Leachate	Leachate from Active Area	Compost - coarse	Willow Trees (x 2) in compost	Timber Chip	Compost - fine grade	Stratified sand / grit / gravel	Willow trees (x2) in sub-soil	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	Denite Unit 1	Denite Unit 2	Denite Unit 3	Denite Unit 4	
Irrigation Rate (l/unit/day)					600	OFF	240	600	240	OFF	600	600	2400	2400	2400	2400	600	2400	2400	2400	2400	2400	
Irrigation Rate (l/m^2/day)					236	OFF	94	236	94	OFF	236	236	945	945	96	96	24	96					
Ammonium	Monthly	461			444		302	428	197		88	16	444	240	3	0	0	1	3	4	7	7	1
Nitrate	Monthly	0			37		482	8	662		1166	1414	0	382	1314	1425	1372	1425	703	790	760	775	19
Nitrite	Monthly	30			7		39	56	42		0.03	0.07	32	30	0.09	0.01	2	3	46	14	14	4	1
TON	Monthly	30			44		521	64	704		1166	1414	32	412	1314	1425	1374	1428	749	804	774	779	20
BOD_5	Monthly	24.75			17.05		17.75	14.40	21.70		15.95	3.31	19.20	20.35	4.66	1.01	0.73	0.99					2.47
COD	Monthly	392			370		360	368	371		278	237	371	303	262	236	122	176	342	329	293	270	13
TOC	Monthly	103			95		89	89	104		78	68	88	82	70	63	42	53	80	82	79	78	4.0
Chloride	Monthly	536			527		513	516	527		508	510	516	508	513	525	478	508	496	491	488	488	24
Cond. (mS/cm)	Monthly	5.24			5.09		4.70	4.91	4.24		4.01	3.81	5.15	4.40	3.68	3.78	3.71	3.82	3.50	3.45	3.41	3.40	389 µS/cm
pH (pH Units)	Monthly	7.53			9.94		7.65	8.16	7.80		7.17	7.14	7.80	7.73	6.90	6.32	7.75	7.72	7.54	7.60	7.71	7.68	7.87
Sus.Sols	Monthly	29.00			78.00		25.50	17.50	23.00		71.00	10.00	114.50	21.50	7.00	7.50	4.50	14.50	44.00	60.00	78.00	86.00	1
Temp (°C)	Monthly	15.60			13.10		13.20	12.70	12.80		13.50	13.50	12.80	13.80	13.90	13.60	13.70	14.40	13.30	13.20	13.00	13.10	13.1
Ratio BOD:COD	Monthly	0.06			0.05		0.05	0.04	0.06		0.06	0.01	0.05	0.07	0.02	0.00	0.01	0.01					
Phosphate (P)	Monthly	0.70															0.03	0.04	14.00	13.00	14.00	15.00	0.028

Colour Code	Sample Date
	14-Oct-10

Unit	Area
Cells	$2.54m^2$
Reed Beds	$25m^2$

Flow Sequence
Raw - Cell 1 - Cell 4
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 2 - N1 - N2 - N3 - N4
Raw - Cell 3 - Cel 5
Raw - Cell 7 - Cell 8 - VP 1

Note: Blank Cells = no data
Weather was dry, cloudy ~ 16* C
No Raw Active sample - sample point destroyed during capping works
No Samples taken for September 2010
All data in mg/l unless indicated otherwise

Phase 5 - Results for *E. coli* Testing

E. coli	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
HLR (l/unit/day)		1200	480	480	300	300	2400	2400	2400	2400	2400	2400	
HLR (l/m^2/day)		472	189	189	118	118	945	945	96	96	96	96	
Sample Dilution # 1	1 in 10	1 in 10	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 2	No Dilution	No Dilution	No Dilution	No Dilution	1 in 20
Sample Dilution # 2	1 in 20	1 in 20	1 in 20	1 in 10	1 in 20	1 in 10	1 in 20	1 in 4	1 in 2	1 in 2	1 in 2	1 in 2	1 in 10
10/10/2011	>2419.6	_	_	_	_	_	>2419.6	1413.6	137.2	65.7	5.2	1	-
10/10/2011	_	_	_	_	_	_	_	_	_	_	_	_	_
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	_	_	_	_	1461.6
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	4479.6	_	_	_	_	541.6
17/10/2011	6488	3609	3255	4082	1968	808	1296	615.2	218.7	52.9	2	1	_
17/10/2011	6152	2038	4718	3255	1918	1178	1466	1302	2604	74.6	4	1	_
24/10/2011	135	30	50	35	10	1	72	2	1	1	1	1	>2419.6
24/10/2011	144	20	60	1	80	30	20	28	1	1	1	1	>2419.6
07/11/2011	1782	670	556	454.5	288	31.5	703	135.4	17.5	3.1	1	1	296.6
08/11/2011	1300	816	738	379	322	86	798	143.6	21.8	1	1	1	97
14/11/2011	1376	185	474	252	85	26	295	85.6	5.2	1	1	1	1297.6
15/11/2011	1382	242	242	246	20	1	398	86.4	12.6	1	2	1	1223
21/11/2011	538	121	52	10	31	1	75	29.6	6.3	1	2	1	2239.8
21/11/2011	374	62	40	41	82	1	148	8	1	1	2	1	4611
28/11/2011	181	75	52	20.5	31	10	75	26.8	8.5	2	1	1	922.2
28/11/2011	178	20	40	41	1	10	60	39.2	14.8	2	1	1	1012
05/12/2011	160	31	20	26	1	5	30	8.2	6.3	3.1	1	1	334
05/12/2011	126	62	1	20	1	1	20	8	2	4	1	1	_
12/12/2011	241	31	108	26	31	5	30	34.6	2	58.3	1	1	1960.8
12/12/2011	322	194	104	10	40	1	218	20.8	4	58.4	1	1	1782

Note: All data as MPN/100ml
Blank Cells / _ = No Data
Over Range Data = >2419.6
For each sample date, lower dilution is on top

Flow Sequence
Raw - Cell 1
Raw - Cell 3 - Cell 5
Raw - Cell 7 - Cell 8
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2

Phase 5 - Results for Total Coliforms Testing

Total Coliforms	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
HLR (l/unit/day)		1200	480	480	300	300	2400	2400	2400	2400	2400	2400	
HLR (l/m^2/day)		472	189	189	118	118	945	945	96	96	96	96	
Sample Dilution # 1	1 in 10	1 in 10	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 2	No Dilution	No Dilution	No Dilution	No Dilution	1 in 20
Sample Dilution # 2	1 in 20	1 in 20	1 in 20	1 in 10	1 in 20	1 in 10	1 in 20	1 in 4	1 in 2	1 in 2	1 in 2	1 in 2	1 in 10
10/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	>2419.6	>2419.6	224.7	1	_
10/10/2011	_	_	_	_	_	_	_	_	_	_	_	_	_
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	_	_	_	_	>2419.6
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	4479.6	_	_	_	_	>2419.6
17/10/2011	>2419.6	>2419.6	17329	>2419.6	>2419.6	>2419.6	9804	>2419.6	>2419.6	1986.3	488.4	307.6	_
17/10/2011	>2419.6	>2419.6	25994	19863	>2419.6	>2419.6	9768	6931.6	3972.6	1960.8	419.2	310.6	_
24/10/2011	>2419.6	7701	12033	6498.5	3076	4604	15531	2092.4	307.6	>2419.6	816.4	158.5	>2419.6
24/10/2011	10950	5818	7308	9208	5510	2481	7308	1379.2	774.6	>2419.6	1297.6	330	>2419.6
07/11/2011	24196	>2419.6	19863	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	1119.9	461.1	240	121.1	>2419.6
07/11/2011	39726	20924	34658	19863	>2419.6	>2419.6	>2419.6	7945.2	1158.8	397.8	235.6	130	>2419.6
14/11/2011	>2419.6	12997	10462	12098	>2419.6	>2419.6	14136	>2419.6	1413.6	1203.3	461.1	248.9	>2419.6
14/11/2011	37726	13734	15402	12033	>2419.6	>2419.6	19608	4813.2	1158.8	922.2	197.4	155.2	>2419.6
21/11/2011	12033	2046	12033	5231	>2419.6	9931.5	9208	3106.2	1299.7	2419.6	325.5	365.4	>2419.6
21/11/2011	9222	7746	13734	5172	>2419.6	10462	8704	3683.2	1373.4	3465.8	334.8	496.2	>2419.6
28/11/2011	5745	2755	461.1	3065.5	>2419.6	1454.5	3076	3972.6	1732.9	>2419.6	488.4	275.5	>2419.6
28/11/2011	4978	4494	7308	2359	31062	2014	4494	3683.2	449.4	4839.2	551	164	>2419.6
05/12/2011	5794	2046	12033	2897	4611	1627.5	3654	3106.2	>2419.6	>2419.6	387.3	195.6	>2419.6
05/12/2011	8704	3214	7308	3255	5226	987	4962	2595.2	>2419.6	>2419.6	323.2	235.6	_
12/12/2011	7270	6794	3654	1179.5	3255	719.5	2755	3972.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6
12/12/2011	6510	6896	5818	1650	5510	813	4494	1642.4	>2419.6	>2419.6	>2419.6	3972.6	>2419.6

Note: All data as MPN/100ml
Blank Cells / _ = No Data
Over Range Data = >2419.6
For each sample date, lower dilution is on top

Flow Sequence
Raw - Cell 1
Raw - Cell 3 - Cell 5
Raw - Cell 7 - Cell 8
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2

Phase 1 - CELL 1, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 1 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 1	**CELL 1**
Aug-07	945	2400
Sep-07	945	2400
Oct-07	945	2400
Average	945	2400

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**Raw**	**Cell 1**
Aug-07	388	174	366	164
Sep-07	440	276	415	260
Oct-07	322	284	304	268
Average	383	245	361	231
Min	322	174	304	164
Max	440	284	415	268
St Dev	59	61	56	58
n	3	3	3	3

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**RAW**	**CELL 1**
Aug-07	36		34	
Sep-07	41	66	39	62
Oct-07	128	64	121	62
Average	68	65	65	62
Min	36	64	34	62
Max	128	66	121	62
St Dev	52	2	49	0
n	3	2	3	2

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**RAW**	**CELL 1**
Aug-07	442	428	417	404
Sep-07	482	465	455	439
Oct-07	408	414	385	390
Average	444	436	419	411
Min	408	414	385	390
Max	482	465	455	439
St Dev	37	26	35	25
n	3	3	3	3

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**RAW**	**CELL 1**
Aug-07	259	260	244	245
Sep-07	324	328	306	309
Oct-07	455	344	429	324
Average	346	311	326	293
Min	259	260	244	245
Max	455	344	429	324
St Dev	100	45	94	42
n	3	3	3	3

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**RAW**	**CELL 1**
Aug-07	4.96	1.12	4.7	1.1
Sep-07	9.20	5.00	8.7	4.7
Oct-07	10.60	5.23	10.0	4.9
Average	8.25	3.78	7.78	3.57
Min	4.96	1.12	4.68	1.06
Max	10.60	5.23	10.00	4.93
St Dev	2.94	2.31	2.77	2.18
n	3	3	3	3

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**RAW**	**CELL 1**
Aug-07	48	12	45	11
Sep-07	51	33	48	31
Oct-07	48	54	46	51
Average	49	33	46	31
Min	48	12	45	11
Max	51	54	48	51
St Dev	2	21	1	20
n	3	3	3	3

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 1**	**RAW**	**CELL 1**
Aug-07	2.95	2.63	2.78	2.48
Sep-07				
Oct-07	3.50	3.21	3.30	3.03
Average	3.23	2.92	3.04	2.75
Min	2.95	2.63	2.78	2.48
Max	3.50	3.21	3.30	3.03
St Dev	0.39	0.41	0.37	0.39
n	2	2	2	2

pH	pH Units	
	RAW	**CELL 1**
Aug-07	7.32	7.24
Sep-07	7.30	7.09
Oct-07	7.37	7.50
Average	7.33	7.28
Min	7.30	7.09
Max	7.37	7.50
St Dev	0.04	0.21
n	3	3

EC	EC mS/cm	
	RAW	**CELL 1**
Aug-07	4.95	4.28
Sep-07	4.95	4.50
Oct-07	4.45	4.28
Average	4.78	4.35
Min	4.45	4.28
Max	4.95	4.50
St Dev	0	0
n	3	3

Methane	Concentration (mg/l)	
	RAW	**CELL 1**
Aug-07	3.50	
Sep-07	6.30	1.20
Oct-07	9.20	0.20
Average	6.33	0.70
Min	3.50	0.20
Max	9.20	1.20
St Dev	2.85	0.71
n	3	2

Phase 1 and Phase 2 - CELL 2, Parameter Concentrations and Loadings

Note: RAW = Influent; CELL 2 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 2	**CELL 2**
Aug-07	945	2400
Sep-07	945	2400
Oct-07	945	2400
Nov-07	945	2400
Dec-07	945	2400
Jan-08	945	2400
Feb-08	945	2400
Mar-08	945	2400
Average	945	2400

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 2**	**RAW**	**CELL 2**
Aug-07	440	364	415	343
Sep-07	440	396	415	373
Oct-07	322	268	304	253
Nov-07	440	370	415	349
Dec-07				
Jan-08	130	66	123	62
Feb-08	260	100	245	94
Mar-08	270	156	255	147
Average	329	246	310	232
Min	130	66	123	62
Max	440	396	415	373
St Dev	119	138	112	130
n	7	7	7	7

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	Raw	**Cell 2**	**RAW**	**CELL 2**
Aug-07	513	479	484	452
Sep-07	482	440	455	415
Oct-07	408	428	385	404
Nov-07	429	423	404	398
Dec-07				
Jan-08	186	147	176	139
Feb-08	275	224	259	211
Mar-08	448	405	422	382
Average	392	364	369	343
Min	186	147	176	139
Max	513	479	484	452
St Dev	118	126	111	118
n	7	7	7	7

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 2**	**RAW**	**CELL 2**
Aug-07	36	60	34	57
Sep-07	41	40	39	38
Oct-07	128	60	121	57
Nov-07	13	44	13	42
Dec-07				
Jan-08	13	16	12	15
Feb-08	32	48	30	45
Mar-08	13	63	12	59
Average	40	47	37	45
Min	13	16	12	15
Max	128	63	121	59
St Dev	41	16	38	15
n	7	7	7	7

Cell 1 - 2, Phase 2

Chloride	Concentration (mg/l)			Loading (g/m^2/day)			HLR l/m^2/day	HLR l/unit/day
	Raw	**Cell 1**	**Cell 2**	**Raw**	**Cell 1**	**Cell 2**	**Cell 1**	**Cell 2**
Apr-08	411	428	437	579	603	615	1408	3576
May-08	431	423	444	607	596	625	1408	3576
Jun-08	844	546	539	1017	658	649	1205	3060
Average	562	466	473	734	619	630	1340	3404
Min	411	423	437	579	596	615		
Max	844	546	539	1017	658	649		
St Dev	244	70	57	245	34	18		

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 2**	**RAW**	**CELL 2**
Aug-07	315	297	297	280
Sep-07	324	308	306	290
Oct-07	455	308	429	290
Nov-07	263	268	248	253
Dec-07				
Jan-08	121	107	115	101
Feb-08	182	137	172	129
Mar-08	227	228	214	215
Average	270	236	254	223
Min	121	107	115	101
Max	455	308	429	290
St Dev	109	83	102	79
n	7	7	7	7

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	Raw	**Cell 2**	**RAW**	**CELL 2**
Aug-07	9.71	2.04	9.16	1.92
Sep-07	9.20	2.56	8.68	2.41
Oct-07	10.60	3.11	10.00	2.93
Nov-07	2.44	0.30	2.30	0.28
Dec-07				
Jan-08	3.48	0.82	3.28	0.77
Feb-08	7.40	0.42	6.98	0.39
Mar-08				
Average	7.14	1.54	6.73	1.45
Min	2.44	0.30	2.30	0.28
Max	10.60	3.11	10.00	2.93
St Dev	3.42	1.19	3.22	1.12
n	6	6	6	6

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 2**	**RAW**	**CELL 2**
Aug-07	62	10	59	9
Sep-07	51	11	48	10
Oct-07	48	25	46	23
Nov-07	38	49	35	46
Dec-07				
Jan-08	62	9	59	9
Feb-08	44	6	42	6
Mar-08	32	6	30	6
Average	48	17	46	16
Min	32	6	30	6
Max	62	49	59	46
St Dev	12	16	11	15
n	7	7	7	7

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 2**	**RAW**	**CELL 2**
Aug-07	3.15	2.21	2.97	2.08
Sep-07				
Oct-07	3.50	3.01	3.30	2.84
Nov-07	2.21	2.61	2.08	2.46
Dec-07				
Jan-08	2.44	2.94	2.40	2.77
Feb-08	3.70	3.46	3.49	3.26
Mar-08				
Average	3.00	2.85	2.85	2.68
Min	2.21	2.21	2.08	2.08
Max	3.70	3.46	3.49	3.26
St Dev	0.65	0.47	0.60	0.44
n	5	5	5	5

pH	pH Units	
	RAW	**CELL 2**
Aug-07	7.32	7.37
Sep-07	7.30	7.23
Oct-07	7.37	7.29
Nov-07	7.29	7.65
Dec-07		
Jan-08	7.07	6.91
Feb-08	7.53	6.80
Mar-08	7.24	7.10
Average	7.30	7.19
Min	7.07	6.80
Max	7.53	7.65
St Dev	0.14	0.29
n	7	7

Methane	Concentration (mg/l)	
	RAW	**CELL 2**
Aug-07	3.50	
Sep-07	6.30	0.19
Oct-07	6.60	0.10
Nov-07	11.00	5.00
Dec-07		
Jan-08	4.20	
Feb-08	4.20	
Mar-08		
Average	5.97	1.76
Min	3.50	0.10
Max	11.00	5.00
St Dev	2.76	2.80
n	6	3

EC	mS/cm	
	RAW	**CELL 2**
Aug-07	5.16	4.90
Sep-07	4.95	4.76
Oct-07	4.45	4.26
Nov-07	4.36	4.38
Dec-07		
Jan-08	2.46	2.01
Feb-08	3.02	2.40
Mar-08	4.12	3.59
Average	4	4
Min	2	2
Max	5	5
St Dev	1	1
n	7	7

Phase 1 - CELL 3, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 3 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 3	**CELL 3**
Aug-07	945	2400
Sep-07	945	2400
Oct-07	945	2400
Nov-07	945	2400
Average	945	2400

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	388	240	366	226
Sep-07	440	400	415	377
Oct-07	322	346	304	326
Nov-07	440	352	415	332
Average	398	334	375	315
Min	322	240	304	226
Max	440	400	415	377
St Dev	56	67	53	64
n	4	4	4	4

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	36		34	
Sep-07	41	29	39	27
Oct-07	128	129	121	122
Nov-07	13	62	13	58
Average	55	73	52	69
Min	13	29	13	27
Max	128	129	121	122
St Dev	50	51	48	48
n	4	3	4	3

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	442	445	417	420
Sep-07	482	513	455	484
Oct-07	408	425	385	401
Nov-07	428	442	404	417
Average	440	457	415	431
Min	408	425	385	401
Max	482	513	455	484
St Dev	31	39	29	37
n	4	4	4	4

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	259	259	244	244
Sep-07	324	331	306	312
Oct-07	455	478	429	451
Nov-07	263	253	248	239
Average	325	330	307	311
Min	259	253	244	239
Max	455	478	429	451
St Dev	91	105	86	99
n	4	4	4	4

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	4.96	0.40	4.68	0.37
Sep-07	9.20	3.28	8.68	3.09
Oct-07	10.60	9.30	10.00	8.77
Nov-07	2.44	0.40	2.30	0.37
Average	7	3	6	3
Min	2	0	2	0
Max	11	9	10	9
St Dev	4	4	4	4
n	4	4	4	4

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	48	3	45	3
Sep-07	51	13	48	13
Oct-07	48	55	46	52
Nov-07	38	21	35	19
Average	46	23	44	22
Min	38	3	35	3
Max	51	55	48	52
St Dev	6	22	6	21
n	4	4	4	4

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 3**	**RAW**	**CELL 3**
Aug-07	2.95	3.03	2.78	2.86
Sep-07				
Oct-07	3.50	4.10	3.30	3.87
Nov-07	2.21	3.22	2.08	3.04
Average	3	3	3	3
Min	2	3	2	3
Max	4	4	3	4
St Dev	1	1	1	1
n	3	3	3	3

pH	pH Units	
	RAW	**CELL 3**
Aug-07	7.32	7.12
Sep-07	7.30	7.64
Oct-07	7.37	7.84
Nov-07	7.29	7.75
Average	7	8
Min	7	7
Max	7	8
St Dev	0	0
n	4	4

EC	mS/cm	
	RAW	**CELL 3**
Aug-07	4.95	4.44
Sep-07	4.95	4.94
Oct-07	4.45	4.49
Nov-07	4.36	4.43
Average	5	5
Min	4	4
Max	5	5
St Dev	0	0
n	4	4

Methane	Concentration (mg/l)	
	RAW	**CELL 3**
Aug-07	3.50	0.02
Sep-07	6.30	4.00
Oct-07	6.60	1.00
Nov-07	11.00	2.80
Average	7	2
Min	4	0
Max	11	4
St Dev	3	2
n	4	4

Phase 1 and Phase 2 - CELL 4, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 4 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 4	**CELL 4**
Aug-07	945	2400
Sep-07	945	2400
Oct-07	945	2400
Nov-07	945	2400
Dec-07	945	2400
Jan-08	945	2400
Feb-08	945	2400
Mar-08	945	2400
Apr-08	945	2400
Average	945	2400

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	440	336	415	317
Sep-07	440	440	415	415
Oct-07	322	396	304	373
Nov-07	440	348	415	328
Dec-07				
Jan-08	130	110	123	104
Feb-08	368	359	347	339
Mar-08	240	170	226	160
Apr-08	384	324	362	306
Average	346	310	326	293
Min	130	110	123	104
Max	440	440	415	415
St Dev	111	112	105	106
n	8	8	8	8

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	36	96	34	90
Sep-07	41	36	39	34
Oct-07	128	130	121	123
Nov-07	13	45	13	42
Dec-07				
Jan-08	13	32	12	30
Feb-08	27	47	26	45
Mar-08	15	40	14	38
Apr-08	28	71	27	66
Average	38	62	36	59
Min	13	32	12	30
Max	128	130	121	123
St Dev	38	35	36	33
n	8	8	8	8

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	513	593	484	559
Sep-07	482	475	455	448
Oct-07	408	462	385	436
Nov-07	428	440	404	415
Dec-07				
Jan-08	186	146	176	138
Feb-08	459	417	433	393
Mar-08	343	272	323	257
Apr-08	454	440	428	415
Average	409	406	386	382
Min	186	146	176	138
Max	513	593	484	559
St Dev	104	137	98	129
n	8	8	8	8

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	315	315	297	297
Sep-07	324	327	306	308
Oct-07	455	481	429	454
Nov-07	263	255	248	240
Dec-07				
Jan-08	122	111	115	105
Feb-08	240	218	226	206
Mar-08	134	145	126	137
Apr-08	305	297	288	280
Average	270	269	254	253
Min	122	111	115	105
Max	455	481	429	454
St Dev	108	116	102	109
n	8	8	8	8

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	9.71	1.92	9.16	1.81
Sep-07	9.20	2.64	8.68	2.49
Oct-07	10.60	3.76	10.00	3.55
Nov-07	2.44	0.43	2.30	0.41
Dec-07				
Jan-08	3.48	1.33	3.28	1.25
Feb-08	7.40			
Mar-08				
Apr-08	13.40	1.70	12.64	1.60
Average	8.03	1.96	7.67	1.85
Min	2.44	0.43	2.30	0.41
Max	13.40	3.76	12.64	3.55
St Dev	3.92	1.14	4.03	1.07
n	7	6	6	6

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	62	10	59	10
Sep-07	51	20	48	18
Oct-07	48	34	46	32
Nov-07	38	46	35	44
Dec-07				
Jan-08	62	14	59	13
Feb-08	42	18	40	17
Mar-08	26	5	25	5
Apr-08	38	5	36	5
Average	46	19	43	18
Min	26	5	25	5
Max	62	46	59	44
St Dev	12	15	12	14
n	8	8	8	8

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 4**	**RAW**	**CELL 4**
Aug-07	3.15	2.27	2.97	2.14
Sep-07				
Oct-07	3.50	4.00	3.30	3.77
Nov-07	2.21	3.21	2.08	3.03
Dec-07				
Jan-08	2.44	2.62	2.31	2.47
Feb-08	3.17	2.02	3.00	1.90
Mar-08				
Apr-08	3.33	2.76	3.14	2.60
Average	2.97	2.81	2.80	2.65
Min	2.21	2.02	2.08	1.90
Max	3.50	4.00	3.30	3.77
St Dev	0.52	0.71	0.49	0.67
n	6	6	6	6

pH	pH Units	
	RAW	**CELL 4**
Aug-07	7.46	7.33
Sep-07	7.30	7.64
Oct-07	7.37	7.81
Nov-07	7.29	7.64
Dec-07		
Jan-08	7.07	7.52
Feb-08	7.24	7.51
Mar-08	7.30	7.35
Apr-08	7.15	7.35
Average	7.27	7.52
Min	7.07	7.33
Max	7.46	7.81
St Dev	0.12	0.17
n	8	8

EC	mS/cm	
	RAW	**CELL 4**
Aug-07	5.16	4.78
Sep-07	4.95	4.97
Oct-07	4.45	4.74
Nov-07	4.36	4.34
Dec-07		
Jan-08	2.46	2.20
Feb-08	4.15	3.97
Mar-08	2.97	2.75
Apr-08	4.91	4.61
Average	4.18	4.05
Min	2.46	2.20
Max	5.16	4.97
St Dev	0.97	1.03
n	8	8

Methane	Concentration (mg/l)	
	RAW	**CELL 4**
Aug-07	3.50	
Sep-07	6.30	4.30
Oct-07	6.60	2.40
Nov-07	11.00	4.40
Dec-07		
Jan-08	4.20	
Feb-08	4.20	
Mar-08		
Apr-08		
Average	5.97	3.70
Min	3.50	2.40
Max	11.00	4.40
St Dev	2.76	1.13
n	6	3

Phase 1 and Phase 2 - CELL 5, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 5 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 5	**CELL 5**
Aug-07	189	480
Sep-07	189	480
Oct-07	189	480
Nov-07	OFF	OFF
Dec-07	189	480
Jan-08	189	480
Feb-08	OFF	OFF
Mar-08	189	480
Apr-08	189	480
May-08	94	240
Jun-08	94	240
Jul-08	94	240
Average	161	408

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	388	356	73	67
Sep-07	440	324	83	61
Oct-07	330	328	62	62
Nov-07				
Dec-07				
Jan-08	180	140	34	26
Feb-08				
Mar-08				
Apr-08	384	216	72	41
May-08	392	124	37	12
Jun-08	308	68	29	6
Jul-08	237	114	22	11
Average	332	209	52	36
Min	180	68	22	6
Max	440	356	83	67
St Dev	88	113	24	25
n	8	8	8	8

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	36		7	
Sep-07	31	21	6	4
Oct-07	29	26	6	5
Nov-07			4	
Dec-07				
Jan-08	24	39	4	7
Feb-08				
Mar-08	15			
Apr-08	28	71	5	13
May-08	23	13	2	2
Jun-08	35	15	3	1
Jul-08	17	21	2	2
Average	27	29	4	5
Min	15	13	2	1
Max	36	71	7	13
St Dev	7	20	2	4
n	9	7	9	7

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	442	485	83	91
Sep-07	508	482	96	91
Oct-07	349	386	66	73
Nov-07				
Dec-07				
Jan-08	235	272	44	51
Feb-08				
Mar-08	343			
Apr-08	454	440	86	83
May-08	447	496	42	47
Jun-08	376	432	35	41
Jul-08	319	305	30	29
Average	386	412	60	63
Min	235	272	30	29
Max	508	496	96	91
St Dev	84	85	26	24
n	9	8	8	8

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	259	237	49	45
Sep-07	337	283	64	53
Oct-07	278	300	52	57
Nov-07				
Dec-07				
Jan-08	153	184	29	35
Feb-08				
Mar-08	227			
Apr-08	305	306	58	58
May-08	252	214	24	20
Jun-08	208	258	20	24
Jul-08	207	174	20	16
Average	247	245	39	38
Min	153	174	20	16
Max	337	306	64	58
St Dev	56	51	18	17
n	9	8	8	8

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	4.96	0.96	0.935	0.181
Sep-07	9.43	0.29	1.779	0.055
Oct-07	6.94	6.10	1.309	1.15
Nov-07	2.37			
Dec-07				
Jan-08	5.56	1.02	1.049	0.19
Feb-08	5.35			
Mar-08				
Apr-08	13.40	1.11	2.527	0.21
May-08	10.75	0.50	1.014	0.09
Jun-08	11.55	1.24	1.089	0.12
Jul-08	2.52	1.19	0.238	0.11
Average	7.28	1.55	1.24	0.26
Min	2.37	0.29	0.24	0.06
Max	13.40	6.10	2.53	1.15
St Dev	3.82	1.87	0.67	0.36
n	10	8	8	8

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	48	13	9	2
Sep-07	45	5	8	1
Oct-07	37	40	7	8
Nov-07				
Dec-07				
Jan-08	18	11	3	2
Feb-08				
Mar-08	26			
Apr-08	38	4	7	1
May-08	32	4	3	1
Jun-08	28	5	3	0.4
Jul-08	28	3	3	0.2
Average	33	10	5	2
Min	18	3	3	0.2
Max	48	40	9	8
St Dev	9	12	3	2
n	9	8	8	8

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 5**	**RAW**	**CELL 5**
Aug-07	2.95	2.73	0.56	0.51
Sep-07	0.93	2.68	0.18	0.51
Oct-07	3.07	4.30	0.58	0.81
Nov-07				
Dec-07				
Jan-08	2.44	2.83	0.46	0.53
Feb-08				
Mar-08				
Apr-08	3.33	4.86	0.63	0.92
May-08	3.50	6.40	0.33	0.60
Jun-08	3.07	5.90	0.29	0.56
Jul-08	2.23	5.90	0.21	0.56
Average	2.69	4.45	0.40	0.62
Min	0.93	2.68	0.18	0.51
Max	3.50	6.40	0.63	0.92
St Dev	0.83	1.55	0.18	0.15
n	8	8	8	8

pH	pH Units	
	RAW	**CELL 5**
Aug-07	7.32	7.32
Sep-07	7.38	7.44
Oct-07	7.22	7.66
Nov-07		
Dec-07		
Jan-08	7.23	7.32
Feb-08		
Mar-08	7.30	
Apr-08	7.15	7.11
May-08	7.60	7.52
Jun-08	7.19	
Jul-08	7.21	7.12
Average	7.29	7.36
Min	7.15	7.11
Max	7.60	7.66
St Dev	0.14	0.20
n	9	7

EC	mS/cm	
	RAW	**CELL 5**
Aug-07	4.95	4.61
Sep-07	5.40	4.70
Oct-07	4.22	4.27
Nov-07		
Dec-07		
Jan-08	2.60	2.75
Feb-08		
Mar-08	4.12	
Apr-08	4.91	4.28
May-08	4.47	3.99
Jun-08	3.80	3.40
Jul-08	3.37	2.70
Average	4.20	3.84
Min	2.60	2.70
Max	5.40	4.70
St Dev	0.87	0.79
n	9	8

Methane	Concentration (mg/l)	
	RAW	**CELL 5**
Aug-07	3.50	0.12
Sep-07	5.60	0.01
Oct-07	9.20	3.50
Nov-07		
Dec-07		
Jan-08	4.20	
Feb-08	4.20	
Mar-08		
Apr-08		
May-08	6.60	0.00
Average	5.55	0.91
Min	3.50	0.00
Max	9.20	3.50
St Dev	2.11	1.73
n	6	4

Phase 1 and Phase 2 - CELL 6, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 6 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 6	**CELL 6**
Aug-07	472	1200
Sep-07	472	1200
Oct-07	472	1200
Nov-07	472	1200
Dec-07	472	1200
Jan-08	472	1200
Feb-08	472	1200
Mar-08	472	1200
Apr-08	472	1200
May-08	472	1200
Jun-08	236	600
Average	451	1145

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	440	400	207	189
Sep-07	440	440	207	207
Oct-07	330	356	156	168
Nov-07	248	256	117	121
Dec-07				
Jan-08	130	160	61	75
Feb-08				
Mar-08	270	150	127	71
Apr-08	384	160	181	75
May-08	392	348	185	164
Jun-08	308	316	73	75
Average	327	287	146	127
Min	130	150	61	71
Max	440	440	207	207
St Dev	101	110	55	55
n	9	9	9	9

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	36	63	17	30
Sep-07	31	37	15	17
Oct-07	29	40	14	19
Nov-07	24	50	11	24
Dec-07				
Jan-08	13	38	6	18
Feb-08	27			
Mar-08	13	14	6	7
Apr-08	28	7	13	3
May-08	23	28	11	13
Jun-08	35	89	8	21
Average	26	41	11	17
Min	13	7	6	3
Max	36	89	17	30
St Dev	8	25	4	8
n	10	9	9	9

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	513	525	242	247
Sep-07	508	474	239	223
Oct-07	349	437	164	206
Nov-07	272	315	128	148
Dec-07				
Jan-08	186	193	88	91
Feb-08	459			
Mar-08	448	343	211	162
Apr-08	454	329	214	155
May-08	447	503	211	237
Jun-08	376	461	89	109
Average	401	398	176	175
Min	186	193	88	91
Max	513	525	242	247
St Dev	106	109	61	56
n	10	9	9	9

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	315	309	149	146
Sep-07	337	324	159	153
Oct-07	278	324	131	153
Nov-07	198	212	93	100
Dec-07				
Jan-08	122	123	58	58
Feb-08	240			
Mar-08	227	160	107	75
Apr-08	305	172	144	81
May-08	252	261	119	123
Jun-08	208	236	49	56
Average	248	236	112	105
Min	122	123	49	56
Max	337	324	159	153
St Dev	64	75	39	40
n	10	9	9	9

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	9.71	8.22	4.58	3.88
Sep-07	9.43	13.40	4.45	6.32
Oct-07	6.94	10.40	3.27	4.90
Nov-07	2.37	2.36	1.12	1.11
Dec-07				
Jan-08	3.48	2.25	1.64	1.06
Feb-08	7.40			
Mar-08				
Apr-08	13.40	0.24	6.32	0.11
May-08	10.75	3.42	5.07	1.61
Jun-08	11.55	3.69	2.72	0.87
Average	8.34	5.50	3.65	2.48
Min	2.37	0.24	1.12	0.11
Max	13.40	13.40	6.32	6.32
St Dev	3.66	4.62	1.78	2.25
n	9	8	8	8

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	62	44	29	21
Sep-07	45	60	21	28
Oct-07	37	76	17	36
Nov-07	32	39	15	18
Dec-07				
Jan-08	62	33	29	16
Feb-08	42			
Mar-08	32	12	15	5
Apr-08	38	4	18	2
May-08	32	44	15	21
Jun-08	28	18	7	4
Average	41	37	19	17
Min	28	4	7	2
Max	62	76	29	36
St Dev	12	23	7	11
n	10	9	9	9

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 6**	**RAW**	**CELL 6**
Aug-07	3.15	4.27	1.49	2.01
Sep-07	0.93	2.06	0.44	0.97
Oct-07	3.07	5.60	1.45	2.64
Nov-07	2.11	2.50	0.99	1.18
Dec-07				
Jan-08	2.54	3.40	1.20	1.60
Feb-08	3.70			
Mar-08				
Apr-08	3.33	5.50	1.57	2.59
May-08	3.50	3.09	1.65	1.46
Jun-08	3.07	3.05	0.72	0.72
Average	2.82	3.68	1.19	1.65
Min	0.93	2.06	0.44	0.72
Max	3.70	5.60	1.65	2.64
St Dev	0.86	1.32	0.44	0.72
n	9	8	8	8

pH	pH Units	
	RAW	**CELL 6**
Aug-07	7.46	7.54
Sep-07	7.38	7.51
Oct-07	7.22	7.52
Nov-07	7.36	7.77
Dec-07		
Jan-08	7.07	7.63
Feb-08	7.24	
Mar-08	7.24	7.35
Apr-08	7.15	7.69
May-08	7.60	7.84
Jun-08	7.19	
Average	7.29	7.61
Min	7.07	7.35
Max	7.60	7.84
St Dev	0.16	0.16
n	10	8

EC	mS/cm	
	RAW	**CELL 6**
Aug-07	5.16	5.01
Sep-07	5.40	5.13
Oct-07	4.22	4.45
Nov-07	3.13	3.37
Dec-07		
Jan-08	2.46	2.65
Feb-08	3.02	
Mar-08	4.12	3.10
Apr-08	4.91	3.18
May-08	4.47	4.78
Jun-08	3.80	4.25
Average	4.07	3.99
Min	2.46	2.65
Max	5.40	5.13
St Dev	0.97	0.93
n	10	9

Methane	Concentration (mg/l)	
	RAW	**CELL 6**
Aug-07	3.50	
Sep-07	5.60	5.00
Oct-07	9.20	5.30
Nov-07	11.00	
Dec-07		
Jan-08	4.20	
Feb-08	4.20	
Mar-08		
Apr-08		
May-08	14.00	0.80
Jun-08		
Average	7.39	3.70
Min	3.50	0.80
Max	14.00	5.30
St Dev	4.06	2.52
n	7	3

Phase 1 and Phase 2 - CELL 7, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 7 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 7	**CELL 7**
Aug-07	945	2400
Sep-07	945	2400
Oct-07	945	2400
Nov-07	945	2400
Dec-07	945	2400
Jan-08	945	2400
Feb-08	945	2400
Mar-08	945	2400
Apr-08	945	2400
May-08	472	1200
Jun-08	472	1200
Jul-08	472	1200
Aug-08	472	1200
Sep-08	472	1200
Average	776	1971

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	388	280	366	264
Sep-07	440	400	415	377
Oct-07	330	268	311	253
Nov-07	248	224	234	211
Dec-07				
Jan-08	180	120	170	113
Feb-08	260	208	245	196
Mar-08	240	220	226	207
Apr-08	384	372	362	351
May-08	392	400	185	189
Jun-08	308	400	145	189
Jul-08	237	216	112	102
Aug-08	249	245	117	116
Sep-08	230	215	108	101
Average	299	274	231	205
Min	180	120	108	101
Max	440	400	415	377
St Dev	80	91	105	89
n	13	13	13	13

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	36		34	
Sep-07	31	80	29	76
Oct-07	29	26	28	25
Nov-07	24	62	22	58
Dec-07				
Jan-08	24	29	22	27
Feb-08	32	29	30	28
Mar-08	15	22	14	20
Apr-08	28	29	27	27
May-08	23	58	11	27
Jun-08	35	81	17	38
Jul-08	17	8	8	4
Aug-08				
Sep-08	16	8	7	4
Average	26	39	21	30
Min	15	8	7	4
Max	36	81	34	76
St Dev	7	26	9	21
n	12	11	12	11

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	442	417	417	393
Sep-07	508	508	479	479
Oct-07	349	420	329	396
Nov-07	272	312	257	294
Dec-07				
Jan-08	235	206	222	194
Feb-08	275	301	259	283
Mar-08	343	320	323	302
Apr-08	454	454	428	428
May-08	447	482	211	227
Jun-08	376	461	177	217
Jul-08	319	305	150	144
Aug-08				
Sep-08	277	305	131	144
Average	358	374	282	292
Min	235	206	131	144
Max	508	508	479	479
St Dev	88	94	114	112
n	12	12	12	12

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	259	259	244	244
Sep-07	337	355	318	335
Oct-07	278	274	262	258
Nov-07	198	211	187	199
Dec-07				
Jan-08	153	280	144	264
Feb-08	182	176	172	166
Mar-08	134	132	126	124
Apr-08	305	270	288	255
May-08	252	242	119	114
Jun-08	208	256	98	121
Jul-08	207	198	98	93
Aug-08				
Sep-08	184	162	87	76
Average	225	235	179	188
Min	134	132	87	76
Max	337	355	318	335
St Dev	62	61	81	83
n	12	12	12	12

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	4.96	3.06	4.68	2.89
Sep-07	9.43	8.03	8.89	7.57
Oct-07	6.94	5.04	6.54	4.75
Nov-07	2.37	1.04	2.23	0.98
Dec-07				
Jan-08	1.99	1.22	1.88	1.15
Feb-08	7.40	2.53	6.98	2.39
Mar-08				
Apr-08	13.40	5.56	12.64	5.24
May-08	10.75	4.14	5.07	1.95
Jun-08	11.55	17.45	5.45	8.23
Jul-08	2.52	2.25	1.19	1.06
Aug-08				
Sep-08	8.05	8.30	3.80	3.91
Average	7.21	5.33	5.39	3.65
Min	1.99	1.04	1.19	0.98
Max	13.40	17.45	12.64	8.23
St Dev	3.91	4.72	3.34	2.56
n	11	11	11	11

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	48	28	45	26
Sep-07	45	50	42	47
Oct-07	37	30	35	28
Nov-07	32	30	30	28
Dec-07				
Jan-08	18	10	17	10
Feb-08	44	24	42	22
Mar-08	26	14	25	14
Apr-08	38	27	36	25
May-08	32	58	15	27
Jun-08	28	64	13	30
Jul-08	28	65	13	31
Aug-08				
Sep-08	28	12	13	6
Average	34	34	27	25
Min	18	10	13	6
Max	48	65	45	47
St Dev	9	20	13	11
n	12	12	12	12

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 7**	**RAW**	**CELL 7**
Aug-07	2.95	2.56	2.78	2.41
Sep-07	0.93	0.81	0.88	0.76
Oct-07	3.07	3.50	2.90	3.30
Nov-07	2.11	2.08	1.99	1.96
Dec-07				
Jan-08	2.44	2.62	2.30	2.47
Feb-08	3.70	2.90	3.49	2.73
Mar-08				
Apr-08	3.33	3.25	3.14	3.06
May-08	3.50	2.83	1.65	1.33
Jun-08	3.07	4.24	1.45	2.00
Jul-08	2.23	3.85	1.05	1.82
Aug-08				
Sep-08	2.98	3.98	1.41	1.88
Average	2.75	2.97	2.09	2.16
Min	0.93	0.81	0.88	0.76
Max	3.70	4.24	3.49	3.30
St Dev	0.79	0.98	0.89	0.74
n	11	11	11	11

pH	pH Units	
	RAW	**CELL 7**
Aug-07	7.32	7.47
Sep-07	7.38	7.60
Oct-07	7.22	7.53
Nov-07	7.36	7.73
Dec-07		
Jan-08	7.23	7.38
Feb-08	7.53	7.36
Mar-08	7.30	7.55
Apr-08	7.15	7.54
May-08	7.60	7.97
Jun-08	7.19	
Jul-08	7.21	7.46
Aug-08		
Sep-08	7.16	7.72
Average	7.30	7.57
Min	7.15	7.36
Max	7.60	7.97
St Dev	0.14	0.18
n	12	11

EC	mS/cm	
	RAW	**CELL 7**
Aug-07	4.95	4.63
Sep-07	5.40	5.17
Oct-07	4.22	4.05
Nov-07	3.13	3.25
Dec-07		
Jan-08	2.60	2.55
Feb-08	3.02	2.88
Mar-08	2.97	2.94
Apr-08	4.91	4.83
May-08	4.47	4.69
Jun-08	3.80	4.26
Jul-08	3.37	2.97
Aug-08		
Sep-08	3.06	2.95
Average	3.83	3.76
Min	2.60	2.55
Max	5.40	5.17
St Dev	0.94	0.93
n	12	12

Methane	Concentration (mg/l)	
	RAW	**CELL 7**
Aug-07	3.50	
Sep-07	5.60	1.50
Oct-07	9.20	3.80
Nov-07	11.00	
Dec-07		
Jan-08	4.20	0.10
Feb-08	4.20	0.10
Mar-08		
Apr-08		
May-08	6.60	0.20
Jun-08		
Jul-08		
Aug-08		
Sep-08	9.80	
Average	6.76	1.14
Min	3.50	0.10
Max	11.00	3.80
St Dev	2.89	1.60
n	8	5

Phase 1 and Phase 2 - CELL 8, Parameter Concentrations and Loadings
Note: RAW = Influent; CELL 8 = Effluent

HLR	l/m^2/day	l/unit/day
	CELL 8	**CELL 8**
Aug-07	472	1200
Sep-07	472	1200
Oct-07	472	1200
Nov-07	OFF	OFF
Dec-07	OFF	OFF
Jan-08	OFF	OFF
Feb-08	OFF	OFF
Mar-08	472	1200
Apr-08	472	1200
May-08	472	1200
Jun-08	236	600
Jul-08	236	600
Aug-08	236	600
Sep-08	236	600
Average	378	960

NH_4	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	440	392	196	185
Sep-07	440	440	207	207
Oct-07	330	352	156	166
Nov-07				
Dec-07				
Jan-08				
Feb-08				
Mar-08	270	238	127	112
Apr-08	384	380	181	179
May-08	392	384	185	181
Jun-08	308	400	73	94
Jul-08	237	190	56	45
Aug-08	249	244	59	58
Sep-08	230	228	54	54
Average	328	325	129	128
Min	230	190	54	45
Max	440	440	207	207
St Dev	82	90	63	63
n	10	10	10	10

BOD_5	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	36	43	16	20
Sep-07	31	37	15	17
Oct-07	29	35	14	16
Nov-07				
Dec-07				
Jan-08				
Feb-08				
Mar-08	13	12	6	6
Apr-08	28	19	13	9
May-08	23	18	11	8
Jun-08	35	98	8	23
Jul-08	17	19	4	4
Aug-08				
Sep-08	19	73	4	17
Average	26	39	10	13
Min	13	12	4	4
Max	36	98	16	23
St Dev	8	29	5	7
n	9	9	9	9

Chloride	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	513	527	242	249
Sep-07	508	502	239	237
Oct-07	349	406	164	191
Nov-07				
Dec-07				
Jan-08				
Feb-08				
Mar-08	448	399	211	188
Apr-08	454	451	214	213
May-08	447	475	211	224
Jun-08	376	496	89	117
Jul-08	319	269	75	63
Aug-08				
Sep-08	468	241	110	57
Average	431	418	173	171
Min	319	241	75	57
Max	513	527	242	249
St Dev	68	102	66	73
n	9	9	9	9

COD	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	315	300	149	141
Sep-07	337	326	159	154
Oct-07	278	302	131	142
Nov-07	263			
Dec-07				
Jan-08	122			
Feb-08	182			
Mar-08	227	208	107	98
Apr-08	305	278	144	131
May-08	252	254	119	120
Jun-08	208	275	49	65
Jul-08	207	169	49	40
Aug-08				
Sep-08	294	205	69	48
Average	249	257	108	104
Min	122	169	49	40
Max	337	326	159	154
St Dev	62	53	43	43
n	12	9	9	9

Iron	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	9.71	2.91	4.59	1.37
Sep-07	9.43	9.93	4.45	4.68
Oct-07	6.94	9.20	3.27	4.34
Nov-07				
Dec-07				
Jan-08				
Feb-08				
Mar-08				
Apr-08	13.40	2.48	6.33	1.17
May-08	10.75	2.10	5.07	0.99
Jun-08	11.55	10.85	2.72	2.56
Jul-08	2.52	2.06	0.59	0.49
Aug-08				
Sep-08	8.05	2.29	1.90	0.54
Average	9.04	5.23	3.62	2.02
Min	2.52	2.06	0.59	0.49
Max	13.40	10.85	6.33	4.68
St Dev	3.31	3.98	1.86	1.67
n	8	8	8	8

SS	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	62	20	28	9
Sep-07	45	52	21	25
Oct-07	37	52	17	25
Nov-07				
Dec-07				
Jan-08				
Feb-08				
Mar-08	32	11	15	5
Apr-08	38	10	18	5
May-08	32	45	15	21
Jun-08	28	47	7	11
Jul-08	28	28	6	6
Aug-08				
Sep-08	34	6	8	1
Average	37	30	15	12
Min	28	6	6	1
Max	62	52	28	25
St Dev	11	19	7	9
n	9	9	9	9

Mn	Concentration (mg/l)		Loading (g/m^2/day)	
	RAW	**CELL 8**	**RAW**	**CELL 8**
Aug-07	3.15	4.86	1.40	2.29
Sep-07	0.93	2.02	0.44	0.95
Oct-07	3.07	4.90	1.45	2.31
Nov-07	2.21			
Dec-07				
Jan-08				
Feb-08				
Mar-08				
Apr-08	3.33	5.10	1.57	2.40
May-08	3.50	4.75	1.65	2.24
Jun-08	3.07	4.34	0.72	1.02
Jul-08	2.23	2.11	0.53	0.50
Aug-08				
Sep-08	2.98	2.62	0.70	0.62
Average	2.72	3.84	1.06	1.54
Min	0.93	2.02	0.44	0.50
Max	3.50	5.10	1.65	2.40
St Dev	0.80	1.34	0.51	0.84
n	9	8	8	8

pH	pH Units	
	RAW	**CELL 8**
Aug-07	7.46	7.61
Sep-07	7.38	7.62
Oct-07	7.22	7.64
Nov-07		
Dec-07		
Jan-08		
Feb-08		
Mar-08	7.24	7.63
Apr-08	7.15	7.56
May-08	7.60	7.90
Jun-08	7.19	
Jul-08	7.21	7.60
Aug-08		
Sep-08	7.16	8.01
Average	7.29	7.70
Min	7.15	7.56
Max	7.60	8.01
St Dev	0.16	0.16
n	9	8

EC	mS/cm	
	RAW	**CELL 8**
Aug-07	5.16	4.99
Sep-07	5.40	5.27
Oct-07	4.22	4.42
Nov-07		
Dec-07		
Jan-08		
Feb-08		
Mar-08	4.12	3.93
Apr-08	4.91	4.94
May-08	4.47	4.81
Jun-08	3.80	4.64
Jul-08	3.37	2.80
Aug-08		
Sep-08	4.14	2.82
Average	4.40	4.29
Min	3.37	2.80
Max	5.40	5.27
St Dev	0.66	0.92
n	9	9

Methane	Concentration (mg/l)	
	RAW	**CELL 8**
Aug-07	3.50	
Sep-07	5.60	4.80
Oct-07	9.20	6.00
Nov-07	11.00	
Dec-07		
Jan-08	4.20	
Feb-08	4.20	
Mar-08		
Apr-08		
May-08	6.60	0.20
Jun-08		
Jul-08		
Aug-08		
Sep-08	13.00	0.30
Average	7.16	2.83
Min	3.50	0.20
Max	13.00	6.00
St Dev	3.52	3.01
n	8	4

Phase 2 - Sequence CELL 1 - VF 2 - HF 2, Parameter Concentrations and Loadings

Note: RAW = Influent; CELL 1, VF 2, HF 2 = Effluent

HLR	l/m^2/day	l/unit/day	l/m^2/day	l/unit/day
	CELL 1	CELL 1	VF 2/HF 2	VF 2/HF 2
Nov-07	945	2400	96	2400
Dec-07	945	2400	96	2400
Jan-08	945	2400	96	2400
Feb-08	945	2400	96	2400
Mar-08	945	2400	96	2400
Av	945	2400	96	2400

NH_4	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	440	324	84	84	415	306	8	8	1054	776	202	200
Dec-07												
Jan-08	180	140	6	15	170	132	1	1	431	335	14	25
Feb-08	260	192	21	32	245	181	2	3	623	460	50	75
Mar-08	240	186	14	10	226	175	1	1	575	446	35	25
Av	280	211	31	35	264	199	3.0	3.3	671	504	75	81
Min	180	140	6	10								
Max	440	324	84	84								
St Dev	112	79	36	34								
n	4	4	4	4								

BOD_5	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	13.30	44.30	42.67	24.95	12.54	42	4	2	32	106	102	60
Dec-07												
Jan-08	23.80	25.45	5.05	4.10	22.44	24	0.5	0.4	57	61	12	10
Feb-08	32.10	30.45	9.00	11.20	30.27	29	0.9	1.1	77	73	22	27
Mar-08	15.30	26.30	23.70	8.60	14.43	25	2.3	0.8	37	63	57	21
Av	21	32	20	12	22	31	2	1	55	80	45	32
Min	13	25	5	4								
Max	32	44	43	25								
St Dev	9	9	17	9								
n	4	4	4	4								

COD	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	263	266	234	179	248	251	22	17	630	637	562	430
Dec-07												
Jan-08	153	133	114	116	144	125	11	11	366	319	274	278
Feb-08	182	161	131	120	172	152	13	12	436	386	314	288
Mar-08	134	145	193	164	126	137	19	16	321	347	463	394
Av	183	176	168	145	173	166	16	14	438	422	403	347
Min	134	133	114	116								
Max	263	266	234	179								
St Dev	57	61	56	32								
n	4	4	4	4								

SS	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	38	38	13	7	35.4	36.3	1.2	0.7	90	92	30	17
Dec-07												
Jan-08	18	10	5	7	17.4	9.8	0.5	0.7	44	25	12	16
Feb-08	44	8	2	2	42.0	7.2	0.2	0.2	107	18	4	5
Mar-08	26	11	4	2	24.9	10.6	0.4	0.2	63	27	10	5
Av	32	17	6	4	29.9	16.0	0.6	0.4	76	41	14	11
Min	18	8	2	2								
Max	44	38	13	7								
St Dev	12	14	5	3								
n	4	4	4	4								

Chloride	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	428	431	357	323	405	407	34	31	1028	1035	858	776
Dec-07												
Jan-08	235	224	156	145	222	212	15	14	564	538	374	347
Feb-08	275	286	233	267	260	271	22	26	660	687	558	640
Mar-08	343	260	330	280	324	246	32	27	823	624	792	672
Av	320	300	269	254	303	284	26	24.3	769	721	646	609
Min	235	224	156	145								
Max	428	431	357	323								
St Dev	85	91	92	77								
n	4	4	4	4								

EC	mS/cm			
	RAW	**CELL 1**	**VF 2**	**HF 2**
Nov-07	4.36	4.29	2.95	2.63
Dec-07				
Jan-08	2.60	2.59	1.60	1.52
Feb-08	3.02	2.66	2.03	2.00
Mar-08	2.97	2.89	2.80	2.44
Av	3.24	3.11	2.35	2.15
Min	2.60	2.59	1.60	1.52
Max	4.36	4.29	2.95	2.63
St Dev	0.77	0.80	0.64	0.49
n	4	4	4	4

Iron	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	2.44	1.70	0.42	0.19	2.31	1.61	0.04	0.02	5.86	4.08	1.01	0.44
Dec-07												
Jan-08	3.48	3.22	0.43	0.07	3.29	3.04	0.04	0.01	8.35	7.73	1.03	0.18
Feb-08	7.40	1.01	0.08	0.12	6.99	0.95	0.01	0.01	17.76	2.42	0.20	0.29
Mar-08												
Av	4.44	1.98	0.31	0.13	4.20	1.87	0.03	0.01	10.66	4.74	0.75	0.30
Min	2.44	1.01	0.08	0.07								
Max	7.40	3.22	0.43	0.19								
St Dev	2.62	1.13	0.20	0.06								
n	3	3	3	3								

Mn	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**	**RAW**	**CELL 1**	**VF 2**	**HF 2**
Nov-07	2.21	1.64	4.80	3.60	2.09	1.55	0.46	0.35	5.30	3.94	11.52	8.64
Dec-07												
Jan-08	2.44	2.60	2.64	2.01	2.31	2.46	0.25	0.19	5.86	6.24	6.34	4.82
Feb-08	3.70	3.30	2.99	2.53	3.50	3.12	0.29	0.24	8.88	7.92	7.18	6.07
Mar-08												
Av	2.78	2.51	3.48	2.71	2.63	2.37	0.33	0.26	6.68	6.03	8.34	6.51
Min	2.21	1.64	2.64	2.01								
Max	3.70	3.30	4.80	3.60								
St Dev	0.80	0.83	1.16	0.81								
n	3	3	3	3								

pH	pH Units			
	RAW	**CELL 1**	**VF 2**	**HF 2**
Nov-07	7.3	7.8	6.9	7.3
Dec-07				
Jan-08	7.2	7.3	6.9	7.1
Feb-08	7.5	7.3	6.9	7.1
Mar-08	7.3	7.4	6.9	7.1
Av	7.3	7.5	6.9	7.2
Min	7.2	7.3	6.9	7.1
Max	7.5	7.8	6.9	7.3
St Dev	0.1	0.2	0.0	0.1
n	4	4	4	4

Methane		Methane Concentration (mg/l)				
		Nov-07	Dec-07	Jan-08	Feb-08	Mar-08
Influent	Raw	11		4.2	4.2	
Effluent	CELL 1	3.5		0.1	0.1	
Effluent	VF 2	0.1				
Effluent	HF 2					

Phase 2 - Sequence CELL 10 - VF 1 - HF 1, Parameter Concentrations and Loadings

Note: RAW = Influent; CELL 10, VF 1, HF 1 = Effluent

HLR	l/m^2/day	l/unit/day	l/m^2/day	l/unit/day
	CELL 10	CELL 10	VF 1/HF 1	VF 1/HF 1
Nov-07	945	2400	96	2400
Dec-07	945	2400	96	2400
Jan-08	945	2400	96	2400
Feb-08	945	2400	96	2400
Mar-08	945	2400	96	2400
Av	945	2400	96	2400

NH_4	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	248	264	152	160	234	249	15	15	594	632	365	384
Dec-07												
Jan-08	130	110	9	21	123	104	1	2	311	263	25	50
Feb-08	368	347	208	129	347	327	20	12	881	831	499	309
Mar-08	240	162	10	84	226	153	1	8	575	388	24	202
Av	247	221	95	98	232	208	9.1	9.5	590	529	228	236
Min	130	110	9	21								
Max	368	347	208	160								
St Dev	97	106	101	60								
n	4	4	4	4								

BOD_5	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	23.60	53.00	90.00	52.90	22.26	50	9	5	57	127	216	127
Dec-07												
Jan-08	13.00	19.25	14.02	26.25	12.26	18	1.3	2.5	31	46	34	63
Feb-08	27.30	29.10	39.30	39.50	25.74	27	3.8	3.8	65	70	94	95
Mar-08	15.30	24.00	15.20	18.60	14.43	23	1.5	1.8	37	57	36	45
Av	20	31	40	34	20	32	5	4	51	81	115	95
Min	13	19	14	19								
Max	27	53	90	53								
St Dev	7	15	36	15								
n	4	4	4	4								

COD	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	198	264	309	242	187	249	30	23	474	632	742	581
Dec-07												
Jan-08	122	105	99	75	115	99	10	7	292	252	238	180
Feb-08	240	211	200	179	226	199	19	17	575	505	480	430
Mar-08	134	124	117	135	126	117	11	13	321	297	281	324
Av	174	176	181	158	164	166	17	15	416	422	435	379
Min	122	105	99	75								
Max	240	264	309	242								
St Dev	55	75	96	71								
n	4	4	4	4								

SS	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	32	38	17	18	30.1	35.4	1.6	1.8	76	90	40	44
Dec-07												
Jan-08	62	10	4	9	59.0	9.1	0.4	0.9	150	23	11	22
Feb-08	42	9	4	34	39.7	8.7	0.3	3.2	101	22	9	81
Mar-08	26	5	3	4	24.9	4.9	0.3	0.4	63	12	7	11
Av	41	15	7	16	38.4	14.5	0.7	1.6	98	37	17	39
Min	26	5	3	4								
Max	62	38	17	34								
St Dev	16	15	7	13								
n	4	4	4	4								

Chloride	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	272	326	387	360	257	308	37	35	653	783	928	864
Dec-07												
Jan-08	186	152	146	126	176	143	14	12	448	364	351	303
Feb-08	459	340	335	366	434	322	32	35	1102	817	803	878
Mar-08	343	297	258	345	324	281	25	33	823	713	619	828
Av	315	279	281	299	298	263	27.0	28.7	756	669	675	718
Min	186	152	146	126								
Max	459	340	387	366								
St Dev	115	87	105	116								
n	4	4	4	4								

EC	mS/cm			
	RAW	**CELL 10**	**VF 1**	**HF 1**
Nov-07	3.13	3.25	3.39	3.05
Dec-07				
Jan-08	2.46	2.16	1.65	1.60
Feb-08	4.15	3.96	3.25	2.81
Mar-08	2.97	2.80	2.26	2.59
Av	3.18	3.04	2.64	2.51
Min	2.46	2.16	1.65	1.60
Max	4.15	3.96	3.39	3.05
St Dev	0.71	0.76	0.83	0.64
n	4	4	4	4

Iron	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	2.37	0.77	0.38	0.15	2.24	0.72	0.04	0.01	5.69	1.84	0.90	0.35
Dec-07												
Jan-08	3.48	0.40	0.14	0.05	3.29	0.37	0.01	0.01	8.35	0.95	0.32	0.13
Feb-08	7.40				6.99				17.76			
Mar-08												
Av	4.42	0.58	0.26	0.10	4.17	0.55	0.02	0.01	10.60	1.39	0.61	0.24
Min	2.37	0.40	0.14	0.05								
Max	7.40	0.77	0.38	0.15								
St Dev	2.64	0.26	0.17	0.07								
n	3	2	2	2								

Mn	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**	**RAW**	**CELL 10**	**VF 1**	**HF 1**
Nov-07	2.11	1.28	3.80	3.06	1.99	1.21	0.36	0.29	5.06	3.07	9.12	7.34
Dec-07												
Jan-08	2.44	1.97	2.41	2.48	2.31	1.86	0.23	0.24	5.86	4.73	5.78	5.95
Feb-08	3.17	2.45	2.73	1.80	3.00	2.31	0.26	0.17	7.61	5.88	6.55	4.32
Mar-08												
Av	2.57	1.90	2.98	2.45	2.43	1.80	0.29	0.23	6.18	4.56	7.15	5.87
Min	2.11	1.28	2.41	1.80								
Max	3.17	2.45	3.80	3.06								
St Dev	0.54	0.59	0.73	0.63								
n	3	3	3	3								

pH	pH Units			
	RAW	**CELL 10**	**VF 1**	**HF 1**
Nov-07	7.4	7.6	7.0	7.5
Dec-07				
Jan-08	7.1	7.4	6.8	7.2
Feb-08	7.2	7.6	7.0	7.5
Mar-08	7.3	7.2	6.8	7.2
Av	7.2	7.4	6.9	7.3
Min	7.1	7.2	6.8	7.2
Max	7.4	7.6	7.0	7.5
St Dev	0.1	0.2	0.1	0.2
n	4	4	4	4

Methane		Methane Concentration (mg/l)				
		Nov-07	Dec-07	Jan-08	Feb-08	Mar-08
Influent	Raw	11		4.2	4.2	
Effluent	CELL 10					
Effluent	VF 1	0.1		≤ 0.01	≤ 0.01	
Effluent	HF 1			≤ 0.01	≤ 0.01	

Phase 3 and Phase 4 - Sequence CELL 3 - CELL 5, Parameter Concentrations and Loadings

Note: RAW = Influent; CELLS 3, 5 = Effluent

HLR	l/m^2/day	l/unit/day
	CELLS	CELLS
Aug-08	94	240
Sep-08	94	240
Oct-08	94	240
Nov-08	94	240
Dec-08	94	240
Jan-09	94	240
Feb-09	189	480
Mar-09	94	240
Apr-09	94	240
May-09	94	240
Jun-09	94	240
Jul-09	94	240
Aug-09	94	240
Sep-09	94	240
Oct-09	94	240
Nov-09	94	240
Dec-09	94	240
Jan-10	94	240
Feb-10	94	240
Mar-10	94	240
Apr-10	94	240
May-10	94	240
Jun-10	94	240
Jul-10	94	240
Aug-10	94	240
Sep-10	94	240
Oct-10	94	240
Av	98	249

NH_4	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08	249	7	2	23.5	0.7	0.2	59.76	1.68	0.48
Sep-08	230	13	0.4	21.7	1.2	0.0	55.2	3.12	0.10
Oct-08	279	23	1	26.3	2.2	0.1	66.96	5.52	0.24
Nov-08									
Dec-08	283	135	31	26.7	12.7	2.9	67.92	32.4	7.44
Jan-09	382	134	20	36.0	12.6	1.9	91.68	32.16	4.80
Feb-09	382	248	94	72.0	46.8	17.7	183.36	119.04	45.12
Mar-09	376	200	16	35.5	18.9	1.5	90.24	48	3.84
Apr-09	263	112	0	24.8	10.6	0.0	63.12	26.88	0.00
May-09	297	95	7	28.0	9.0	0.7	71.28	22.8	1.68
Jun-09	407	52	0	38.4	4.9	0.0	97.68	12.48	0.00
Jul-09	288	20	0	27.2	1.9	0.0	69.12	4.8	0.00
Aug-09	270	41	22	25.5	3.9	2.1	64.8	9.84	5.28
Sep-09	163	12	1	15.4	1.1	0.1	39.12	2.88	0.24
Oct-09	337	65	0	31.8	6.1	0.0	80.88	15.6	0.00
Nov-09									
Dec-09	264	41	0	24.9	3.9	0.0	63.36	9.84	0.00
Jan-10									
Feb-10									
Mar-10	390	120	64	36.8	11.3	6.0	93.6	28.8	15.36
Apr-10	260	41	22	24.5	3.9	2.1	62.4	9.84	5.28
May-10	438	68	77	41.3	6.4	7.3	105.12	16.32	18.48
Jun-10	418	87	71	39.4	8.2	6.7	100.32	20.88	17.04
Jul-10	218	27	24	20.6	2.5	2.3	52.32	6.48	5.76
Aug-10	458	53		43.2	5.0		109.92	12.72	
Sep-10									
Oct-10	461	302	197	43.5	28.5	18.6	110.64	72.48	47.28
Av	323	86	31	32	9	3	82	23	8
St Dev	85	79	48	12	11	5	30	27	14
Max	461	302	197	72	47	19	183	119	47
Min	163	7	0	15	1	0	39	2	0
n	22	22	21	22	22	21	22	22	21

BOD_5	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08									
Sep-08	15.70	8.00	3.50	1.48	0.76	0.33	3.77	1.92	0.84
Oct-08	20.07	49.37	1.20	1.90	4.66	0.11	4.82	11.85	0.29
Nov-08									
Dec-08	10.90	22.50	15.00	1.03	2.13	1.42	2.62	5.40	3.60
Jan-09	20.40	41.25	11.75	1.93	3.90	1.11	4.90	9.90	2.82
Feb-09	22.78	94.95	35.00	4.30	17.94	6.61	10.93	45.58	16.80
Mar-09									
Apr-09									
May-09	11.10	39.40	5.20	1.05	3.72	0.49	2.66	9.46	1.25
Jun-09	24.95	20.90	2.15	2.36	1.97	0.20	5.99	5.02	0.52
Jul-09	39.90	2.20	1.10	3.77	0.21	0.10	9.58	0.53	0.26
Aug-09	13.60	4.55	0.90	1.29	0.43	0.09	3.26	1.09	0.22
Sep-09									
Oct-09	21.50	10.60	7.25	2.03	1.00	0.69	5.16	2.54	1.74
Nov-09							0.00	0.00	0.00
Dec-09	18.40	7.65	1.61	1.74	0.72	0.15	4.42	1.84	0.39
Jan-10									
Feb-10									
Mar-10	22.65	16.85	27.60	2.14	1.59	2.61	5.44	4.04	6.62
Apr-10	6.05	3.65	2.75	0.57	0.34	0.26	1.45	0.88	0.66
May-10	25.00	7.35	15.00	2.36	0.69	1.42	6.00	1.76	3.60
Jun-10	26.65	17.20	33.95	2.52	1.63	3.21	6.40	4.13	8.15
Jul-10	5.10	9.60	14.45	0.48	0.91	1.37	1.22	2.30	3.47
Aug-10	27.35	19.50	6.28	2.58	1.84	0.59	6.56	4.68	1.51
Sep-10									
Oct-10	24.75	17.75	21.70	2.34	1.68	2.05	5.94	4.26	5.21
Av	20	22	11	1.99	2.56	1.27	4.80	6.17	3.05
St Dev	8	23	11	0.99	4.04	1.62	2.70	10.09	4.07
Max	40	95	35	4.30	17.94	6.61	10.93	45.58	16.80
Min	5	2	1	0.48	0.21	0.09	0.00	0.00	0.00
n	18	18	18	18	18	18	19	19	19

COD	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08									
Sep-08	184	134	122.0	17.39	12.66	11.53	44.16	32.16	29.28
Oct-08	228	155	149	21.54	14.65	14.08	54.72	37.20	35.76
Nov-08									
Dec-08	239	248	159	22.58	23.43	15.02	57.36	59.52	38.16
Jan-09	420	247	314	39.69	23.34	29.67	100.80	59.28	75.36
Feb-09	338	272	232	63.87	51.40	43.84	162.24	130.56	111.36
Mar-09									
Apr-09									
May-09	236	206	184	22.30	19.46	17.39	56.64	49.44	44.16
Jun-09	345	251	284	32.60	23.72	26.83	82.80	60.24	68.16
Jul-09	235	173	140	22.20	16.35	13.23	56.40	41.52	33.60
Aug-09	212	145	129	20.03	13.70	12.19	50.88	34.80	30.96
Sep-09									
Oct-09	235	197	138	22.20	18.61	13.04	56.40	47.28	33.12
Nov-09									
Dec-09	205	155	127	19.37	14.65	12.00	49.20	37.20	30.48
Jan-10									
Feb-10									
Mar-10	340	243	225	32.13	22.96	21.26	81.60	58.32	54.00
Apr-10	211	159	166	19.94	15.02	15.69	50.64	38.16	39.84
May-10	368	236	312	34.77	22.30	29.48	88.32	56.64	74.88
Jun-10	333	232	645	31.46	21.92	60.94	79.92	55.68	154.80
Jul-10	177	160	197	16.72	15.12	18.61	42.48	38.40	47.28
Aug-10	385	260	390	36.38	24.57	36.85	92.40	62.40	93.60
Sep-10									
Oct-10	392	360	371	37.04	34.02	35.06	94.08	86.40	89.04
Av	282	213	238	28.46	21.55	23.71	72.28	54.73	60.21
St Dev	80	58	133	11.58	9.17	13.54	29.42	23.29	34.40
Max	420	360	645	63.87	51.40	60.94	162.24	130.56	154.80
Min	177	134	122	16.72	12.66	11.53	42.48	32.16	29.28
n	18	18	18	18	18	18	18	18	18

SS	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08									
Sep-08	27.75	1.50	2.90	2.62	0.14	0.27	6.66	0.36	0.70
Oct-08	31.00	2.50	1.00	2.93	0.24	0.09	7.44	0.6	0.24
Nov-08									
Dec-08	19.00	6.50	3.00	1.80	0.61	0.28	4.56	1.56	0.72
Jan-09	32.00	4.50	3.50	3.02	0.43	0.33	7.68	1.08	0.84
Feb-09	43.15	9.75	3.40	8.15	1.84	0.64	20.712	4.68	1.63
Mar-09									
Apr-09									
May-09	27.50	8.00	9.00	2.60	0.76	0.85	6.6	1.92	2.16
Jun-09	30.00	8.00	9.50	2.83	0.76	0.90	7.2	1.92	2.28
Jul-09	31.50	7.25	3.85	2.98	0.69	0.36	7.56	1.74	0.92
Aug-09	33.50	7.00	5.50	3.17	0.66	0.52	8.04	1.68	1.32
Sep-09									
Oct-09	16.50	9.00	7.00	1.56	0.85	0.66	3.96	2.16	1.68
Nov-09									
Dec-09	33.00	5.00	9.00	3.12	0.47	0.85	7.92	1.2	2.16
Jan-10									
Feb-10									
Mar-10	44.50	8.00	6.50	4.20	0.76	0.61	10.68	1.92	1.56
Apr-10	26.50	6.00	39.00	2.50	0.57	3.69	6.36	1.44	9.36
May-10	46.50	12.00	13.00	4.39	1.13	1.23	11.16	2.88	3.12
Jun-10	24.00	12.50	19.00	2.27	1.18	1.80	5.76	3	4.56
Jul-10	14.50	7.00	9.00	1.37	0.66	0.85	3.48	1.68	2.16
Aug-10	34.50	20.00	89.50	3.26	1.89	8.46	8.28	4.8	21.48
Sep-10									
Oct-10	29.00	25.50	23.00	2.74	2.41	2.17	6.96	6.12	5.52
Av	30	9	14	3.1	0.9	1.4	7.8	2.3	3.5
St Dev	9	6	21	1.5	0.6	2.0	3.8	1.5	5.0
Max	47	26	90	8.2	2.4	8.5	20.7	6.1	21.5
Min	15	2	1	1.4	0.1	0.1	3.5	0.4	0.2
n	18	18	18	18	18	18	18	18	18

Chloride	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08									
Sep-08	277	266	241.0	26.17	25.13	22.77	66.48	63.84	57.84
Oct-08	383	383	411	36.19	36.19	38.83	91.92	91.92	98.64
Nov-08									
Dec-08	454	418	418	42.90	39.50	39.50	108.96	100.32	100.32
Jan-09	588	581	574	55.56	54.90	54.24	141.12	139.44	137.76
Feb-09	496	425	440	93.73	80.31	83.15	238.08	204.00	211.20
Mar-09	489	461	454	46.22	43.54	42.87	117.41	110.60	108.90
Apr-09									
May-09	372	431	414	35.15	40.72	39.12	89.28	103.44	99.36
Jun-09	474	440	431	44.79	41.57	40.72	113.76	105.60	103.44
Jul-09	340	323	323	32.13	30.52	30.52	81.60	77.52	77.52
Aug-09	269	292	292	25.42	27.59	27.59	64.56	70.08	70.08
Sep-09									
Oct-09	369	383	377	34.87	36.19	35.62	88.56	91.92	90.48
Nov-09									
Dec-09	286	272	267	27.02	25.70	25.23	68.64	65.28	64.08
Jan-10									
Feb-10									
Mar-10	444	440	440	41.95	41.54	41.54	106.56	105.50	105.50
Apr-10	269	287	287	25.42	27.12	27.12	64.56	68.88	68.88
May-10	476	457	465	45.02	43.14	43.95	114.35	109.58	111.62
Jun-10	452	454	457	42.71	42.90	43.18	108.48	108.96	109.68
Jul-10	241	269	269	22.77	25.42	25.42	57.84	64.56	64.56
Aug-10	522	479	510	49.32	45.26	48.19	125.28	114.96	122.40
Sep-10									
Oct-10	536	513	527	50.65	48.47	49.80	128.64	123.12	126.48
Av	407	399	400	40.9	39.8	40.0	104.0	101.0	101.5
St Dev	105	91	96	16.0	13.0	13.8	40.7	33.1	35.0
Max	588	581	574	93.7	80.3	83.1	238.1	204.0	211.2
Min	241	266	241	22.8	25.1	22.8	57.8	63.8	57.8
n	19	19	19	19	19	19	19	19	19

Iron	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08									
Sep-08	8.05	0.69	0.38	0.76	0.07	0.04	1.93	0.17	0.09
Oct-08	4.10	1.02	0.42	0.39	0.10	0.04	0.98	0.24	0.10
Nov-08									
Dec-08	7.50	1.73	0.68	0.71	0.16	0.06	1.80	0.42	0.16
Jan-09									
Feb-09									
Mar-09									
Apr-09									
May-09									
Jun-09	10.60	1.90	0.66	1.00	0.18	0.06	2.54	0.46	0.16
Jul-09									
Aug-09									
Sep-09									
Oct-09									
Nov-09									
Dec-09									
Jan-10									
Feb-10									
Mar-10	12.55	1.88	1.22	1.19	0.18	0.12	3.01	0.45	0.29
Apr-10									
May-10									
Jun-10									
Jul-10									
Aug-10	6.25	1.39	2.43	0.59	0.13	0.23	1.50	0.33	0.58
Sep-10									
Oct-10									
Av	8.2	1.4	1.0	0.77	0.14	0.09	1.96	0.34	0.23
St Dev	3.0	0.5	0.8	0.29	0.05	0.07	0.73	0.12	0.19
Max	12.6	1.9	2.4	1.19	0.18	0.23	3.01	0.46	0.58
Min	4.1	0.7	0.4	0.39	0.07	0.04	0.98	0.17	0.09
n	6	6	6	6	6	6	6	6	6

Mn	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08									
Sep-08	2.98	0.52	0.31	0.28	0.05	0.03	0.72	0.13	0.07
Oct-08	2.21	0.72	0.52	0.21	0.07	0.05	0.53	0.17	0.12
Nov-08									
Dec-08	3.10	0.35	1.10	0.29	0.03	0.10	0.74	0.08	0.26
Jan-09									
Feb-09									
Mar-09									
Apr-09									
May-09									
Jun-09	2.94	2.79	1.19	0.28	0.26	0.11	0.71	0.67	0.29
Jul-09									
Aug-09									
Sep-09									
Oct-09									
Nov-09									
Dec-09									
Jan-10									
Feb-10									
Mar-10	3.79	1.43	0.63	0.36	0.14	0.06	0.91	0.34	0.15
Apr-10									
May-10									
Jun-10									
Jul-10									
Aug-10	2.71	3.11	1.00	0.26	0.29	0.09	0.65	0.75	0.24
Sep-10									
Oct-10									
Av	2.95	1.49	0.79	0.28	0.14	0.07	0.71	0.36	0.19
St Dev	0.51	1.20	0.35	0.05	0.11	0.03	0.12	0.29	0.09
Max	3.79	3.11	1.19	0.36	0.29	0.11	0.91	0.75	0.29
Min	2.21	0.35	0.31	0.21	0.03	0.03	0.53	0.08	0.07
n	6	6	6	6	6	6	6	6	6

TON	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08	236	938	880	22	89	83	57	225	211
Sep-08	149	806	734.0	14	76	69	36	193	176
Oct-08	87	1207	37	8	114	3	21	290	9
Nov-08									
Dec-08	83	649	1195	8	61	113	20	156	287
Jan-09	116	1120	1418	11	106	134	28	269	340
Feb-09	304	539	1159	57	102	219	146	259	556
Mar-09	198	961	1339	19	91	127	48	231	321
Apr-09	62	446	1035	6	42	98	15	107	248
May-09	0	763	1035	0	72	98	0	183	248
Jun-09	0	1110	1228	0	105	116	0	266	295
Jul-09	148	772	359	14	73	34	36	185	86
Aug-09	124	924	1074	12	87	101	30	222	258
Sep-09	79	580	660	7	55	62	19	139	158
Oct-09	0	940	1100	0	89	104	0	226	264
Nov-09									
Dec-09	34	787	899	3	74	85	8	189	216
Jan-10									
Feb-10									
Mar-10	0	898	1076	0	85	102	0	216	258
Apr-10	0	794	818	0	75	77	0	191	196
May-10	20	1220	1002	2	115	95	5	293	240
Jun-10	25	1101	1022	2	104	97	6	264	245
Jul-10	10	754	684	1	71	65	2	181	164
Aug-10	124	1404		12	133		30	337	
Sep-10									
Oct-10	30	521	704	3	49	67	7	125	169
Av	83	874	927	9	85	93	23	216	236
St Dev	85	250	323	13	23	42	32	58	106
Max	304	1404	1418	57	133	219	146	337	556
Min	0	446	37	0	42	3	0	107	9
n	22	22	21	22	22	21	22	22	21

Total N	Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 3**	**CELL 5**	**RAW**	**CELL 3**	**CELL 5**
Aug-08	23	21	19			
Sep-08	20	18	16			
Oct-08	22	27	1			
Nov-08						
Dec-08	23	24	28			
Jan-09	31	34	32			
Feb-09	69	59	63			
Mar-09	32	35	30			
Apr-09	21	18	22			
May-09	22	23	23			
Jun-09	30	28	26			
Jul-09	24	18	8			
Aug-09	22	23	25			
Sep-09	14	13	14			
Oct-09	25	25	23			
Nov-09						
Dec-09	20	20	19			
Jan-10						
Feb-10						
Mar-10	29	28	28			
Apr-10	19	20	19			
May-10	33	31	27			
Jun-10	31	30	27			
Jul-10	16	18	16			
Aug-10	36	34				
Sep-10						
Oct-10	34	33	29			
Av	27	26	24	69	67	60
St Dev	11	10	12			
Max	69	59	63			
Min	14	13	1			
n	22	22	21			

Phase 3 and Phase 4 - Parameter Concentrations and Loadings
Sequence CELL 9 - CELL 10 - VF 1 - VF 2 - (HF 2) - VP 1 - VP 2
Note: RAW = Influent; CELLS, VF, HF, VP = Effluent

HLR	l/m^2/day	l/unit/day	l/m^2/day	l/unit/day
	CELLS	CELLS	VF / VP	VF / VP
Aug-08	945	2400	96	2400
Sep-08	945	2400	96	2400
Oct-08	945	2400	96	2400
Nov-08	945	2400	96	2400
Dec-08	945	2400	96	2400
Jan-09	945	2400	96	2400
Feb-09	472	1200	48	1200
Mar-09	472	1200	48	1200
Apr-09	472	1200	48	1200
May-09	945	2400	96	2400
Jun-09	945	2400	96	2400
Jul-09	945	2400	96	2400
Aug-09	945	2400	96	2400
Sep-09	945	2400	96	2400
Oct-09	945	2400	96	2400
Nov-09	945	2400	96	2400
Dec-09	945	2400	96	2400
Jan-10	945	2400	96	2400
Feb-10	945	2400	96	2400
Mar-10	945	2400	96	2400
Apr-10	945	2400	96	2400
May-10	945	2400	96	2400
Jun-10	945	2400	96	2400
Jul-10	945	2400	96	2400
Aug-10	945	2400	96	2400
Sep-10	945	2400	96	2400
Oct-10	945	2400	96	2400
Av	892	2267	91	2267

NH_4	Concentration (mg/l)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08	249	76	75	1	0.4	28		
Sep-08	230	134	71	2	0.4	1		
Oct-08	279	163	99	10	1	2		
Nov-08								
Dec-08	283	160	142	86	39	33		
Jan-09	382	226	188	122	17	41		
Feb-09	382	184	103	14	0			
Mar-09	376	347	128	13	0			
Apr-09	263	137	65	4	2			
May-09	297	187	185	65	14		14	7
Jun-09	407	295	261	67	11		0	0
Jul-09	288	216	9	0	0		0	0
Aug-09	270	214	23	22	23		18	18
Sep-09	163	138	3	1	1		0	0
Oct-09	337	288	266	146	41		0	0
Nov-09								
Dec-09	264	194	165	46	10		2	2
Jan-10								
Feb-10								
Mar-10	390	325	309	207	73		25	5
Apr-10	260	235	110	5	6		2	1
May-10	438	374	174	12	4		4	4
Jun-10	418	417	120	34	8			1
Jul-10	218	233	140	58	6			2
Aug-10	458	420	26	3	0			0
Sep-10								
Oct-10	461	444	240	3	0			1
Av	323	246	132	42	12	21	7	3
St Dev	85	104	86	55	18	18	9	5
Max	461	444	309	207	73	41	25	18
Min	163	76	3	0	0	1	0	0
n	22	22	22	22	22	5	10	14

NH_4	Loading (g/m^2/day)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08	235.28	71.81	70.87	0.10	0.04	2.69		
Sep-08	217.32	126.61	67.09	0.19	0.04	0.10		
Oct-08	263.62	154.02	93.54	0.96	0.10	0.19		
Nov-08								
Dec-08	267.40	151.18	134.17	8.26	3.74	3.17		
Jan-09	360.94	213.54	177.64	11.71	1.63	3.94		
Feb-09	180.47	86.93	48.66	0.67	0.00			
Mar-09	177.64	163.94	60.47	0.62	0.00			
Apr-09	124.25	64.72	30.71	0.19	0.10			
May-09	280.63	176.69	174.80	6.24	1.34		1.34	0.67
Jun-09	384.57	278.74	246.61	6.43	1.06		0.00	0.00
Jul-09	272.13	204.09	8.50	0.00	0.00		0.00	0.00
Aug-09	255.12	202.20	21.73	2.11	2.21		1.73	1.73
Sep-09	154.02	130.39	2.83	0.10	0.10		0.00	0.00
Oct-09	318.43	272.13	251.34	14.02	3.94		0.00	0.00
Nov-09								
Dec-09	249.45	183.31	155.91	4.42	0.96		0.19	0.19
Jan-10								
Feb-10								
Mar-10	368.50	307.09	291.97	19.87	7.01		2.40	0.48
Apr-10	245.67	222.05	103.94	0.48	0.58		0.19	0.10
May-10	413.86	353.39	164.41	1.15	0.38		0.38	0.38
Jun-10	394.96	394.02	113.39	3.26	0.77			0.10
Jul-10	205.98	220.16	132.28	5.57	0.58			0.19
Aug-10	432.76	396.85	24.57	0.29	0.00			0.00
Sep-10								
Oct-10	435.59	419.53	226.77	0.29	0.00			0.10
Av	284	218	118	4	1	2	1	0.28
St Dev	93	105	85	5	2	2	1	0
Max	436	420	292	20	7	4	2	2
Min	124	65	3	0	0	0	0	0
n	22	22	22	22	22	5	10	14

NH_4	Loading (g/unit/day)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08	597.60	182.40	180.00	2.40	0.96	67.20		
Sep-08	552.00	321.60	170.40	4.80	0.96	2.40		
Oct-08	669.60	391.20	237.60	24.00	2.40	4.80		
Nov-08								
Dec-08	679.20	384.00	340.80	206.40	93.60	79.20		
Jan-09	916.80	542.40	451.20	292.80	40.80	98.40		
Feb-09	458.40	220.80	123.60	16.80	0.00			
Mar-09	451.20	416.40	153.60	15.60	0.00			
Apr-09	315.60	164.40	78.00	4.80	2.40			
May-09	712.80	448.80	444.00	156.00	33.60		33.60	16.80
Jun-09	976.80	708.00	626.40	160.80	26.40		0.00	0.00
Jul-09	691.20	518.40	21.60	0.00	0.00		0.00	0.00
Aug-09	648.00	513.60	55.20	52.80	55.20		43.20	43.20
Sep-09	391.20	331.20	7.20	2.40	2.40		0.00	0.00
Oct-09	808.80	691.20	638.40	350.40	98.40		0.00	0.00
Nov-09								
Dec-09	633.60	465.60	396.00	110.40	24.00		4.80	4.80
Jan-10								
Feb-10								
Mar-10	936.00	780.00	741.60	496.80	175.20		60.00	12.00
Apr-10	624.00	564.00	264.00	12.00	14.40		4.80	2.40
May-10	1051.20	897.60	417.60	28.80	9.60		9.60	9.60
Jun-10	1003.20	1000.80	288.00	81.60	19.20			2.40
Jul-10	523.20	559.20	336.00	139.20	14.40			4.80
Aug-10	1099.20	1008.00	62.40	7.20	0.00			0.00
Sep-10								
Oct-10	1106.40	1065.60	576.00	7.20	0.00			2.40
Av	720	553	300	99	28	50	16	7
St Dev	235	265	216	134	44	44	22	12
Max	1106	1066	742	497	175	98	60	43
Min	316	164	7	0	0	2	0	0
n	22	22	22	22	22	5	10	14

BOD_5	Concentration (mg/l)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08								
Sep-08	16	13	6	3	0.7	1		
Oct-08	13	54.48	66.48	10	1.2	0		
Nov-08								
Dec-08	24.9	59.3	72.6	46	19.75	14		
Jan-09	20.4	80	83	58	5	6		
Feb-09	24	21.3	9.45	6.4	7			
Mar-09								
Apr-09								
May-09	11	33.5	18.3	19	3		4.1	5.2
Jun-09	25	23.9	30.6	29.4	31		1	1
Jul-09	40	10	2	1	1		0	1
Aug-09	14	14.25	5.35	1.35	1		1.17	1
Sep-09								
Oct-09	22	26.45	2.61	19.9	10		1.69	8
Nov-09								
Dec-09	18	14.5	15.45	10.45	3		1.37	10
Jan-10								
Feb-10								
Mar-10	23	33	29	UR	UR		19	3
Apr-10	6	5	11	5	2		2	2
May-10	25	26	38	6	2		1	5
Jun-10	27	24	27	10	2			1
Jul-10	5	37	16.95	7	1			1
Aug-10	27	30.3	48.8	7.24	4			1
Sep-10								
Oct-10	25	19.2	20.35	4.66	1			1
Av	20	29	28	14	6	5	4	3
St Dev	8	19	25	16	8	6	6	3
Max	40	80	83	58	31	14	19	10
Min	5	5	2	1	1	0.40	0.35	1
n	18	18	18	17	17	4	9	13

BOD_5	Loading ($g/m^2/day$)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08								
Sep-08	14.83	12.57	5.48	0.29	0.07	0.07		
Oct-08	12.55	51.48	62.82	0.94	0.12	0.04		
Nov-08								
Dec-08	23.53	56.03	68.60	4.45	1.90	1.30		
Jan-09	19.28	75.21	78.24	5.59	0.45	0.60		
Feb-09	11.34	10.06	4.46	0.31	0.32			
Mar-09								
Apr-09								
May-09	10.49	31.65	17.29	1.82	0.32		0.39	0.50
Jun-09	23.57	22.58	28.91	2.82	3.00		0.10	0.10
Jul-09	37.70	9.69	1.70	0.10	0.11		0.03	0.12
Aug-09	12.85	13.46	5.06	0.13	0.07		0.11	0.08
Sep-09								
Oct-09	20.31	24.99	2.47	1.91	1.00		0.16	0.75
Nov-09								
Dec-09	17.39	13.70	14.60	1.00	0.27		0.13	0.98
Jan-10								
Feb-10								
Mar-10	21.40	31.13	26.98				1.82	0.32
Apr-10	5.72	4.58	10.11	0.48	0.15		0.19	0.15
May-10	23.62	24.61	36.33	0.60	0.20		0.11	0.51
Jun-10	25.18	23.10	25.09	0.98	0.18			0.11
Jul-10	4.82	34.96	16.02	0.67	0.10			0.06
Aug-10	25.84	28.63	46.11	0.70	0.42			0.13
Sep-10								
Oct-10	23.39	18.14	19.23	0.45	0.10			0.10
Av	19	27	26	1	0.51	0.50	0.34	0.30
St Dev	8	18	24	2	0.79	0.59	0.57	0.30
Max	38	75	78	6	3.00	1.30	1.82	0.98
Min	5	5	2	0	0.07	0.04	0.03	0.06
n	18	18	18	17	17	4	9	13

BOD_5	Loading (g/unit/day)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08								
Sep-08	37.68	31.92	13.92	7.20	1.68	1.68		
Oct-08	31.87	130.75	159.55	23.59	2.88	0.96		
Nov-08								
Dec-08	59.76	142.32	174.24	111.24	47.40	32.52		
Jan-09	48.96	191.04	198.72	139.68	11.28	15.00		
Feb-09	28.80	25.56	11.34	7.68	7.92			
Mar-09								
Apr-09								
May-09	26.64	80.40	43.92	45.60	8.04		9.84	12.48
Jun-09	59.88	57.36	73.44	70.56	74.88		2.40	2.40
Jul-09	95.76	24.60	4.32	2.40	2.64		0.84	3.02
Aug-09	32.64	34.20	12.84	3.24	1.73		2.81	2.11
Sep-09								
Oct-09	51.60	63.48	6.26	47.76	24.96		4.06	18.84
Nov-09								
Dec-09	44.16	34.80	37.08	25.08	6.70		3.29	24.53
Jan-10								
Feb-10								
Mar-10	54.36	79.08	68.52				45.60	8.11
Apr-10	14.52	11.64	25.68	12.00	3.65		4.75	3.74
May-10	60.00	62.52	92.28	15.12	5.11		2.76	12.82
Jun-10	63.96	58.68	63.72	24.48	4.54			2.66
Jul-10	12.24	88.80	40.68	16.80	2.40			1.39
Aug-10	65.64	72.72	117.12	17.38	10.58			3.24
Sep-10								
Oct-10	59.40	46.08	48.84	11.18	2.42			2.38
Av	47	69	66	34	12.9	12.5	8.5	7.5
St Dev	21	46	60	39	19.6	14.8	14.1	7.5
Max	96	191	199	140	74.9	32.5	45.6	24.5
Min	12	12	4	2	1.7	1.0	0.8	1.4
n	18	18	18	17	17	4	9	13

COD	Concentration (mg/l)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08								
Sep-08	184	152	122	110	107	98		
Oct-08	216	276	190	187	128	164		
Nov-08								
Dec-08	240	261	254	264	232	204		
Jan-09	420	342	325	296	150	230		
Feb-09	292	232	189	161	129			
Mar-09								
Apr-09								
May-09	236	237	241	233	184		153	141
Jun-09	345	413	392	393	370		200	170
Jul-09	235	181	150	174	130		88	80
Aug-09	212	136	127	117	103		78	68
Sep-09								
Oct-09	235	229	298	204	186		105	101
Nov-09								
Dec-09	205	175	171	151	134		111	322
Jan-10								
Feb-10								
Mar-10	340	333	296	322	325		269	251
Apr-10	211	215	192	131	112		72	69
May-10	368	337	292	196	159		128	118
Jun-10	333	342	275	242	309			162
Jul-10	177	225	209	138	120			106
Aug-10	385	372	364	230	191			125
Sep-10								
Oct-10	392	371	303	262	236			176
Av	279	268	244	212	184	174	134	145
St Dev	80	83	80	76	81	57	65	74
Max	420	413	392	393	370	230	269	322
Min	177	136	122	110	103	98.00	72.00	68
n	18	18	18	18	18	4	9	13

COD	Loading ($g/m^2/day$)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08	174	144	115	11	10	9.4		
Sep-08	204	261	180	18	12	15.7		
Oct-08								
Nov-08	227	247	240	25	22	19.6		
Dec-08	397	323	307	28	14	22.1		
Jan-09	138	110	89	8	6			
Feb-09								
Mar-09								
Apr-09	223	224	228	22	18		15	14
May-09	326	390	370	38	36		19	16
Jun-09	222	171	142	17	12		8	8
Jul-09	200	129	120	11	10		7	7
Aug-09								
Sep-09	222	216	282	20	18		10	10
Oct-09								
Nov-09	194	165	162	14	13		11	31
Dec-09								
Jan-10								
Feb-10	321	315	280	31	31		26	24
Mar-10	199	203	181	13	11		7	7
Apr-10	348	318	276	19	15		12	11
May-10	315	323	260	23	30			16
Jun-10	167	213	197	13	12			10
Jul-10	364	351	344	22	18			12
Aug-10								
Sep-10	370	351	286	25	23			17
Oct-10								
Av	256	247	225	20	17	16.7	13	14
St Dev	81	85	82	8	8	5.5	6	7
Max	397	390	370	38	36	22.1	26	31
Min	138	110	89	8	6	9.4	7	7
n	18	18	18	18	18	4	9	13

COD	Loading (g/unit/day)							
	RAW	**CELL 9**	**CELL 10**	**VF 1**	**VF 2**	**HF 2**	**VP 1**	**VP 2**
Aug-08	442	365	293	264	257	235		
Sep-08	518	662	456	449	307	394		
Oct-08								
Nov-08	576	626	610	634	557	490		
Dec-08	1008	821	780	710	360	552		
Jan-09	350	278	227	193	155			
Feb-09								
Mar-09								
Apr-09	566	569	578	559	442		367	338
May-09	828	991	941	943	888		480	408
Jun-09	564	434	360	418	312		211	192
Jul-09	509	326	305	281	247		187	163
Aug-09								
Sep-09	564	550	715	490	446		252	242
Oct-09								
Nov-09	492	420	410	362	322		266	773
Dec-09								
Jan-10								
Feb-10	816	799	710	773	780		646	602
Mar-10	506	516	461	314	269		173	166
Apr-10	883	809	701	470	382		307	283
May-10	799	821	660	581	742			389
Jun-10	425	540	502	331	288			254
Jul-10	924	893	874	552	458			300
Aug-10								
Sep-10	941	890	727	629	566			422
Oct-10								
Av	651	628	573	497	432	418	321	349
St Dev	205	217	207	196	203	138	155	177
Max	1008	991	941	943	888	552	646	773
Min	350	278	227	193	155	235	173	163
n	18	18	18	18	18	4	9	13

SS	Concentration (mg/l)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	27.75	5.30	3.50	11.05	6.05	6.00		
Oct-08	18.30	13.55	4.60	3.60	23.75	9.20		
Nov-08								
Dec-08	22.50	59.30	72.60	46.35	19.75	13.55		
Jan-09	32.00	13.00	9.50	5.00	4.50	4.00		
Feb-09	54.50	6.00	2.00	1.00	1.50			
Mar-09								
Apr-09								
May-09	27.50	10.50	8.00	4.50	11.00		10.50	5.50
Jun-09	30.00	14.50	10.00	9.00	9.00		36.50	11.50
Jul-09	31.50	11.85	4.55	2.90	2.75		6.70	4.75
Aug-09	33.50	8.50	5.00	5.00	4.50		2.50	1.50
Sep-09								
Oct-09	16.50	21.50	25.50	5.50	4.00		3.50	2.50
Nov-09								
Dec-09	33.00	22.50	12.50	4.50	4.00		3.50	12.12
Jan-10								
Feb-10								
Mar-10	44.50	22.00	15.00	9.00	6.50		22.50	5.00
Apr-10	26.50	10.50	9.00	5.50	5.00		3.50	3.50
May-10	46.50	18.00	11.00	10.00	10.50		16.00	7.00
Jun-10	24.00	36.00	14.00	10.00	6.50			8.50
Jul-10	14.50	28.50	20.00	6.50	5.00			3.50
Aug-10	34.50	71.00	10.50	11.00	6.50			59.50
Sep-10								
Oct-10	29.00	114.50	21.50	7.00	7.50			14.50
Av	30	27	14	9	8	8	12	11
St Dev	10	28	16	10	6	4	12	15
Max	55	115	73	46	24	14	37	60
Min	15	5	2	1	2	4.00	2.50	2
n	18	18	18	18	18	4	9	13

SS	Loading (g/m^2/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	26.17	5.00	3.30	1.06	0.58	0.58		
Oct-08	17.26	12.78	4.34	0.35	2.28	0.88		
Nov-08								
Dec-08	21.22	55.92	68.46	4.45	1.90	1.30		
Jan-09	30.18	12.26	8.96	0.48	0.43	0.38		
Feb-09	25.70	2.83	0.94	0.05	0.07			
Mar-09								
Apr-09								
May-09	25.93	9.90	7.54	0.43	1.06		1.01	0.53
Jun-09	28.29	13.67	9.43	0.86	0.86		3.50	1.10
Jul-09	29.71	11.17	4.29	0.28	0.26		0.64	0.46
Aug-09	31.59	8.02	4.72	0.48	0.43		0.24	0.14
Sep-09								
Oct-09	15.56	20.28	24.05	0.53	0.38		0.34	0.24
Nov-09								
Dec-09	31.12	21.22	11.79	0.43	0.38		0.34	1.16
Jan-10								
Feb-10								
Mar-10	41.96	20.75	14.15	0.86	0.62		2.16	0.48
Apr-10	24.99	9.90	8.49	0.53	0.48		0.34	0.34
May-10	43.85	16.97	10.37	0.96	1.01		1.54	0.67
Jun-10	22.63	33.95	13.20	0.96	0.62			0.82
Jul-10	13.67	26.88	18.86	0.62	0.48			0.34
Aug-10	32.53	66.95	9.90	1.06	0.62			5.71
Sep-10								
Oct-10	27.35	107.98	20.28	0.67	0.72			1.39
Av	27.21	25.36	13.50	0.84	0.73	0.79	1.12	1.03
St Dev	7.89	26.64	15.03	0.95	0.55	0.40	1.11	1.46
Max	43.85	107.98	68.46	4.45	2.28	1.30	3.50	5.71
Min	13.67	2.83	0.94	0.05	0.07	0.38	0.24	0.14
n	18	18	18	18	18	4	9	13

SS	Loading (g/unit/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	66.47	12.70	8.38	26.52	14.52	14.40		
Oct-08	43.83	32.46	11.02	8.64	57.00	22.08		
Nov-08								
Dec-08	53.89	142.04	173.90	111.24	47.40	32.52		
Jan-09	76.65	31.14	22.76	12.00	10.80	9.60		
Feb-09	65.27	7.19	2.40	1.20	1.80			
Mar-09								
Apr-09								
May-09	65.87	25.15	19.16	10.80	26.40		25.20	13.20
Jun-09	71.86	34.73	23.95	21.60	21.60		87.60	27.60
Jul-09	75.45	28.38	10.90	6.96	6.60		16.08	11.40
Aug-09	80.24	20.36	11.98	12.00	10.80		6.00	3.60
Sep-09								
Oct-09	39.52	51.50	61.08	13.20	9.60		8.40	6.00
Nov-09								
Dec-09	79.04	53.89	29.94	10.80	9.60		8.40	29.09
Jan-10								
Feb-10								
Mar-10	106.59	52.70	35.93	21.60	15.60		54.00	12.00
Apr-10	63.48	25.15	21.56	13.20	12.00		8.40	8.40
May-10	111.38	43.12	26.35	24.00	25.20		38.40	16.80
Jun-10	57.49	86.23	33.53	24.00	15.60			20.40
Jul-10	34.73	68.27	47.91	15.60	12.00			8.40
Aug-10	82.64	170.07	25.15	26.40	15.60			142.80
Sep-10								
Oct-10	69.46	274.26	51.50	16.80	18.00			34.80
Av	69.10	64.41	34.30	20.92	18.34	19.65	28.05	25.73
St Dev	20.04	67.68	38.17	23.64	13.84	10.00	27.66	36.45
Max	111.38	274.26	173.90	111.24	57.00	32.52	87.60	142.80
Min	34.73	7.19	2.40	1.20	1.80	9.60	6.00	3.60
n	18	18	18	18	18	4	9	13

Chloride	Concentration (mg/l)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	277	298	291	312	284	255		
Oct-08	390	397	390	390	418	411		
Nov-08								
Dec-08	454	425	418	415	418	415		
Jan-09	588	574	588	574	425	475		
Feb-09	436	397	404	404	347			
Mar-09	489	454	475	447	454			
Apr-09								
May-09	372	366	374	380	366		352	329
Jun-09	474	434	423	423	423		417	411
Jul-09	340	323	318	326	320		303	302
Aug-09	269	284	295	281	264		221	208
Sep-09								
Oct-09	369	386	391	383	332		261	250
Nov-09								
Dec-09	286	271	272	261	244		238	227
Jan-10								
Feb-10								
Mar-10	444	444	450	442	434		421	425
Apr-10	269	294	287	252	230		151	145
May-10	476	468	457	442	448		445	413
Jun-10	452	457	450	464	465			465
Jul-10	241	258	261	320	301			312
Aug-10	522	493	479	513	525			519
Sep-10								
Oct-10	536	516	508	513	525			508
Av	404	397	396	397	380	389	312	347
St Dev	103	90	90	89	90	94	103	120
Max	588	574	588	574	525	475	445	519
Min	241	258	261	252	230	255.00	151.00	145
n	19	19	19	19	19	4	9	13

Chloride	Loading (g/m^2/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08	261.73	281.57	274.96	29.95	27.26	24.48		
Sep-08	368.50	375.12	368.50	37.44	40.13	39.46		
Oct-08								
Nov-08	428.98	401.57	394.96	39.84	40.13	39.84		
Dec-08	555.59	542.36	555.59	55.10	40.80	45.60		
Jan-09	205.98	187.56	190.87	19.39	16.66			
Feb-09	231.12	214.37	224.42	21.44	21.78			
Mar-09								
Apr-09	351.50	345.83	353.39	36.48	35.14		33.79	31.58
May-09	447.87	410.08	399.69	40.61	40.61		40.03	39.46
Jun-09	321.26	305.20	300.47	31.30	30.72		29.09	28.99
Jul-09	254.17	268.35	278.74	26.98	25.34		21.22	19.97
Aug-09								
Sep-09	348.66	364.72	369.45	36.77	31.87		25.06	24.00
Oct-09								
Nov-09	270.24	256.06	257.01	25.06	23.42		22.85	21.79
Dec-09								
Jan-10								
Feb-10	419.53	419.37	424.73	42.47	41.66		40.43	40.84
Mar-10	254.17	277.80	271.18	24.19	22.08		14.50	13.92
Apr-10	450.19	442.15	431.43	42.47	43.02		42.74	39.61
May-10	427.09	431.81	425.20	44.54	44.64			44.64
Jun-10	227.72	243.78	246.61	30.72	28.90			29.95
Jul-10	493.23	465.83	452.60	49.25	50.40			49.82
Aug-10								
Sep-10	506.46	487.56	480.00	49.25	50.40			48.77
Oct-10								
Av	359	354	353	36	34	37	30	33
St Dev	107	100	98	10	10	9	10	11
Max	556	542	556	55	50	46	43	50
Min	206	188	191	19	17	24	14	14
n	19	19	19	19	19	4	9	13

Chloride	Loading (g/unit/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	664.80	715.20	698.40	748.80	681.60	612.00		
Oct-08	936.00	952.80	936.00	936.00	1003.20	986.40		
Nov-08								
Dec-08	1089.60	1020.00	1003.20	996.00	1003.20	996.00		
Jan-09	1411.20	1377.60	1411.20	1377.60	1020.00	1140.00		
Feb-09	523.20	476.40	484.80	484.80	416.40			
Mar-09	587.05	544.51	570.04	536.00	544.51			
Apr-09								
May-09	892.80	878.40	897.60	912.00	878.40		844.80	789.60
Jun-09	1137.60	1041.60	1015.20	1015.20	1015.20		1000.80	986.40
Jul-09	816.00	775.20	763.20	782.40	768.00		727.20	724.80
Aug-09	645.60	681.60	708.00	674.40	633.60		530.40	499.20
Sep-09								
Oct-09	885.60	926.40	938.40	919.20	796.80		626.40	600.00
Nov-09								
Dec-09	686.40	650.40	652.80	626.40	585.60		571.20	544.80
Jan-10								
Feb-10								
Mar-10	1065.60	1065.20	1078.81	1061.80	1041.38		1010.75	1020.96
Apr-10	645.60	705.60	688.80	604.80	552.00		362.40	348.00
May-10	1143.48	1123.06	1095.83	1061.80	1075.41		1068.60	990.33
Jun-10	1084.80	1096.80	1080.00	1113.60	1116.00			1116.00
Jul-10	578.40	619.20	626.40	768.00	722.40			748.80
Aug-10	1252.80	1183.20	1149.60	1231.20	1260.00			1245.60
Sep-10								
Oct-10	1286.40	1238.40	1219.20	1231.20	1260.00			1219.20
Av	912	899	896	899	862	934	749	833
St Dev	272	254	249	252	251	226	247	287
Max	1411	1378	1411	1378	1260	1140	1069	1246
Min	523	476	485	485	416	612	362	348
n	19	19	19	19	19	4	9	13

Iron	Concentration (mg/l)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	8.05		0.35	1.00	0.17	0.90		
Oct-08	4.92	2.42	1.14	0.58	0.31	0.31		
Nov-08								
Dec-08	7.50	2.16	1.34	0.78	0.55	0.36		
Jan-09								
Feb-09								
Mar-09								
Apr-09								
May-09								
Jun-09	10.60	5.28	2.46	1.51	1.15		0.31	1.17
Jul-09								
Aug-09								
Sep-09								
Oct-09								
Nov-09								
Dec-09								
Jan-10								
Feb-10								
Mar-10	12.55	5.66	2.87	1.62	0.95		0.42	0.19
Apr-10								
May-10								
Jun-10								
Jul-10								
Aug-10	6.25	4.52	1.99	0.52	0.29			0.04
Sep-10								
Oct-10								
Av	8.3	4.0	1.7	1.0	0.6	0.5	0.4	0.5
St Dev	2.8	1.6	0.9	0.5	0.4	0.3	0.1	0.6
Max	12.6	5.7	2.9	1.6	1.2	0.9	0.4	1.2
Min	4.9	2.2	0.4	0.5	0.2	0.3	0.3	0.0
n	6	5	6	6	6	3	2	3

Iron	Loading (g/m^2/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	7.59		0.33	0.10	0.02	0.09		
Oct-08	4.64	2.28	1.08	0.06	0.03	0.03		
Nov-08								
Dec-08	7.07	2.04	1.26	0.07	0.05	0.03		
Jan-09								
Feb-09								
Mar-09								
Apr-09								
May-09								
Jun-09	10.00	4.98	2.32	0.14	0.11		0.03	0.11
Jul-09								
Aug-09								
Sep-09								
Oct-09								
Nov-09								
Dec-09								
Jan-10								
Feb-10								
Mar-10	11.83	5.34	2.71	0.16	0.09		0.04	0.02
Apr-10								
May-10								
Jun-10								
Jul-10								
Aug-10	5.89	4.26	1.88	0.05	0.03			0.00
Sep-10								
Oct-10								
Av	7.84	3.78	1.60	0.10	0.05	0.05	0.03	0.04
St Dev	2.66	1.53	0.87	0.04	0.04	0.03	0.01	0.06
Max	11.83	5.34	2.71	0.16	0.11	0.09	0.04	0.11
Min	4.64	2.04	0.33	0.05	0.02	0.03	0.03	0.00
n	6	5	6	6	6	3	2	3

Iron	Loading (g/unit/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	19.28		0.84	2.39	0.41	2.16		
Oct-08	11.78	5.80	2.73	1.39	0.74	0.74		
Nov-08								
Dec-08	17.96	5.17	3.21	1.87	1.33	0.86		
Jan-09								
Feb-09								
Mar-09								
Apr-09								
May-09								
Jun-09	25.39	12.65	5.89	3.62	2.76		0.73	2.81
Jul-09								
Aug-09								
Sep-09								
Oct-09								
Nov-09								
Dec-09								
Jan-10								
Feb-10								
Mar-10	30.06	13.56	6.87	3.89	2.28		1.00	0.46
Apr-10								
May-10								
Jun-10								
Jul-10								
Aug-10	14.97	10.83	4.77	1.25	0.70			0.09
Sep-10								
Oct-10								
Av	19.9	9.6	4.1	2.4	1.4	1.3	0.9	1.1
St Dev	6.7	3.9	2.2	1.1	1.0	0.8	0.2	1.5
Max	30.1	13.6	6.9	3.9	2.8	2.2	1.0	2.8
Min	11.8	5.2	0.8	1.3	0.4	0.7	0.7	0.1
n	6	5	6	6	6	3	2	3

Mn	Concentration (mg/l)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	2.98		2.42	1.28	0.29	0.27		
Oct-08	2.43	2.87	2.38	2.18	1.45	1.11		
Nov-08								
Dec-08	3.10	2.77	1.42	1.42	1.31	0.49		
Jan-09								
Feb-09								
Mar-09								
Apr-09								
May-09								
Jun-09	2.94	3.03	1.48	1.77	2.38		0.49	0.15
Jul-09								
Aug-09								
Sep-09								
Oct-09								
Nov-09								
Dec-09								
Jan-10								
Feb-10								
Mar-10	3.79	2.94	2.17	1.76	1.78		0.14	0.03
Apr-10								
May-10								
Jun-10								
Jul-10								
Aug-10	2.71	2.28	7.81	7.79	6.98			0.02
Sep-10								
Oct-10								
Av	2.99	2.78	2.95	2.70	2.36	0.62	0.31	0.06
St Dev	0.46	0.29	2.42	2.51	2.36	0.44	0.25	0.07
Max	3.79	3.03	7.81	7.79	6.98	1.11	0.49	0.15
Min	2.43	2.28	1.42	1.28	0.29	0.27	0.14	0.02
n	6	5	6	6	6	3	2	3

Mn	Loading (g/m^2/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	2.82		2.29	0.12	0.03	0.03		
Oct-08	2.30	2.71	2.25	0.21	0.14	0.11		
Nov-08								
Dec-08	2.93	2.62	1.34	0.14	0.13	0.05		
Jan-09								
Feb-09								
Mar-09								
Apr-09								
May-09								
Jun-09	2.78	2.86	1.40	0.17	0.23		0.05	0.01
Jul-09								
Aug-09								
Sep-09								
Oct-09								
Nov-09								
Dec-09								
Jan-10								
Feb-10								
Mar-10	3.58	2.78	2.05	0.17	0.17		0.01	0.00
Apr-10								
May-10								
Jun-10								
Jul-10								
Aug-10	2.56	2.15	7.38	0.75	0.67			0.00
Sep-10								
Oct-10								
Av	2.83	2.62	2.78	0.26	0.23	0.06	0.03	0.01
St Dev	0.43	0.28	2.29	0.24	0.23	0.04	0.02	0.01
Max	3.58	2.86	7.38	0.75	0.67	0.11	0.05	0.01
Min	2.30	2.15	1.34	0.12	0.03	0.03	0.01	0.00
n	6	5	6	6	6	3	2	3

Mn	Loading (g/unit/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08								
Sep-08	7.15		5.81	3.07	0.69	0.65		
Oct-08	5.83	6.89	5.71	5.23	3.48	2.66		
Nov-08								
Dec-08	7.44	6.65	3.41	3.41	3.14	1.17		
Jan-09								
Feb-09								
Mar-09								
Apr-09								
May-09								
Jun-09	7.06	7.27	3.55	4.25	5.71		1.16	0.36
Jul-09								
Aug-09								
Sep-09								
Oct-09								
Nov-09								
Dec-09								
Jan-10								
Feb-10								
Mar-10	9.08	7.06	5.21	4.22	4.27		0.33	0.06
Apr-10								
May-10								
Jun-10								
Jul-10								
Aug-10	6.50	5.47	18.74	18.70	16.75			0.04
Sep-10								
Oct-10								
Av	7.18	6.67	7.07	6.48	5.68	1.49	0.75	0.15
St Dev	1.09	0.71	5.81	6.03	5.67	1.05	0.59	0.18
Max	9.08	7.27	18.74	18.70	16.75	2.66	1.16	0.36
Min	5.83	5.47	3.41	3.07	0.69	0.65	0.33	0.04
n	6	5	6	6	6	3	2	3

TON	Concentration (mg/l)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08	236	746	554	764	786	531		
Sep-08	149	533	335	635	635	531		
Oct-08	87	459	756	1050	1013	934		
Nov-08								
Dec-08	83	740	975	1091	1228	1170		
Jan-09	116	860	918	1161	860	951		
Feb-09	304	924	924	1153	1283			
Mar-09	198	843	763	1035	1135			
Apr-09	62	124	440	775	738			
May-09	0	422	422	856	899		961	843
Jun-09	0	285	403	831	1153		1321	1141
Jul-09	148	752	574	797	686		657	715
Aug-09	124	263	856	942	787		594	769
Sep-09	79	124	536	541	565		531	570
Oct-09	0	190	170	500	740		610	530
Nov-09								
Dec-09	34	279	198	632	719		725	663
Jan-10								
Feb-10								
Mar-10	0	119	124	446	883		1007	987
Apr-10	0	84	466	799	714		471	466
May-10	20	45	734	1329	1250		1190	1121
Jun-10	25	35	848	1185	1270			1309
Jul-10	10	55.002	312.044	724	868			947
Aug-10	124	12	1260	1617	1632			1508
Sep-10								
Oct-10	30	32	412	1314.085	1425			1428
Av	83	360	590	917	967	823	807	928
St Dev	85	317	297	300	287	283	294	336
Max	304	924	1260	1617	1632	1170	1321	1508
Min	0	12	124	446	565	531	471	466
n	22	22	22	22	22	5	10	14

TON	Loading (g/m^2/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08	223	705	523	73	75	51		
Sep-08	141	504	317	61	61	51		
Oct-08	82	434	714	101	97	90		
Nov-08								
Dec-08	78	699	921	105	118	112		
Jan-09	110	813	867	111	83	91		
Feb-09	144	437	437	55	62			
Mar-09	94	398	360	50	54			
Apr-09	29	59	208	37	35			
May-09	0	399	399	82	86		92	81
Jun-09	0	269	381	80	111		127	110
Jul-09	140	711	542	77	66		63	69
Aug-09	117	249	809	90	76		57	74
Sep-09	75	117	506	52	54		51	55
Oct-09	0	180	161	48	71		59	51
Nov-09								
Dec-09	32	264	187	61	69		70	64
Jan-10								
Feb-10								
Mar-10	0	112	117	43	85		97	95
Apr-10	0	79	440	77	69		45	45
May-10	19	43	694	128	120		114	108
Jun-10	24	33	801	114	122			126
Jul-10	9	52	295	70	83			91
Aug-10	117	11	1191	155	157			145
Sep-10								
Oct-10	28	30	389	126	137			137
Av	66	300	512	82	86	79	77	89
St Dev	63	258	280	31	30	27	28	32
Max	223	813	1191	155	157	112	127	145
Min	0	11	117	37	35	51	45	45
n	22	22	22	22	22	5	10	14

TON	Loading (g/unit/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08	566	1790	1330	1834	1886	1274		
Sep-08	358	1279	804	1524	1524	1274		
Oct-08	209	1102	1814	2520	2431	2242		
Nov-08								
Dec-08	199	1776	2340	2618	2947	2808		
Jan-09	278	2064	2203	2786	2064	2282		
Feb-09	365	1109	1109	1384	1540			
Mar-09	238	1012	916	1242	1362			
Apr-09	74	149	528	930	886			
May-09	0	1013	1013	2054	2158		2306	2023
Jun-09	0	684	967	1994	2767		3170	2738
Jul-09	355	1805	1378	1913	1646		1577	1716
Aug-09	298	631	2054	2261	1889		1426	1846
Sep-09	190	298	1286	1298	1356		1274	1368
Oct-09	0	456	408	1200	1776		1464	1272
Nov-09								
Dec-09	82	670	475	1517	1726		1740	1591
Jan-10								
Feb-10								
Mar-10	0	286	298	1070	2119		2417	2369
Apr-10	0	202	1118	1918	1714		1130	1118
May-10	48	108	1762	3190	3000		2856	2690
Jun-10	60	84	2035	2844	3049			3142
Jul-10	24	132	749	1738	2083			2273
Aug-10	298	29	3024	3881	3917			3619
Sep-10								
Oct-10	72	77	989	3154	3420			3427
Av	169	762	1300	2040	2148	1976	1936	2228
St Dev	160	656	710	786	752	678	705	806
Max	566	2064	3024	3881	3917	2808	3170	3619
Min	0	29	298	930	886	1274	1130	1118
n	22	22	22	22	22	5	10	14

Total N	Loading (g/m^2/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08	233	215	173	17	17	14		
Sep-08	201	212	124	14	14	12		
Oct-08	223	218	234	24	22	20		
Nov-08								
Dec-08	225	275	312	30	30	28		
Jan-09	305	349	334	34	20	24		
Feb-09	173	166	136	13	14			
Mar-09	159	217	128	12	12			
Apr-09	103	63	71	9	8			
May-09	218	227	226	23	21		22	19
Jun-09	299	277	278	23	26		29	25
Jul-09	243	319	129	17	15		14	16
Aug-09	225	213	200	22	19		14	18
Sep-09	136	128	117	12	12		12	12
Oct-09	247	252	231	22	19		13	11
Nov-09								
Dec-09	201	202	163	17	16		16	15
Jan-10								
Feb-10								
Mar-10	286	264	253	25	25		24	22
Apr-10	191	190	180	18	16		10	10
May-10	326	284	284	30	27		26	25
Jun-10	312	313	269	28	28			28
Jul-10	162	183	169	20	19			21
Aug-10	363	311	288	35	35			33
Sep-10								
Oct-10	345	333	264	29	31			31
Av	235	237	208	22	20	19	18	20
St Dev	69	70	73	7	7	7	7	7
Max	363	349	334	35	35	28	29	33
Min	103	63	71	9	8	12	10	10
n	22	22	22	22	22	5	10	14

Total N	Loading (g/unit/day)							
	RAW	CELL 9	CELL 10	VF 1	VF 2	HF 2	VP 1	VP 2
Aug-08	592	546	440	416	427	340		
Sep-08	509	539	314	348	345	290		
Oct-08	567	553	595	588	551	510		
Nov-08								
Dec-08	572	700	793	752	739	696		
Jan-09	775	888	848	858	498	592		
Feb-09	438	422	347	326	348			
Mar-09	404	552	326	293	308			
Apr-09	262	161	180	214	202			
May-09	553	577	574	586	514		547	470
Jun-09	758	704	705	576	646		717	619
Jul-09	617	810	328	432	372		356	388
Aug-09	570	541	507	552	470		356	451
Sep-09	347	324	296	295	308		288	309
Oct-09	628	640	588	544	478		331	287
Nov-09								
Dec-09	510	513	415	429	409		397	363
Jan-10								
Feb-10								
Mar-10	727	670	643	628	615		593	545
Apr-10	485	483	458	443	398		259	255
May-10	827	721	722	743	685		653	615
Jun-10	793	796	684	706	704			712
Jul-10	412	464	430	501	482			517
Aug-10	921	789	732	883	885			818
Sep-10								
Oct-10	875	845	671	718	773			776
Av	597	602	527	538	507	486	450	509
St Dev	176	177	185	187	175	170	163	181
Max	921	888	848	883	885	696	717	818
Min	262	161	180	214	202	290	259	255
n	22	22	22	22	22	5	10	14

Phase 3 and Phase 4 - Sequence CELL 7 - CELL 8, Parameter Concentrations and Loadings

Note: RAW = Influent; CELLS 7, 8 = Effluent

HLR	l/m^2/day	l/unit/day
	CELLS	CELLS
Jun-09	945	2400
Jul-09	945	2400
Aug-09	945	2400
Sep-09	945	2400
Oct-09	945	2400
Nov-09	945	2400
Dec-09	945	2400
Jan-10	945	2400
Feb-10	945	2400
Mar-10	945	2400
Apr-10	945	2400
May-10	945	2400
Av	945	2400

NH_4	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	407	229	113	384	216	107	975	549	271
Jul-09	288	110	41	272	104	39	690	263	98
Aug-09	270	106	52	255	100	49	647	254	125
Sep-09	163	59	16	154	56	15	390	141	38
Oct-09	337	133	40	318	125	38	807	319	96
Nov-09									
Dec-09	264	111	41	249	105	39	632	266	98
Jan-10									
Feb-10									
Mar-10	390	212	114	368	200	108	934	508	273
Apr-10	260	110	31	245	104	29	623	263	74
May-10	438	198	87	413	187	82	1049	474	208
Av	313	141	59	295	133	56	750	337	142
St Dev	87	58	36	82	55	34	209	139	86
Max	438	229	114	413	216	108	1049	549	273
Min	163	59	16	154	56	15	390	141	38
n	9	9	9	9	9	9	9	9	9

BOD_5	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	25	50	51	24	47	48	60	119	123
Jul-09	40	13	8	38	12	8	96	32	19
Aug-09	14	21	10	13	20	9	33	51	24
Sep-09									
Oct-09	22	15	10	20	14	9	52	35	23
Nov-09									
Dec-09	18	11	8	17	10	8	44	26	19
Jan-10									
Feb-10									
Mar-10	23	28	35	21	27	33	54	68	84
Apr-10	6	7	4	6	6	4	15	16	10
May-10	25	27	24	24	26	22	60	66	57
Av	22	21	19	20	20	18	52	52	45
St Dev	10	14	17	9	13	16	24	33	40
Max	40	50	51	38	47	48	96	119	123
Min	6	7	4	6	6	4	15	16	10
n	8	8	8	8	8	8	8	8	8

COD	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	345	377	372	326	356	351	828	905	893
Jul-09	235	174	175	222	164	165	564	418	420
Aug-09	212	197	179	200	186	169	509	473	430
Sep-09									
Oct-09	235	212	196	222	200	185	564	509	470
Nov-09									
Dec-09	205	156	167	194	147	158	492	374	401
Jan-10									
Feb-10									
Mar-10	340	284	250	321	268	236	816	682	600
Apr-10	211	203	149	199	192	141	506	487	358
May-10	368	303	262	348	286	248	883	727	629
Av	269	238	219	254	225	207	645	572	525
St Dev	69	76	74	66	71	70	166	182	177
Max	368	377	372	348	356	351	883	905	893
Min	205	156	149	194	147	141	492	374	358
n	8	8	8	8	8	8	8	8	8

SS	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	30.0	18.0	13.0	28.3	17.0	12.3	71.9	43.1	31.1
Jul-09	31.5	8.7	4.0	29.7	8.2	3.7	75.5	20.8	9.5
Aug-09	33.5	9.0	6.0	31.6	8.5	5.7	80.2	21.6	14.4
Sep-09									
Oct-09	16.5	8.0	6.5	15.6	7.5	6.1	39.5	19.2	15.6
Nov-09									
Dec-09	33.0	20.0	7.0	31.1	18.9	6.6	79.0	47.9	16.8
Jan-10									
Feb-10									
Mar-10	44.5	12.5	9.5	42.0	11.8	9.0	106.6	29.9	22.8
Apr-10	26.5	9.0	4.5	25.0	8.5	4.2	63.5	21.6	10.8
May-10	46.5	17.5	9.5	43.9	16.5	9.0	111.4	41.9	22.8
Av	33	13	7	30.9	12.1	7.1	78.4	30.7	17.9
St Dev	10	5	3	9.0	4.6	2.8	22.9	11.8	7.2
Max	47	20	13	43.9	18.9	12.3	111.4	47.9	31.1
Min	17	8	4	15.6	7.5	3.7	39.5	19.2	9.5
n	8	8	8	8	8	8	8	8	8

Chloride	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	474	428	431	447.9	404.4	407.2	1137.6	1027.2	1034.4
Jul-09	340	320	320	321.3	302.4	302.4	816.0	768.0	768.0
Aug-09	269	284	294	254.2	268.3	277.8	645.6	681.6	705.6
Sep-09									
Oct-09	369	383	386	348.7	361.9	364.7	885.6	919.2	926.4
Nov-09									
Dec-09	286	275	267	270.2	259.8	252.3	686.4	660.0	640.8
Jan-10									
Feb-10									
Mar-10	444	442	437	419.5	418.0	412.7	1065.6	1061.8	1048.2
Apr-10	444	442	437	419.5	418.0	412.7	1065.6	1061.8	1048.2
May-10	476	464	457	450.2	438.1	431.4	1143.5	1112.8	1095.8
Av	388	380	379	366.4	358.9	357.6	930.7	911.6	908.4
St Dev	83	76	74	78.8	72.3	70.2	200.2	183.6	178.4
Max	476	464	457	450.2	438.1	431.4	1143.5	1112.8	1095.8
Min	269	275	267	254.2	259.8	252.3	645.6	660.0	640.8
n	8	8	8	8	8	8	8	8	8

Iron	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	10.60	4.31	2.12	10.02	4.07	2.00	25.44	10.34	5.09
Jul-09									
Aug-09									
Sep-09									
Oct-09									
Nov-09									
Dec-09									
Jan-10									
Feb-10									
Mar-10	12.55	3.99	2.15	11.86	3.77	2.03	30.12	9.58	5.16
Apr-10									
May-10									
Av	11.6	4.2	2.1	10.94	3.92	2.02	27.78	9.96	5.12
St Dev	1.4	0.2	0.0	1.30	0.21	0.02	3.31	0.54	0.05
Max	12.6	4.3	2.2	11.86	4.07	2.03	30.12	10.34	5.16
Min	10.6	4.0	2.1	10.02	3.77	2.00	25.44	9.58	5.09
n	2	2	2	2	2	2	2	2	2

Mn	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	2.94	2.49	1.69	2.78	2.35	1.60	7.06	5.98	4.06
Jul-09									
Aug-09									
Sep-09									
Oct-09									
Nov-09									
Dec-09									
Jan-10									
Feb-10									
Mar-10	3.79	2.53	0.89	3.58	2.39	0.84	9.08	6.07	2.13
Apr-10									
May-10									
Av	3.36	2.51	1.29	3.18	2.37	1.22	8.07	6.02	3.09
St Dev	0.60	0.03	0.57	0.56	0.03	0.54	1.43	0.07	1.36
Max	3.79	2.53	1.69	3.58	2.39	1.60	9.08	6.07	4.06
Min	2.94	2.49	0.89	2.78	2.35	0.84	7.06	5.98	2.13
n	2	2	2	2	2	2	2	2	2

TON	Concentration (mg/l)			Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	0	651	1066	0	615	1007	0	1562	2558
Jul-09	148	252	206	140	238	195	355	605	494
Aug-09	124	725	980	117	685	926	298	1740	2352
Sep-09	79	422	526	75	399	497	190	1013	1262
Oct-09	0	780	1020	0	737	964	0	1872	2448
Nov-09									
Dec-09	34	639	831	32	604	785	82	1534	1994
Jan-10									
Feb-10									
Mar-10	0	565	923	0	534	872	0	1356	2215
Apr-10	0	546	833	0	516	787	0	1310	1999
May-10	20	729	1076	19	689	1017	48	1750	2582
Av	45	590	829	43	557	783	108	1416	1990
St Dev	58	168	288	55	158	272	139	402	692
Max	148	780	1076	140	737	1017	355	1872	2582
Min	0	252	206	0	238	195	0	605	494
n	9	9	9	9	9	9	9	9	9

Total N	Loading (g/m^2/day)			Loading (g/unit/day)		
	RAW	**CELL 7**	**CELL 8**	**RAW**	**CELL 7**	**CELL 8**
Jun-09	299	307	311	758	780	789
Jul-09	243	135	74	617	342	188
Aug-09	225	233	247	570	591	628
Sep-09	136	133	124	347	339	315
Oct-09	247	264	247	628	671	628
Nov-09						
Dec-09	201	218	208	510	553	527
Jan-10						
Feb-10						
Mar-10	286	276	281	727	702	713
Apr-10	191	197	201	485	501	510
May-10	326	301	294	827	764	746
Av	239	229	221	608	583	560
St Dev	59	65	79	150	165	200
Max	326	307	311	827	780	789
Min	136	133	74	347	339	188
n	9	9	9	9	9	9

Phase 3 and Phase 4 - Sequence CELL 7 - CELL 8 - VP 1, Parameter Concentrations and Loadings

Note: RAW = Influent; CELLS, VP = Effluent

HLR	l/m^2/day	l/unit/day	l/m^2/day	l/unit/day
	CELLS	CELLS	VP 1	VP 1
Jun-10	236	600	24	600
Jul-10	236	600	24	600
Aug-10	236	600	24	600
Sep-10	236	600	24	600
Oct-10	236	600	24	600
Av	236	600	24	600

NH_4	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	418	61	9	1	99	14.38	2.12	0.02	250.8	36.6	5.4	0.6
Jul-10	218	45	4	1	51	10.61	0.94	0.02	130.8	27	2.4	0.6
Aug-10	458	62	4	0	108	14.62	0.94	0	274.8	37.2	2.4	0
Sep-10												
Oct-10	461	88	16	0	109	20.75	3.77	0	276.6	52.8	9.6	0
Av	389	64	8	1	92	15	1.94	0.01	233	38	5	0.3
St Dev	116	18	6	1	27	4	1.34	0.01	69	11	3	0.3
Max	461	88	16	1	109	21	3.77	0.02	277	53	10	0.6
Min	218	45	4	0	51	11	0.94	0.00	131	27	2	0.0
n	4	4	4	4	4	4	4	4	4	4	4	4

BOD_5	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	27	17.35	4.75	1	6	4.10	1.12	0.02	15.99	10.41	2.85	0.612
Jul-10	5	8.7	5.3	1.06	1	2.06	1.25	0.03	3.06	5.22	3.18	0.636
Aug-10	27	30.1	9.3		6	7.11	2.20	0	16.41	18.06	5.58	
Sep-10												
Oct-10	25	15.95	3.31	0.73	6	3.77	0.78	0	14.85	9.57	1.986	0.438
Av	21	18	6	0.94	4.95	4.26	1.34	0.02	12.58	10.82	3.40	0.56
St Dev	11	9	3	0.18	2.51	2.10	0.61	0.01	6.38	5.34	1.54	0.11
Max	27	30	9	1.06	6.46	7.11	2.20	0.03	16.41	18.06	5.58	0.64
Min	5	9	3	0.73	1.20	2.06	0.78	0.00	3.06	5.22	1.99	0.44
n	4	4	4	3	4	4	4	4	4	4	4	3

COD	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	333	227	259	137	79	54	61	3	200	136	155	82
Jul-10	177	191	188	86	42	45	44	2	106	115	113	52
Aug-10	385	281	273	125	91	66	64	3	231	169	164	75
Sep-10												
Oct-10	392	278	237	122	92	66	56	3	235	167	142	73
Av	322	244	239	118	76	58	56	3	193	147	144	71
St Dev	100	43	37	22	24	10	9	1	60	26	22	13
Max	392	281	273	137	92	66	64	3	235	169	164	82
Min	177	191	188	86	42	45	44	2	106	115	113	52
n	4	4	4	4	4	4	4	4	4	4	4	4

SS	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	24.00	18.00	14.50	9.50	5.66	4.24	3.42	0.23	14.37	10.78	8.68	5.70
Jul-10	14.50	11.50	7.50	4.00	3.42	2.71	1.77	0.10	8.68	6.89	4.49	2.40
Aug-10	34.50	59.50	19.50	8.00	8.13	14.03	4.60	0.19	20.66	35.63	11.68	4.80
Sep-10												
Oct-10	29.00	71.00	10.00	4.50	6.84	16.74	2.36	0.11	17.37	42.52	5.99	2.70
Av	26	40	13	7	6.0	9.4	3.0	0.2	15.3	24.0	7.7	3.9
St Dev	8	30	5	3	2.0	7.0	1.2	0.1	5.1	17.8	3.2	1.6
Max	35	71	20	10	8.1	16.7	4.6	0.2	20.7	42.5	11.7	5.7
Min	15	12	8	4	3.4	2.7	1.8	0.1	8.7	6.9	4.5	2.4
n	4	4	4	4	4	4	4	4	4	4	4	4

Chloride	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	452	444	451	476	106.6	104.7	106.3	11.4	270.7	265.9	270.1	285.6
Jul-10	241	281	312	315	56.8	66.2	73.6	7.6	144.3	168.3	186.8	189.0
Aug-10	522	476	457	394	123.1	112.2	107.7	9.5	312.6	285.0	273.7	236.4
Sep-10												
Oct-10	536	508	510	478	126.4	119.8	120.2	11.5	321.0	304.2	305.4	286.8
Av	438	427	433	416	103.2	100.7	102.0	10.0	262.1	255.8	259.0	249.5
St Dev	136	101	85	78	32.1	23.8	19.9	1.9	81.6	60.4	50.7	46.6
Max	536	508	510	478	126.4	119.8	120.2	11.5	321.0	304.2	305.4	286.8
Min	241	281	312	315	56.8	66.2	73.6	7.6	144.3	168.3	186.8	189.0
n	4	4	4	4	4	4	4	4	4	4	4	4

Iron	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10												
Jul-10												
Aug-10	6.25	3.16	1.41	0.02	1	0.75	0.33	0.001	3.75	1.90	0.85	0.01
Sep-10												
Oct-10												
Av	6.25	3.16	1.41	0.02	1.48	0.75	0.33	0.001	3.75	1.90	0.85	0.01
St Dev												
Max												
Min												
n	1	1	1	1	1	1	1	1	1	1	1	1

Mn	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10												
Jul-10												
Aug-10	2.71	6.60	0.47	0.007	0.64	1.56	0.11	0.0002	1.63	3.96	0.28	0.004
Sep-10												
Oct-10												
Av	2.71	6.60	0.47	0.007	0.64	1.56	0.11	0.0002	1.63	3.96	0.28	0.004
St Dev												
Max												
Min												
n	1	1	1	1	1	1	1	1	1	1	1	1

TON	Concentration (mg/l)				Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	25	1146	1369	1428	6	271	323	34	15	688	821	857
Jul-10	10	684	893	942	2	162	211	23	6	410	536	565
Aug-10	124	1295	1285	1245	29	306	304	30	74	777	771	747
Sep-10												
Oct-10	30	1166	1414	1374	7	275	334	33	18	700	848	824
Av	47	1073	1240	1247	11	253	293	30	28	644	744	748
St Dev	52	267	238	218	12	63	56	5	31	160	143	130
Max	124	1295	1414	1428	29	306	334	34	74	777	848	857
Min	10	684	893	942	2	162	211	23	6	410	536	565
n	4	4	4	4	4	4	4	4	4	4	4	4

Total N	Loading (g/m^2/day)				Loading (g/unit/day)			
	RAW	**CELL 7**	**CELL 8**	**VP 1**	**RAW**	**CELL 7**	**CELL 8**	**VP 1**
Jun-10	78.0	72.4	74.7	7.8	198	184	190	194
Jul-10	40.5	44.8	48.4	5.1	103	114	123	128
Aug-10	90.6	80.5	69.3	6.8	230	204	176	169
Sep-10								
Oct-10	86.2	78.4	78.4	7.5	219	199	199	186
Av	73.8	69.0	67.7	6.8	188	175	172	169
St Dev	22.8	16.5	13.4	1.2	58	42	34	29
Max	90.6	80.5	78.4	7.8	230	204	199	194
Min	40.5	44.8	48.4	5.1	103	114	123	128
n	4	4	4	4	4	4	4	4

Concentrations for Metals & Salts - LEACHATE - CELLS / REED BEDS - Phases 1 - 4

Note: Blank Cells = no data; 0 = Limit of Detection (LOD)

Statistical Data for Leachate includes combined data for RAW 1, RAW 2 and RAW C

HF 1 and HF 2 converted to VP 1 and VP 2 in April 2009. Data for June 2009, March 2010 and August 2010 refers to VP 1 and VP 2

Boron (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08																			
Jun-09	1.36			1.39		1.14						1.26					1.00	0.14	0.02
Mar-10																			
Aug-10	1.34			1.33		1.24	1.69			0.28	1.17	1.13	1.63	1.83	1.99	0.93	1.71	0.03	1.49
Min	1.34			1.33		1.14						1.13					1.00	0.03	0.02
Max	1.36			1.39		1.24						1.26					1.71	0.14	1.49
Mean	1.35			1.36		1.19	1.69			0.28	1.17	1.20	1.63	1.83	1.99	0.93	1.36	0.09	0.76
St Dev	0.01			0.04		0.07						0.09					0.50	0.08	1.04
n	2			2		2	1			1	1	2	1	1	1	1	2	2	2

Cadmium (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	1.0			1.0	1.0	1.0	1.0		1.0	1.0	1.0		1.0	1.0	1.0	1.0	1.0		
Dec-08	0.0		0.0	0.0		0.0	0.0	0.0	0.0			0.0	0.0	0.0	0.0	0.0	0.0		
Jun-09	2.0			2.0		1.0	1.0	1.0		1.0	2.0	2.0	1.0	6.0	1.0	6.0	10.0	0.0	1.0
Mar-10	0.0			0.0		0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aug-10	0.0			0.0		0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0
Min	0.0			0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	2.0			2.0		1.0	1.0	1.0	1.0	1.0	2.0	2.0	1.0	6.0	1.0	6.0	10.0	0.0	1.0
Mean	1.5			0.6	1.0	0.4	0.4	0.3	0.5	0.5	0.8	0.5	0.4	1.4	0.4	1.4	2.4	0.0	0.3
St Dev	0.8			0.9		0.5	0.5	0.5	0.7	0.6	1.0	1.0	0.5	2.6	0.5	2.6	4.3	0.0	0.6
n	6			5	1	5	5	4	2	4	4	4	5	5	5	5	5	3	3

Chromium (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	7			6	6	3	5		3	5	5		5	4	5	3	3		
Dec-08	5		5	5		4	4	3	5			4	3	3	3		3		
Jun-09	10			7		10	4	2		8	4	7	9	4	1	2	1	0	87
Mar-10	11			0		0	0	0		0	1	0		2	1	0	0	2	21
Aug-10	6			5		5	4	7		5	4	5	4	6	4	3	3	0	85
Min	5			0		0	0	0	3	0	1	0	3	2	1	0	0	0	21
Max	11			7		10	5	7	5	8	5	7	9	6	5	3	3	2	87
Mean	7			5	6	4	3	3	4	5	4	4	5	4	3	2	2	1	64
St Dev	3			3		4	2	3	1	3	2	3	3	1	2	1	1	1	38
n	6			5	1	5	5	4	2	4	4	4	4	5	5	4	5	3	3

Copper (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	49			15	13	23	15		26	19	21		49	33	44	33	25		
Dec-08	6		15	26		34	9	41	14			11	10	24	25		21		
Jun-09	20			41		53	42	43		88	92	46	89	89	93	94	98	17	2
Mar-10	25			97		87	80	91		202	74	111	66	78	99	101	97	57	48
Aug-10	9			22		15	28	27		59	65	14	34	32	24	32	24	7	20
Min	6			15		15	9	27	14	19	21	11	10	24	24	32	21	7	2
Max	49			97		87	80	91	26	202	92	111	89	89	99	101	98	57	48
Mean	21			40	13	42	35	51	20	92	63	46	50	51	57	65	53	27	23
St Dev	16			33		29	28	28	8	79	30	46	30	30	37	38	41	26	23
n	6			5	1	5	5	4	2	4	4	4	5	5	5	4	5	3	3

Iron (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	1.20		0.83	0.63	0.59	0.23	0.20		0.08	0.94	0.48		0.31	0.14	0.31	0.07	0.10		
Dec-08	7.50		5.68	3.59		1.73	0.59	0.68	3.68			2.16	1.34	0.78	0.55		0.36		
Jun-09	10.60			4.46		1.90	0.26	0.66		4.31	2.12	5.28	2.46	1.51	1.15	0.31	1.17	0.23	
Mar-10	12.55			3.57		1.88	0.61	1.22		3.99	2.15	5.66	2.87	1.62	0.95	0.42	0.19	0.73	
Aug-10	6.25			0.99		1.39	0.16	2.43		3.16	1.41	4.52	1.99	0.52	0.29	0.02	0.04	0.08	
Min	0.83			0.63		0.23	0.16	0.66	0.08	0.94	0.48	2.16	0.31	0.14	0.29	0.02	0.04	0.08	
Max	12.55			4.46		1.90	0.61	2.43	3.68	4.31	2.15	5.66	2.87	1.62	1.15	0.42	1.17	0.73	
Mean	6.37			2.65	0.59	1.43	0.36	1.25	1.88	3.10	1.54	4.41	1.79	0.91	0.65	0.20	0.37	0.35	
St Dev	4.38			1.72		0.70	0.22	0.83	2.54	1.52	0.79	1.57	1.00	0.64	0.39	0.19	0.46	0.34	
n	7			5	1	5	5	4	2	4	4	4	5	5	5	4	5	3	

Lead (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	1.0		0.0	0.0	1.0	0.0	0.0		0.0	0.0	0.0		2.0	1.0	1.0	1.0	0.0		
Dec-08	1.0		1.0	1.0		4.0	1.0	1.0	1.0			1.0	2.0	1.0	1.0		0.0		
Jun-09	0.0			2.0		6.0	2.0	1.0		3.0	15.0	1.0	8.0	5.0	3.0	1.0	2.0	0.0	11.0
Mar-10	0.0			5.0		1.0	0.0	0.0		1.0	2.0	12.0	1.0	1.0	0.0	0.0	1.0	2.0	3.0
Aug-10	1.0			1.0		1.0	0.0	0.0		3.0	9.0	0.0	1.0	0.0	1.0	1.0	1.0	0.0	13.0
Min	0.0			0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0
Max	1.0			5.0		6.0	2.0	1.0	1.0	3.0	15.0	12.0	8.0	5.0	3.0	1.0	2.0	2.0	13.0
Mean	0.6			1.8	1.0	2.4	0.6	0.5	0.5	1.8	6.5	3.5	2.8	1.6	1.2	0.8	0.8	0.7	9.0
St Dev	0.5			1.9		2.5	0.9	0.6	0.7	1.5	6.9	5.7	2.9	1.9	1.1	0.5	0.8	1.2	5.3
n	7			5	1	5	5	4	2	4	4	4	5	5	5	4	5	3	3

Magnesium (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08	69		69	59		63	68	65	62			66	57	63	59				
Jun-09	55			49		55	67	52		58	60	60	61	64	63	56	53	7	196
Mar-10	59			56		47	55	54		56	53	55	55	55	52	57	60	6	62
Aug-10	65			57		70	78	63		67	62	67	69	71	77	57	76	7	186
Min	55			49		47	55	52		56	53	55	55	55	52	56	53	6	62
Max	69			59		70	78	65		67	62	67	69	71	77	57	76	7	196
Mean	63			55		59	67	59	62	60	58	62	60	63	63	57	63	7	148
St Dev	6			4		10	9	6		6	5	6	6	7	11	0.5	12	1	75
n	5			4		4	4	4	1	3	3	4	4	4	4	3	3	3	3

Manganese (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	2.03		2.54	1.90	2.46	0.15	2.77		2.28	1.34	0.21		1.34	2.43	3.02	0.41	2.59		
Dec-08																			
Jun-09	2.94			2.90		2.79	3.76	1.19		2.49	1.69	3.03	1.48	1.77	2.38	0.49	0.15	0.09	
Mar-10	3.79			2.78		1.43	1.53	0.63		2.53	0.89	2.94	2.17	1.76	1.78	0.14	0.03	0.24	
Aug-10	2.71			1.40		3.11	5.00	1.00		6.60	0.47	2.28	7.81	7.79	6.98	0.01	0.02	0.02	
Min	2.03			1.40		0.15	1.53	0.63		1.34	0.21	2.28	1.34	1.76	1.78	0.01	0.02	0.02	
Max	3.79			2.90		3.11	5.00	1.19		6.60	1.69	3.03	7.81	7.79	6.98	0.49	2.59	0.24	
Mean	2.80			2.25	2.46	1.87	3.27	0.94	2.28	3.24	0.82	2.75	3.20	3.44	3.54	0.26	0.70	0.11	
St Dev	0.64			0.72		1.36	1.47	0.28		2.31	0.65	0.41	3.09	2.92	2.35	0.22	1.26	0.11	
n	5			4	1	4	4	3	1	4	4	3	4	4	4	4	4	3	

Mercury (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08																			
Jun-09	< 0.02			< 0.02		< 0.02						< 0.02					< 0.02	< 0.02	
Mar-10																			
Aug-10	<0.02			<0.02		<0.02	<0.02			<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.040	<0.02	
Min																			
Max																			
Mean	<0.02			<0.02		<0.02	<0.02			<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.0400	<0.02	
St Dev																			
n	2			2		2	1			1	1	2	1	1	1	1	2	2	

Nickel (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08	32		28	55		47	43	46	45			44	33	5	5		5		
Jun-09	153			141		45	48	43		47	49	48	49	50	54	56	59	7	40
Mar-10	45			36		36	35	33		32	31	35	26	46	45	42	38	4	43
Aug-10	19			48		56	64	72		75	79	81	82	76	80	74	81	102	131
Min	19			36		36	35	33		32	31	35	26	5	5	42	5	4	40
Max	153			141		56	64	72		75	79	81	82	76	80	74	81	102	131
Mean	55			70		46	48	49	45	51	53	52	48	44	46	57	46	38	71
St Dev	55			48		8	12	17		22	24	20	25	29	31	16	32	56	52
n	5			4		4	4	4	1	3	3	4	4	4	4	3	4	3	3

Phosphate (P) (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08																			
Jun-09	0.50			1.02		0.13	0.42	0.13	0.19		0.07	0.43	0.22	0.18	0.10	0.06	0.07	0.07	0.80
Mar-10	0.90			0.37		0.13	0.32	0.16		0.29	0.17	0.48	0.28	0.30	0.19	0.12	0.09	0.13	1.75
Aug-10																			
Min	0.50			0.37		0.13	0.32	0.13			0.07	0.43	0.22	0.18	0.10	0.06	0.07	0.07	0.80
Max	0.90			1.02		0.13	0.42	0.16			0.17	0.48	0.28	0.30	0.19	0.12	0.09	0.13	1.75
Mean	0.70			0.69		0.13	0.37	0.14	0.19	0.29	0.12	0.46	0.25	0.24	0.14	0.09	0.08	0.10	1.28
St Dev	0.28			0.46		0.00	0.07	0.02			0.07	0.03	0.04	0.08	0.07	0.04	0.01	0.04	0.67
n	2			2		2	2	2	1	1	2	2	2	2	2	2	2	2	2

Potassium (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	205		198	179	197	195	187		157	203	200		192	181	187	163	164		
Dec-08	188		174	156		165	156	157	164			187	181	188	173				
Jun-09	195			177		182	150	18		206	201	206	213	217	217	208	197	3	547
Mar-10	171			165		176	178	166		171	184	184	174	173	146	175	172	3	112
Aug-10	225			257		211	176	227		233	227	223	205	199	214	178	214	7	282
Min	171			156		165	150	18	157	171	184	184	174	173	146	163	164	3	112
Max	225			257		211	187	227	164	233	227	223	213	217	217	208	214	7	547
Mean	194			187	197	186	169	142	161	203	203	200	193	192	187	181	187	4	314
St Dev	18			40		18	16	88	5	25	18	18	16	17	30	19	23	3	219
n	7			5	1	5	5	4	2	4	4	4	5	5	5	4	4	3	3

Sodium (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	246		286	225	257	184	225		174	219	253		224	283	239	203	252		
Dec-08	284		284	206		231	214	213	251			284	242	298	291				
Jun-09	318			351		332	904	471		462	437	434	419	420	427	422	381	14	1060
Mar-10	340			330		333	340	328		330	340	338	340	330	308	335	350	44	260
Aug-10	392			372		376	363	362		366	337	348	340	367	386	276	337	13	1030
Min	246			206	257	184	214	213	174	219	253	284	224	283	239	203	252	13	260
Max	392			372	257	376	904	471	251	462	437	434	419	420	427	422	381	44	1060
Mean	307			297	257	291	409	343	212	344	342	351	313	340	330	309	330	24	783
St Dev	48			76		80	285	106	54	100	75	62	80	55	76	93	55	18	453
n	7			5	1	5	5	4	2	4	4	4	5	5	5	4	4	3	3

Zinc (µg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08	26		22	17	33	8	29		16	11	11		65	38	79	19	12		
Dec-08	33		51	39		143	46	99	36			72	57	83	120		58		
Jun-09	10			29		90	49	45		66	78	32	65	77	63	39	38	9	416
Mar-10	16			56		71	49	49		311	48	116	60	63	72	35	32	57	91
Aug-10	1			29		111	74	23		109	166	14	81	174	52	22	36	9	209
Min	1			17		8	29	23	16	11	11	14	57	38	52	19	12	9	91
Max	51			56		143	74	99	36	311	166	116	81	174	120	39	58	57	416
Mean	23			34	33	85	49	54	26	124	76	59	66	87	77	29	35	25	239
St Dev	16			15		50	16	32	14	131	66	45	9	52	26	10	16	28	165
n	7			5	1	5	5	4	2	4	4	4	5	5	5	4	5	3	3

Alkalinity (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08																			
Jun-09	140			1100		280	560	130		700	360	1300	250	240	180	180	200	140	880
Mar-10																			
Aug-10																			
Min																			
Max																			
Mean	140			1100		280	560	130		700	360	1300	250	240	180	180	200	140	880
St Dev																			
n	1			1		1	1	1		1	1	1	1	1	1	1	1	1	

Calcium (mg/l)	RAW 1	RAW 2	RAW C	CELL 1	CELL 2	CELL 3	CELL 4	CELL 5	CELL 6	CELL 7	CELL 8	CELL 9	CELL 10	VF 1	VF 2	HF 1 / VP 1	HF 2 / VP 2	Tramore River	Raw Active
Mar-08																			
Dec-08																			
Jun-09				134		160	170	152		170	184	120	176	144	128	109	128	64	
Mar-10																			
Aug-10																			
Min																			
Max																			
Mean	144			134		160	170	152		170	184	120	176	144	128	109	128	64	
St Dev																			
n	1			1		1	1	1		1	1	1	1	1	1	1	1	1	

Phase 5 - Statistical Analysis for *E. coli* Testing

E. coli	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
HLR (l/unit/day)		1200	480	480	300	300	2400	2400	2400	2400	2400	2400	
HLR (l/m^2/day)		472	189	189	118	118	945	945	96	96	96	96	
Sample Dilution # 1	1 in 10	1 in 10	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 2	No Dilution	No Dilution	No Dilution	No Dilution	1 in 20
Sample Dilution # 2	1 in 20	1 in 20	1 in 20	1 in 10	1 in 20	1 in 10	1 in 20	1 in 4	1 in 2	1 in 2	1 in 2	1 in 2	1 in 10
10/10/2011	>2419.6	_	_	_	_	_	>2419.6	1413.6	137.2	65.7	5.2	1	-
10/10/2011	_	_	_	_	_	_	_	_	_	_	_	_	_
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	_	_	_	_	1461.6
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	4479.6	_	_	_	_	541.6
17/10/2011	6488	3609	3255	4082	1968	808	1296	615.2	218.7	52.9	2	1	_
17/10/2011	6152	2038	4718	3255	1918	1178	1466	1302	2604	74.6	4	1	_
24/10/2011	135	30	50	35	10	1	72	2	1	1	1	1	>2419.6
24/10/2011	144	20	60	1	80	30	20	28	1	1	1	1	>2419.6
07/11/2011	1782	670	556	454.5	288	31.5	703	135.4	17.5	3.1	1	1	296.6
08/11/2011	1300	816	738	379	322	86	798	143.6	21.8	1	1	1	97
14/11/2011	1376	185	474	252	85	26	295	85.6	5.2	1	1	1	1297.6
15/11/2011	1382	242	242	246	20	1	398	86.4	12.6	1	2	1	1223
21/11/2011	538	121	52	10	31	1	75	29.6	6.3	1	2	1	2239.8
21/11/2011	374	62	40	41	82	1	148	8	1	1	2	1	4611
28/11/2011	181	75	52	20.5	31	10	75	26.8	8.5	2	1	1	922.2
28/11/2011	178	20	40	41	1	10	60	39.2	14.8	2	1	1	1012
05/12/2011	160	31	20	26	1	5	30	8.2	6.3	3.1	1	1	334
05/12/2011	126	62	1	20	1	1	20	8	2	4	1	1	_
12/12/2011	241	31	108	26	31	5	30	34.6	2	58.3	1	1	1960.8
12/12/2011	322	194	104	10	40	1	218	20.8	4	58.4	1	1	1782

Note: All data as MPN/100ml
Blank Cells / _ = No Data
Over Range Data = >2419.6
For each sample date, lower dilution is on top

Flow Sequence
Raw - Cell 1
Raw - Cell 3 - Cell 5
Raw - Cell 7 - Cell 8
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2

Selected Results for *E . coli* Calculations

E. coli	**Raw**	**Cell 1**	**Cell 3**	**Cell 5**	**Cell 7**	**Cell 8**	**Cell 9**	**Cell 10**	**VF 1**	**VF 2**	**VP 1**	**VP 2**	**Tramore River**
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
10/10/2011	>2419.6	_	_	_	_	_	>2419.6	1413.6	137.2	65.7	5.2	1	-
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	_	_	_	_	1461.6
17/10/2011	6488	3609	3255	4082	1968	808	1296	615.2	218.7	52.9	2	1	_
24/10/2011	135	30	50	35	10	1	72	2	1	1	1	1	>2419.6
07/11/2011	1782	670	556	454.5	288	31.5	703	135.4	17.5	3.1	1	1	296.6
14/11/2011	1376	185	474	252	85	26	295	85.6	5.2	1	1	1	1297.6
21/11/2011	538	121	52	10	31	1	75	29.6	6.3	1	2	1	2239.8
28/11/2011	181	75	52	20.5	31	10	75	26.8	8.5	2	1	1	922.2
05/12/2011	160	31	20	26	1	5	30	8.2	6.3	3.1	1	1	334
12/12/2011	241	31	108	26	31	5	30	34.6	2	58.3	1	1	1960.8
Average	1363	594	571	613	306	111	322	117	33	15	1	1	1175
St Dev	2162	1237	1105	1411	678	282	455	206	75	25	0.5	0	814
Max	6488	3609	3255	4082	1968	808	1296	615	219	58	2	1	2240
Min	135	30	20	10	1	1	30	2	1	1	1	1	297

Note: Calculations based on data from 17/10/11 to 12/12/11
Over Range Data (>2419.6) not included in calculations
All data as MPN/100ml

E. coli	**Raw**	**Cell 1**	**Cell 3**	**Cell 5**	**Cell 7**	**Cell 8**	**Cell 9**	**Cell 10**	**VF 1**	**VF 2**	**VP 1**	**VP 2**	**Tramore River**
Average	630	163	187	118	68	11	183	46	7	10	1	1	1175
St Dev	672	231	227	171	101	12	247	48	5	21	0.4	0	814
Max	1782	670	556	455	288	32	703	135	18	58	2	1	2240
Min	135	30	20	10	1	1	30	2	1	1	1	1	297
n	7	7	7	7	7	7	7	7	7	7	7	7	6

Excluding outlier data from 17/10/2011
Note: Calculations based on data from 24/10/11 to 12/12/11 (statistical analysis more reflective of actual results)
For the purpose of calculation, MPN/100 ml < 1 is represented as 1 MPN/100 ml
All data as MPN/100ml

Raw - Cell 1		
E. coli	Raw	Cell 1
Average	630	163
St Dev	672	231
Max	1782	670
Min	135	30

Raw - Cell 1 Cumulative Removal (%)	
E. coli	Cell 1
24/10/2011	78
07/11/2011	62
14/11/2011	87
21/11/2011	78
28/11/2011	59
05/12/2011	81
12/12/2011	87
Average	76

Raw - Cell 3 - Cell 5			
E. coli	Raw	Cell 3	Cell 5
Average	630	187	118
St Dev	672	227	171
Max	1782	556	455
Min	135	20	10

Raw - Cell 3 - Cell 5 Cumulative Removal Efficiency (%)		
E. coli	Cell 3	Cell 5
24/10/2011	63	74
07/11/2011	69	74
14/11/2011	66	82
21/11/2011	90	98
28/11/2011	71	89
05/12/2011	88	84
12/12/2011	55	89
Average	72	84

Raw - Cell 7 - Cell 8			
E. coli	Raw	Cell 7	Cell 8
Average	630	68	11
St Dev	672	101	12
Max	1782	288	32
Min	135	1	1

Raw - Cell 7 - Cell 8 Cumulative Removal Efficiency (%)		
E. coli	Cell 7	Cell 8
24/10/2011	93	99
07/11/2011	84	98
14/11/2011	94	98
21/11/2011	94	99.8
28/11/2011	83	94
05/12/2011	99	97
12/12/2011	87	98
Average	91	98

Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2							
E. coli	Raw	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2
Average	630	183	46	7	10	1	1
St Dev	672	247	48	5	21	0.4	0
Max	1782	703	135	18	58	2	1
Min	135	30	2	1	1	1	1

Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - Cumulative Removal Efficiency (%)						
E. coli	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2
24/10/2011	47	99	99	99.3	99.3	99.3
07/11/2011	61	92	99	99.8	99.9	99.9
14/11/2011	79	94	100	99.9	99.9	99.9
21/11/2011	86	94	99	99.8	99.6	99.8
28/11/2011	59	85	95	98.9	99.4	99.4
05/12/2011	81	95	96	98.1	99.4	99.4
12/12/2011	88	86	99	75.8	99.6	99.6
Average	71	92	98	96	99.6	99.6

Phase 5 - Statistical Analysis for Total Coliforms Testing

Total Coliforms	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
HLR (l/unit/day)		1200	480	480	300	300	2400	2400	2400	2400	2400	2400	
HLR (l/m^2/day)		472	189	189	118	118	945	945	96	96	96	96	
Sample Dilution # 1	1 in 10	1 in 10	1 in 10	1 in 5	1 in 10	1 in 5	1 in 10	1 in 2	No Dilution	No Dilution	No Dilution	No Dilution	1 in 20
Sample Dilution # 2	1 in 20	1 in 20	1 in 20	1 in 10	1 in 20	1 in 10	1 in 20	1 in 4	1 in 2	1 in 2	1 in 2	1 in 2	1 in 10
10/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	>2419.6	>2419.6	224.7	1	_
10/10/2011	_	_	_	_	_	_	_	_	_	_	_	_	_
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	_	_	_	_	>2419.6
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	4479.6	_	_	_	_	>2419.6
17/10/2011	>2419.6	>2419.6	17329	>2419.6	>2419.6	>2419.6	9804	>2419.6	>2419.6	1986.3	488.4	307.6	_
17/10/2011	>2419.6	>2419.6	25994	19863	>2419.6	>2419.6	9768	6931.6	3972.6	1960.8	419.2	310.6	_
24/10/2011	>2419.6	7701	12033	6498.5	3076	4604	15531	2092.4	307.6	>2419.6	816.4	158.5	>2419.6
24/10/2011	10950	5818	7308	9208	5510	2481	7308	1379.2	774.6	>2419.6	1297.6	330	>2419.6
07/11/2011	24196	>2419.6	19863	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6	1119.9	461.1	240	121.1	>2419.6
07/11/2011	39726	20924	34658	19863	>2419.6	>2419.6	>2419.6	7945.2	1158.8	397.8	235.6	130	>2419.6
14/11/2011	>2419.6	12997	10462	12098	>2419.6	>2419.6	14136	>2419.6	1413.6	1203.3	461.1	248.9	>2419.6
14/11/2011	37726	13734	15402	12033	>2419.6	>2419.6	19608	4813.2	1158.8	922.2	197.4	155.2	>2419.6
21/11/2011	12033	2046	12033	5231	>2419.6	9931.5	9208	3106.2	1299.7	2419.6	325.5	365.4	>2419.6
21/11/2011	9222	7746	13734	5172	>2419.6	10462	8704	3683.2	1373.4	3465.8	334.8	496.2	>2419.6
28/11/2011	5745	2755	461.1	3065.5	>2419.6	1454.5	3076	3972.6	1732.9	>2419.6	488.4	275.5	>2419.6
28/11/2011	4978	4494	7308	2359	31062	2014	4494	3683.2	449.4	4839.2	551	164	>2419.6
05/12/2011	5794	2046	12033	2897	4611	1627.5	3654	3106.2	>2419.6	>2419.6	387.3	195.6	>2419.6
05/12/2011	8704	3214	7308	3255	5226	987	4962	2595.2	>2419.6	>2419.6	323.2	235.6	_
12/12/2011	7270	6794	3654	1179.5	3255	719.5	2755	3972.6	>2419.6	>2419.6	>2419.6	>2419.6	>2419.6
12/12/2011	6510	6896	5818	1650	5510	813	4494	1642.4	>2419.6	>2419.6	>2419.6	3972.6	>2419.6

Note: All data as MPN/100ml
Blank Cells / _ = No Data
Over Range Data = >2419.6
For each sample date, lower dilution is on top

Flow Sequence
Raw - Cell 1
Raw - Cell 3 - Cell 5
Raw - Cell 7 - Cell 8
Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2

Selected Results for Total Coliforms Calculations

Total Coliforms	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
10/10/2011	**>2419.6**	_	_	_	_	_	**>2419.6**	**>2419.6**	**>2419.6**	**>2419.6**	**224.7**	**1**	_
11/10/2011	**>2419.6**	_	_	_	_	_	**>2419.6**	4479.6	_	_	_	_	**>2419.6**
17/10/2011	**>2419.6**	**>2419.6**	**17329**	**>2419.6**	**>2419.6**	**>2419.6**	**9804**	6931.6	3972.6	**1986.3**	**488.4**	**307.6**	_
24/10/2011	10950	**7701**	**12033**	**6498.5**	**3076**	**4604**	**15531**	**2092.4**	**307.6**	**>2419.6**	**816.4**	**158.5**	**>2419.6**
07/11/2011	**24196**	20924	**19863**	19863	**>2419.6**	**>2419.6**	**>2419.6**	7945.2	**1119.9**	**461.1**	**240**	**121.1**	**>2419.6**
14/11/2011	37726	**12997**	**10462**	**12098**	**>2419.6**	**>2419.6**	**14136**	4813.2	**1413.6**	**1203.3**	**461.1**	**248.9**	**>2419.6**
21/11/2011	**12033**	**2046**	**12033**	**5231**	**>2419.6**	**9931.5**	**9208**	**3106.2**	**1299.7**	**2419.6**	**325.5**	**365.4**	**>2419.6**
28/11/2011	**5745**	**2755**	**461.1**	**3065.5**	31062	**1454.5**	**3076**	**3972.6**	**1732.9**	4839.2	**488.4**	**275.5**	**>2419.6**
05/12/2011	**5794**	**2046**	**12033**	**2897**	**4611**	**1627.5**	**3654**	**3106.2**	**>2419.6**	**>2419.6**	**387.3**	**195.6**	**>2419.6**
12/12/2011	**7270**	**6794**	**3654**	**1179.5**	**3255**	**719.5**	**2755**	**3972.6**	**>2419.6**	**>2419.6**	**>2419.6**	3972.6	**>2419.6**

Note: Possible outlier data, 31062 MPN/100ml, Cell 7, 28/11/2011

Selected Results for Total Coliforms Calculations

Total Coliforms	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Medium	Leachate	Compost - coarse	Timber Chip	Stratified sand / grit / gravel	Timber Chip	Timber Chip	Compost (coarse) & Timber Chip	Compost (coarse) & Timber Chip	Vertical Flow Reed Bed *(Phragmites)*	Vertical Flow Reed Bed *(Typha)*	Vegetated Grass Plane	Vegetated Grass Plane	
10/10/2011	>2419.6	_	_	_	_	_	>2419.6	>2419.6	>2419.6	>2419.6	224.7	1	_
11/10/2011	>2419.6	_	_	_	_	_	>2419.6	4479.6	_	_	_	_	>2419.6
17/10/2011	>2419.6	>2419.6	17329	>2419.6	>2419.6	>2419.6	9804	6931.6	3972.6	1986.3	488.4	307.6	_
24/10/2011	10950	7701	12033	6498.5	3076	4604	15531	2092.4	307.6	>2419.6	816.4	158.5	>2419.6
07/11/2011	24196	20924	19863	19863	>2419.6	>2419.6	>2419.6	7945.2	1119.9	461.1	240	121.1	>2419.6
14/11/2011	37726	12997	10462	12098	>2419.6	>2419.6	14136	4813.2	1413.6	1203.3	461.1	248.9	>2419.6
21/11/2011	12033	2046	12033	5231	>2419.6	9931.5	9208	3106.2	1299.7	3465.8	325.5	365.4	>2419.6
28/11/2011	5745	2755	461.1	3065.5	31062	1454.5	3076	3972.6	1732.9	4839.2	488.4	275.5	>2419.6
05/12/2011	5794	2046	12033	2897	4611	1627.5	3654	3106.2	>2419.6	>2419.6	387.3	195.6	>2419.6
12/12/2011	7270	6794	3654	1179.5	3255	719.5	2755	3972.6	>2419.6	>2419.6	>2419.6	3972.6	>2419.6
Average	14816	7895	10077	7262	3647	3667	8060	4144	1175	2492	453	763	
St Dev	11945	6975	6339	6590	839	3803	5770	1885	534	2020	200	1418	
Max	37726	20924	19863	19863	4611	9932	15531	7945	1733	4839	816	3973	
Min	5745	2046	461	1180	3076	720	2755	2092	308	461	240	121	
n	7	7	7	7	3	5	6	7	5	4	6	7	7

Note: Calculations based on data from 17/10/11 to 12/12/11
Over Range Data (>2419.6) not included in calculations
Excluding outlier data for 17/10/2011 and 28/11/11 for Cell 7
For the purpose of calculation, MPN/100 ml < 1 is represented as 1 MPN/100 ml

Total Coliforms	Raw	Cell 1	Cell 3	Cell 5	Cell 7	Cell 8	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2	Tramore River
Average	14816	7895	10077	7262	3647	3667	8060	4144	1175	2492	453	763	NA
St Dev	11945	6975	6339	6590	839	3803	5770	1885	534	2020	200	1418	NA
Max	37726	20924	19863	19863	4611	9932	15531	7945	1733	4839	816	3973	NA
Min	5745	2046	461	1180	3076	720	2755	2092	308	461	240	121	NA
n	7	7	7	7	3	5	6	7	5	4	6	7	NA

Raw - Cell 1		
Total Coliforms	Raw	Cell 1
Average	14816	7895
St Dev	11945	6975
Max	37726	20924
Min	5745	2046
n	7	7

Raw - Cell 1 Cumulative Removal (%)	
Total Coliforms	Cell 1
24/10/2011	30
07/11/2011	14
14/11/2011	66
21/11/2011	83
28/11/2011	52
05/12/2011	65
12/12/2011	7
Average	45

Raw - Cell 3 - Cell 5			
Total Coliforms	Raw	Cell 3	Cell 5
Average	14816	10077	7262
St Dev	11945	6339	6590
Max	37726	19863	19863
Min	5745	461	1180
n	7	7	7

Raw - Cell 3 - Cell 5 Cumulative Removal Efficiency (%)		
Total Coliforms	Cell 3	Cell 5
24/10/2011	-10	41
07/11/2011	18	18
14/11/2011	72	68
21/11/2011	0	57
28/11/2011	92	47
05/12/2011	-108	50
12/12/2011	50	84
Average	16	52

Raw - Cell 7 - Cell 8			
Total Coliforms	Raw	Cell 7	Cell 8
Average	14816	3647	3667
St Dev	11945	839	3803
Max	37726	4611	9932
Min	5745	3076	720
n	7	3	5

Raw - Cell 7 - Cell 8 Cumulative Removal Efficiency (%)		
Total Coliforms	Cell 7	Cell 8
24/10/2011	72	58
07/11/2011		
14/11/2011		
21/11/2011		17.5
28/11/2011		75
05/12/2011	20	72
12/12/2011	55	90
Average	49	62

Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2							
Total Coliforms	Raw	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2
Average	14816	8060	4144	1175	2492	453	763
St Dev	11945	5770	1885	534	2020	200	1418
Max	37726	15531	7945	1733	4839	816	3973
Min	5745	2755	2092	308	461	240	121
n	7	6	7	5	4	6	7

Raw - Cell 9 - Cell 10 - VF 1 - VF 2 - VP 1 - VP 2 - Cumulative Removal Efficiency (%)						
Total Coliforms	Cell 9	Cell 10	VF 1	VF 2	VP 1	VP 2
24/10/2011	-42	81	97		92.5	98.6
07/11/2011		67	95	98.1	99.0	99.5
14/11/2011	63	87	96	96.8	98.8	99.3
21/11/2011	23	74	89	71.2	97.3	97.0
28/11/2011	46	31	70	15.8	91.5	95.2
05/12/2011	37	46			93.3	96.6
12/12/2011	62	45				45.4
Average	32	62	90	70	95	90

Note: Excluding outlier data (12/12/2011 of 45.4%), 97.7% Cumulative Treatment Efficiency achieved in VP 2

APPENDIX 1 B

Results from External Laboratory Testing

- List I and II Substances
- Toxicological Analysis

ENVIRONMENTAL LABORATORY SERVICES
Acorn Business Campus,
Mahon Industrial Park,
Blackrock,
CorkTel: 021-4536141
Fax: 021-4536149

Supplement to Analysis Report Rev A

Attention:
Kevin Ryan
Cork City Council
Kinsale Road Landfill,
Cork.

Fax No: 021-320884
Tel No: 021-4705924 / 086-8152765
PO Number: 283369
Sample Type Wastewater

Condition on receipt Satisfactory

Report No: 14076
Date of receipt: 29/06/2009
Date Started: 01/07/2009
Issue Date: 29/07/2009
Page 1 **of** 3
Delivery Mode Hand
No. of Samples 7

Client Ref: Below

Test No	Parameter	Test Method
00130	Metals	EM130 ICP-MS
00025	Volatile Organic Compounds	EO 025 Purge and Trap/GC/MS
00129	SVOC-Pesticides/PAHs Screen	EO 129 By SPE, GC/MS Detection

ELS Ref	Client Ref	Boron mg/l	Mercury ug/l
14076-1	Raw	1.36	<0.02
14076-2	Raw Active	<0.02	<0.02
14076-3	Cell 1	1.39	<0.02
14076-4	Cell 3	1.14	<0.02
14076-5	Cell 9	1.26	<0.02
14076-6	VP2	1.00	<0.02
14076-7	Tramore River	0.14	<0.02

SUPPLEMENT DETAILS
This report replaces report 14076 issued 15/07/09.The VOC results for samples -1,2 were mixed up.

Technical Manager (or Deputy) Brendan Murray 29/07/2009

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SVOC Pesticides and PAH

Chlorinated Pesticides, PCB	LOD (ug/l)	14076-1	14076-2	14076-3	14076-4	14076-5	14076-6	14076-7
Aldrin	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dieldrin	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Heptachlor	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Heptachlor Epoxide	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
alpha-BHC	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
beta-BHC	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
delta-BHC	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Endosulfan I	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Endosulfan II	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Endosulfan Sulfate	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Endrin	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Endrin Aldehyde	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Gamma-BHC (Lindane)	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
4,4-DDD	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
4-4-DDE	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
4,4-DDT	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Organophosphorus Pesticides								
Thionazin	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dimethoate	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Parathion	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Disulfoton	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Sulfotepp	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Triethy phosphorothioate	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Methyl parathion	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Famphur	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Phorate	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Acid Herbicides								
Acifluorfen	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Bentazon	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Chloroamben	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
2,4-D	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dalapon	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
2,4-DB	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
DCPA Diacid	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dicamba	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
3,5-Dochlorobenzoic acid	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dichloroprop	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dinoseb	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Pentachlorophenol	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Picloram	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
2,4,5-T	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Triazines								
Atrazine	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Simazine	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
PAH								
Acenaphthene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Acenaphthylene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Anthracene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Benzo -a-pyrene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Benzo(b)fluoranthene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Benzo(g,h,i)perylene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Benzo(k)fluoranthene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Chrysene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Dibenzo(a,h)anthracene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Fluoranthene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Fluorene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Indeno(1,2,3-cd)pyrene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Naphthalene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Phenanthrene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Pyrene	0.01	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025

NOTES
1. LOD rasied due to sample volume extracted.

Appendix A

EO 025 Determination of Volatile Organic Carbons in Water by Purge and Trap/GC/MS

No.	Analyte	LOD	14076-1	14076-2	14076-3	14076-4	14076-5	14076-6	14076-7
		ug/l	Raw	Raw Active (Diluted 1:100)	Cell 1	Cell 3	Cell 9	VP 2	Tramore River
2	Dichlorodifluoromethane	10.0	ND	<1000	ND	ND	ND	ND	ND
3	Chloromethane	0.5	ND	<50	ND	ND	ND	ND	ND
4	Ethyl Chloride/Chloroethane	0.5	ND	<50	ND	ND	ND	ND	ND
5	Vinyl Chloride/Chloroethene	0.5	ND	<50	ND	ND	ND	ND	ND
6	Bromomethane	0.5	ND	<50	ND	ND	ND	ND	ND
8	Trichloromonofluoromethane	0.5	ND	<50	ND	ND	ND	ND	ND
9	Ethyl Ether/Diethyl Ether	0.5	ND	<50	ND	ND	ND	ND	ND
10	11 Dichloroethene	0.5	ND	<50	ND	ND	ND	ND	ND
11	Acetone	2.0	ND	<200	ND	ND	ND	ND	ND
12	Iodomethane/Methyl Iodide	0.5	ND	<50	ND	ND	ND	ND	ND
13	Carbon Disulphide	0.5	ND	<50	ND	ND	ND	ND	ND
14	Allyl Chloride	0.5	ND	<50	ND	ND	ND	ND	ND
15	Methylene Chloride/DCM	5.0	ND	<500	ND	ND	ND	ND	ND
16	2-Propenenitrile/Acrylonitrile	2.0	ND	<200	ND	ND	ND	ND	ND
17	Chlormethyl Cyanide/Chloroacetonitrile	0.5	ND	<50	ND	ND	ND	ND	ND
18	Nitrobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
19	Propanenitrile	10.0	ND	<1000	ND	ND	ND	ND	ND
20	Hexachlorobutadiene	0.5	ND	<50	ND	ND	ND	ND	ND
21	Trans-1,2 Dichloroethene	0.5	ND	<50	ND	ND	ND	ND	ND
22	MtBE	0.5	ND	<50	ND	ND	ND	ND	ND
23	11 Dichloroethane	0.5	ND	<50	ND	ND	ND	ND	ND
24	22 Dichloropropane	0.5	ND	<50	ND	ND	ND	ND	ND
25	cis-12 Dichloroethene	0.5	ND	<50	ND	ND	ND	ND	ND
26	2-Butanone	5.0	ND	<500	ND	ND	ND	ND	ND
27	Methyl Acrylate	5.0	ND	<500	ND	ND	ND	ND	ND
28	Bromochloromethane	0.5	ND	<50	ND	ND	ND	ND	ND
29	Methacrylonitrile	5.0	ND	<500	ND	ND	ND	ND	ND
30	Tetrahydrofuran	5.0	ND	<500	ND	ND	ND	ND	ND
31	Trichloromethane/ Chloroform¶	1.0	ND	<100	ND	ND	ND	ND	ND
32	111 Trichloroethane	0.5	ND	<50	ND	ND	ND	ND	ND
33	1-Chlorobutane	0.5	ND	<50	ND	ND	ND	ND	ND
34	Carbon Tetrachloride	0.5	ND	<50	ND	ND	ND	ND	ND
35	11 Dichloropropene	0.5	ND	<50	ND	ND	ND	ND	ND
36	Benzene	0.1	ND	<10	ND	ND	ND	ND	ND
37	12 Dichloroethane	0.1	ND	<10	ND	ND	ND	ND	ND
39	Trichloroethylene/ Trichloroethene	0.1	ND	<10	ND	ND	ND	ND	ND
40	12 Dichloropropane	0.5	ND	<50	ND	ND	ND	ND	ND
41	Dibromomethane	0.5	ND	<50	ND	ND	ND	ND	ND
42	Methyl Methacrylate	0.5	ND	<50	ND	ND	ND	ND	ND
43	Bromodichloromethane	2.0	ND	<200	ND	ND	ND	ND	ND
44	13 Dichloropropene,cis	2.0	ND	<200	ND	ND	ND	ND	ND
45	MIBK/4 Methyl 2 Pentanone	2.0	ND	<200	ND	ND	ND	ND	ND
46	Toluene	0.5	ND	<50	ND	ND	ND	ND	ND
47	13 Dichloropropene,trans	2.0	ND	<200	ND	ND	ND	ND	ND
48	Ethyl Methacrylate	2.0	ND	<200	ND	ND	ND	ND	ND
49	112 Trichloroethane	0.5	ND	<50	ND	ND	ND	ND	ND
50	Tetrachloroethylene/ Tetrachloroethene	0.1	ND	<10	ND	ND	ND	ND	ND
51	13 Dichloropropane	0.5	ND	<50	ND	ND	ND	ND	ND
52	2-Hexanone	1.0	ND	<100	ND	ND	ND	ND	ND
53	Dibromochloromethane	1.0	ND	<100	ND	ND	ND	ND	ND
54	12 Dibromoethane	0.5	ND	<50	ND	ND	ND	ND	ND
55	Chlorobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
56	1112 Tetrachloroethane	2.0	ND	<200	ND	ND	ND	ND	ND
57	Ethyl Benzene	0.5	ND	<50	ND	ND	ND	ND	ND
58	m & p Xylene	0.5	ND	<50	ND	ND	ND	ND	ND
59	o Xylene	0.5	ND	<50	ND	ND	ND	ND	ND
60	Styrene	2.0	ND	<200	ND	ND	ND	ND	ND
61	Bromoform	1.0	ND	<100	ND	ND	ND	ND	ND
62	Isopropyl Benzene	0.5	ND	<50	ND	ND	ND	ND	ND
63	Bromobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
64	1122 Tetrachloroethane	0.5	ND	<50	ND	ND	ND	ND	ND
65	123 Trichloropropane	2.0	ND	<200	ND	ND	ND	ND	ND
66	Trans 14 Dichloro 2 Butene, tran	2.0	ND	<200	ND	ND	ND	ND	ND
67	Propyl Benzene	0.5	ND	<50	ND	ND	ND	ND	ND
68	2-Chlorotoluene	0.5	ND	<50	ND	ND	ND	ND	ND
69	4 Chlorotoluene	0.5	ND	<50	ND	ND	ND	ND	ND
70	135 Trimethylbenzene	0.5	ND	<50	ND	ND	ND	ND	ND
71	Tert Butyl Benzene	0.5	ND	<50	ND	ND	ND	ND	ND
72	124 Trimethylbenzene	0.5	ND	<50	ND	ND	ND	ND	ND
73	Sec Butyl Benzene	0.5	ND	<50	ND	ND	ND	ND	ND
74	13 Dichlorobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
75	P Isopropyltoluene	0.5	ND	<50	ND	ND	ND	ND	ND
76	14 Dichlorobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
77	12 Dichlorobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
78	N Butyl Benzene	0.5	ND	<50	ND	ND	ND	ND	ND
79	Hexachloroethane	5.0	ND	<500	ND	ND	ND	ND	ND
80	12 Dibromo 3 Chloropropane	2.0	ND	<200	ND	ND	ND	ND	ND
81	124 Trichlorobenzene	0.5	ND	<50	ND	ND	ND	ND	ND
82	Napththalene	2.0	ND	<200	ND	ND	ND	ND	ND
83	123 Trichlorobenzene	0.50	ND	<50	ND	ND	ND	ND	ND

NOTES

1. ND=Concentration was below the limit of detectio
2. Reporting limit raised for 14076-2 as sample was very dirty and required 1:100 dilution for analysi

ENVIRONMENTAL LABORATORY SERVICES
Acorn Business Campus,
Mahon Industrial Park,
Blackrock,
CorkTel: 021-4536141
Fax: 021-4536149

Analysis Report

Attention:		**Report No:**	18240
Kevin Ryan			
Cork City Council (Kinsale Rd)		**Date of receipt:**	17/08/2010
Kinsale Road Landfill,		**Date Started:**	23/08/2010
Cork.			
Fax No:	021-320884	**Issue Date:**	01/09/2010
Tel No:	021-4705911 / 086 8152765	**Page**	1 of 4
PO Number:	320671	**Delivery Mode**	Hand
Sample Type	Waste Water	**No. of Samples**	15
Condition on receipt	Satisfactory	**Client Ref:**	Below

QN2205 Cork City Council Leachate Testing

SIGNED (01/09/2010)

Technical Manager (or Deputy)
Brendan Murray

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Method		ICPMS		Purge & Trap	GCMS
Method Number		EM130		EO025	EO129
Parameter		Hg	B	VOC	GCMS Full suite
Units		ug/l	mg/l	ug/l	ug/l
Limit of Detection		0.02	0.02	Pg4	P3
Date Testing Initiated		23/08		24/08	24/08
ELS Ref	Client Ref				
18240-1	Raw	<0.02	1.34	Pg4	Pg3
18240-2	Cell 1	<0.02	1.33	Pg4	Pg3
18240-3	Cell 3	<0.02	1.24	Pg4	Pg3
18240-4	Cell 4	<0.02	1.69	Pg4	Pg3
18240-5	Cell 7	<0.02	0.28	Pg4	Pg3
18240-6	Cell 8	<0.02	1.17	Pg4	Pg3
18240-7	Cell 9	<0.02	1.13	Pg4	Pg3
18240-8	Cell 10	<0.02	1.63	Pg4	Pg3
18240-9	VF 1	<0.02	1.83	Pg4	Pg3
18240-10	VF 2	<0.02	1.99	Pg4	Pg3
18240-11	VP 1	<0.02	0.93	Pg4	Pg3
18240-12	VP 2	0.04	1.71	Pg4	Pg3
18240-13	N 1	<0.02	0.31	Pg4	Pg3
18240-14	N 4	<0.02	1.14	Pg4	Pg3
18240-15	Raw Active	0.16	1.49	Pg4	Pg3

NOTES

1 Sub-contract analysis denoted by *

2 ND = Concentration was below the limit of detection

Pesticides and PAH

Chlorinated Pesticides, PCB	LOD (ug/l)	18240-1	18240-2	18240-3	18240-4	18240-5	18240-6	18240-7	18240-8	18240-9	18240-10	18240-11	18240-12	18240-13	18240-14	18240-15
Aldrin	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dieldrin	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Heptachlor	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Heptachlor Epoxide	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
alpha-BHC	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
beta-BHC	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
delta-BHC	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endosulfan I	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endosulfan II	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endosulfan Sulfate	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endrin	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Endrin Aldehyde	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Gamma-BHC (Lindane)	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4,4-DDD	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4-4-DDE	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
4,4-DDT	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Organophosphorus Pesticides																
Thionazin	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dimethoate	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Parathion	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Triethy phosphorothioate	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Methyl parathion	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Famphur	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Acid Herbicides																
2,4-D	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dalapon	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
2,4-DB	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dichloroprop	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dinoseb	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Pentachlorophenol	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Picloram	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
2,4,5-T	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Triazines																
Atrazine	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Simazine	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
PAH																
Benzo-a-pyrene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Benzo(b)fluoranthene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Benzo(k)fluoranthene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Benzo(g,h,i)perylene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Indeno(1,2,3-cd)pyrene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Naphthalene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Acenaphthylene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Acenaphthene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Fluorene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Phenanthrene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Anthracene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Fluoranthene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Pyrene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chrysene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dibenzo(a,h)anthracene	0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

NOTES

1. ND = Concentration was below the limit of detection

Appendix A

EO 025 Determination of Volatile Organic Carbons in Water by Purge and Trap/GC/MS

No.	Analyte	LOD	18240-1	18240-2	18240-3	18240-4	18240-5	18240-6	18240-7	18240-8	18240-9	18240-10	18240-11	18240-12	18240-13	18240-14	18240-15
		ug/l															
2	Dichlorodifluoromethane	10.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
3	Chloromethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
4	Ethyl Chloride/Chloroethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
5	Vinyl Chloride/Chloroethene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
6	Bromomethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
8	Trichloromonofluoromethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
9	Ethyl Ether/Diethyl Ether	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
10	11 Dichloroethene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
11	Acetone	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	476.9	N.D	39.0
12	Iodomethane/Methyl Iodide	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
13	Carbon Disulphide	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
14	Allyl Chloride	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
15	Methylene Chloride/DCM	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
16	2-Propenenitrile/Acrylonitrile	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
17	Chlormethyl Cyanide/Chloroacetonitrile	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
18	Nitrobenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
19	Propanenitrile	10.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
20	Hexachlorobutadiene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
21	Trans-1,2 Dichloroethene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
22	MtBE	0.5	4.0	N.D	2.6	N.D	N.D	N.D	1.7	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
23	11 Dichloroethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
24	22 Dichloropropane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
25	cis-12 Dichloroethene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
26	2-Butanone	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
27	Methyl Acrylate	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
28	Bromochloromethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
29	Methacrylonitrile	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
30	Tetrahydrofuran	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
31	Trichloromethane/ Chloroform*	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
32	111 Trichloroethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
33	1-Chlorobutane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
34	Carbon Tetrachloride	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
35	11 Dichloropropene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
36	Benzene	0.1	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
37	12 Dichloroethane	0.1	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
39	Trichloroethylene/ Trichloroethene	0.1	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
40	12 Dichloropropane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
41	Dibromomethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
42	Methyl Methacrylate	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
43	Bromodichloromethane	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
44	13 Dichloropropene,cis	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
45	MIBK/4 Methyl 2 Pentanone	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
46	Toluene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	2.3	N.D	N.D
47	13 Dichloropropene,trans	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
48	Ethyl Methacrylate	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
49	112 Trichloroethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
50	Tetrachloroethylene/ Tetrachloroethene	0.1	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
51	13 Dichloropropane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
52	2-Hexanone	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
53	Dibromochloromethane	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
54	12 Dibromoethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
55	Chlorobenzene	0.5	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
56	1112 Tetrachloroethane	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
57	Ethyl Benzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
58	m & p Xylene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	2.7	N.D	N.D
59	o Xylene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	1.9	N.D	N.D
60	Styrene	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
61	Bromoform	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
62	Isopropyl Benzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
63	Bromobenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
64	1122 Tetrachloroethane	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
65	123 Trichloropropane	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
66	Trans 14 Dichloro 2 Butene, tra	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
67	Propyl Benzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
68	2-Chlorotoluene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
69	4 Chlorotoluene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
70	135 Trimethylbenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
71	Tert Butyl Benzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
72	124 Trimethylbenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
73	Sec Butyl Benzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
74	13 Dichlorobenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
75	P Isopropyltoluene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
76	14 Dichlorobenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
77	12 Dichlorobenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
78	N Butyl Benzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
79	Hexachloroethane	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
80	12 Dibromo 3 Chloropropane	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
81	124 Trichlorobenzene	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
82	Napthalene	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
83	123 Trichlorobenzene	0.50	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

NOTES
1. ND=Concentration was below the limit of detection

ENVIRONMENTAL LABORATORY SERVICES
Acorn Business Campus,
Mahon Industrial Park,
Blackrock,
CorkTel: 021-4536141
Fax: 021-4536149

Analysis Report

Attention:
Kevin Ryan
Cork City Council (Kinsale Rd)
Kinsale Road Landfill,
Cork.

Fax No:	021-320884
Tel No:	021-4705924
PO Number:	320671
Sample Type	Surface Water
Condition on receipt	Satisfactory

Report No:	18263
Date of receipt:	17/08/2010
Date Started:	26/08/2010
Issue Date:	01/09/2010
Page	1 **of** 4
Delivery Mode	Hand
No. of Samples	1
Client Ref:	Below

QN2205 Cork City Council Leachate Testing

SIGNED (01/09/2010)

Technical Manager (or Deputy)
Brendan Murray

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Method		ICPMS		Purge & Trap	GCMS
Method Number		EM130		EO025	EO129
Parameter		Hg	B	VOC	GCMS Full suite
Units		ug/l	mg/l	ug/l	ug/l
Limit of Detection		0.02	0.02	Pg4	P3
Date Testing Initiated		23/08		24/08	24/08
ELS Ref	**Client Ref**				
18263-1	Tramore	<0.02	0.03	Pg4	Pg3

NOTES

1 Sub-contract analysis denoted by *

2 ND = Concentration was below the limit of detection

Pesticides and PAH

Chlorinated Pesticides, PCB	LOD (ug/l)	18263-1
Aldrin	0.05	<0.05
Dieldrin	0.05	<0.05
Heptachlor	0.05	<0.05
Heptachlor Epoxide	0.05	<0.05
alpha-BHC	0.05	<0.05
beta-BHC	0.05	<0.05
delta-BHC	0.05	<0.05
Endosulfan I	0.05	<0.05
Endosulfan II	0.05	<0.05
Endosulfan Sulfate	0.05	<0.05
Endrin	0.05	<0.05
Endrin Aldehyde	0.05	<0.05
Gamma-BHC (Lindane)	0.05	<0.05
4,4-DDD	0.05	<0.05
4-4-DDE	0.05	<0.05
4,4-DDT	0.05	<0.05
Organophosphorus Pesticides		
Thionazin	0.05	<0.05
Dimethoate	0.05	<0.05
Parathion	0.05	<0.05
Triethy phosphorothioate	0.05	<0.05
Methyl parathion	0.05	<0.05
Famphur	0.05	<0.05
Acid Herbicides		
2,4-D	0.05	<0.05
Dalapon	0.05	<0.05
2,4-DB	0.05	<0.05
Dichloroprop	0.05	<0.05
Dinoseb	0.05	<0.05
Pentachlorophenol	0.05	<0.05
Picloram	0.05	<0.05
2,4,5-T	0.05	<0.05
Triazines		
Atrazine	0.05	<0.05
Simazine	0.05	<0.05
PAH		
Benzo-a-pyrene	0.05	<0.05
Benzo(b)fluoranthene	0.05	<0.05
Benzo(k)fluoranthene	0.05	<0.05
Benzo(g,h,i)perylene	0.05	<0.05
Indeno(1,2,3-cd)pyrene	0.05	<0.05
Naphthalene	0.05	<0.05
Acenaphthylene	0.05	<0.05
Acenaphthene	0.05	<0.05
Fluorene	0.05	<0.05
Phenanthrene	0.05	<0.05
Anthracene	0.05	<0.05
Fluoranthene	0.05	<0.05
Pyrene	0.05	<0.05
Chrysene	0.05	<0.05
Dibenzo(a,h)anthracene	0.05	<0.05

NOTES
1. ND = Concentration was below the limit of detection
2. Not accredited due to QC breach

Appendix A

EO 025 Determination of Volatile Organic Carbons in Water by Purge and Trap/GC/MS

No.	Analyte	LOD	18263-1
		ug/l	
2	Dichlorodifluoromethane	10.0	N.D
3	Chloromethane	0.5	N.D
4	Ethyl Chloride/Chloroethane	0.5	N.D
5	Vinyl Chloride/Chloroethene	0.5	N.D
6	Bromomethane	0.5	N.D
8	Trichloromonofluoromethane	0.5	N.D
9	Ethyl Ether/Diethyl Ether	0.5	N.D
10	11 Dichloroethene	0.5	N.D
11	Acetone	2.0	N.D
12	Iodomethane/Methyl Iodide	0.5	N.D
13	Carbon Disulphide	0.5	N.D
14	Allyl Chloride	0.5	N.D
15	Methylene Chloride/DCM	5.0	N.D
16	2-Propenenitrile/Acrylonitrile	2.0	N.D
17	Chlormethyl Cyanide/Chloroacetonitril	0.5	N.D
18	Nitrobenzene	0.5	N.D
19	Propanenitrile	10.0	N.D
20	Hexachlorobutadiene	0.5	N.D
21	Trans-1,2 Dichloroethene	0.5	N.D
22	MtBE	0.5	N.D
23	11 Dichloroethane	0.5	N.D
24	22 Dichloropropane	0.5	N.D
[illegible]	cis-12 Dichloroethene	0.5	N.D
26	2-Butanone	5.0	N.D
27	Methyl Acrylate	5.0	N.D
28	Bromochloromethane	0.5	N.D
29	Methacrylonitrile	5.0	N.D
30	Tetrahydrofuran	5.0	N.D
31	Trichloromethane/ Chloroform*	1.0	1.1
32	111 Trichloroethane	0.5	N.D
33	1-Chlorobutane	0.5	N.D
34	Carbon Tetrachloride	0.5	N.D
35	11 Dichloropropene	0.5	N.D
36	Benzene	0.1	N.D
37	12 Dichloroethane	0.1	N.D
39	Trichloroethylene/ Trichloroethene	0.1	N.D
40	12 Dichloropropane	0.5	N.D
41	Dibromomethane	0.5	N.D
42	Methyl Methacrylate	0.5	N.D
43	Bromodichloromethane	2.0	N.D
44	13 Dichloropropene,cis	2.0	N.D
45	MIBK/4 Methyl 2 Pentanone	2.0	N.D
46	Toluene	0.5	N.D
47	13 Dichloropropene,trans	2.0	N.D
48	Ethyl Methacrylate	2.0	N.D
49	112 Trichloroethane	0.5	N.D
50	Tetrachloroethylene/ Tetrachloroethene	0.1	N.D
51	13 Dichloropropane	0.5	N.D
52	2-Hexanone	1.0	N.D
53	Dibromochloromethane	1.0	N.D
54	12 Dibromoethane	0.5	N.D
55	Chlorobenzene	0.5	N.D
56	1112 Tetrachloroethane	2.0	N.D
[illegible]	Ethyl Benzene	0.5	N.D
[illegible]	m & p Xylene	0.5	N.D
59	o Xylene	0.5	N.D
60	Styrene	2.0	N.D
61	Bromoform	1.0	N.D
62	Isopropyl Benzene	0.5	N.D
63	Bromobenzene	0.5	N.D
64	1122 Tetrachloroethane	0.5	N.D
65	123 Trichloropropane	2.0	N.D
66	Trans 14 Dichloro 2 Butene, tran	2.0	N.D
67	Propyl Benzene	0.5	N.D
68	2-Chlorotoluene	0.5	N.D
69	4 Chlorotoluene	0.5	N.D
70	135 Trimethylbenzene	0.5	N.D
71	Tert Butyl Benzene	0.5	N.D
72	124 Trimethylbenzene	0.5	N.D
73	Sec Butyl Benzene	0.5	N.D
74	13 Dichlorobenzene	0.5	N.D
75	P Isopropyltoluene	0.5	N.D
76	14 Dichlorobenzene	0.5	N.D
77	12 Dichlorobenzene	0.5	N.D
78	N Butyl Benzene	0.5	N.D
79	Hexachloroethane	5.0	N.D
80	12 Dibromo 3 Chloropropane	2.0	N.D
81	124 Trichlorobenzene	0.5	N.D
82	Napththalene	2.0	N.D
83	123 Trichlorobenzene	0.50	N.D

NOTES

1. ND=Concentration was below the limit of detectio



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CONFIDENTIAL REPORT
SHANNON AQUATIC TOXICITY LABORATORY

Front Cover Report Sheet

Dept. Toxicity
Sheet no. 1 of 12 sheets

Tox F020 Ver. 2.2

Customer
Cork City Council
Kinsale Road Landfill Site
Landfill Office
Cork

Title
Toxicological analysis of seven samples

Attn: Mr. Kevin Ryan

Report reference: 09T070

Order no.:

Report by: Robert Hernan

Date received: 30.06.09

Approved by: Jim Clancy
Head of Department

Copies to: R.6. Files

Date of issue: 06.07.09

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SHANNON AQUATIC TOXICITY LABORATORY

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TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: Raw, 29.06.09

Tox. Ref. No.: 09T070-1

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	19.5	5.1	17.1-22.5	Moving Average
5 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*
100% of the *Daphnia* were immobilized at 32% vol./vol.
25% of the *Daphnia* were immobilized at 18% vol./vol.
5% of the *Daphnia* were immobilized at 10% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Less than 21% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: Raw active, 29.06.09

Tox. Ref. No.: 09T070-2

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	7.5	13.3	6.6-8.5	Probit
5 min EC_{50} to *Vibrio fischeri*	1.89	52.9	1.4-2.5	Microtox
15 min EC_{50} to *Vibrio fischeri*	1.44	69.4	0.40-5.20	Microtox

Comments:

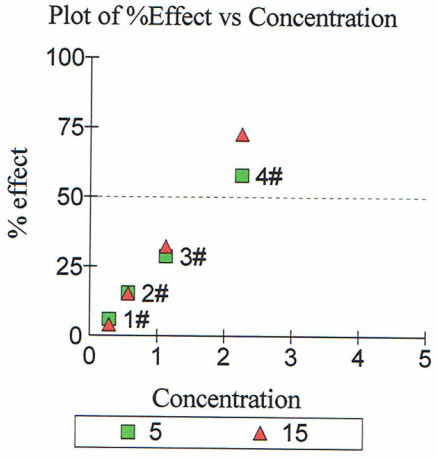
48 h EC_{50} to *Daphnia magna*
90% of the *Daphnia* were immobilized at 10% vol./vol.
10% of the *Daphnia* were immobilized at 5.6% vol./vol.
No *Daphnia* were immobilized at 3.2% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Vibrio test report is presented on the next page.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

Date: - -

Test Protocol: Basic-type Test
Sample: 09T070-2
Toxicant:
Reagent Lot no.:
Test description: -
Data File: 09T070-2b.K5; 09T070-2b.K15;



			5 Mins Data:			15 Mins Data:		
Sample	Conc	Io	It	Gamma	% effect	It	Gamma	% effect
Control	0.000	95.25	80.46	0.8447 #		74.99	0.7873 #	
1	0.2813	85.31	67.70	0.0644 #	6.055%	64.47	0.0417 *	4.011%
2	0.5625	83.47	59.45	0.1860 #	15.68%	55.55	0.1830 #	15.47%
3	1.125	80.76	48.60	0.4037 #	28.76%	43.11	0.4749 #	32.20%
4	2.250	87.58	31.17	1.373 #	57.87%	18.89	2.650 #	72.60%

- used in calculation; * - invalid data; D - deleted from calcs.

Calculations on 5 Mins data:
EC50 Concentration:1.893% (95% confidence range: 1.414 to 2.534)
95% Confidence Factor: 1.339
Estimating Equation:LOG C =0.6918 x LOG G +0.2772
Coeff. of Determination (R^2):0.9932
Slope: 1.436
Correction Factor: 0.8447

Calculations on 15 Mins data:
EC50 Concentration:1.440% (95% confidence range: 0.3992 to 5.197)
95% Confidence Factor: 3.608
Estimating Equation:LOG C =0.5048 x LOG G +0.1585
Coeff. of Determination (R^2):0.9734
Slope: 1.928
Correction Factor: 0.7873

Signature: RHernan, 1.7.09

Printed: 01/07/2009 04:42 PM

SHANNON AQUATIC TOXICITY LABORATORY

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TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: Cell 1, 29.06.09

Tox. Ref. No.: 09T070-3

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	34.6	2.9	30.4-39.7	Moving Average
5 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*
100% of the *Daphnia* were immobilized at 56% vol./vol.
25% of the *Daphnia* were immobilized at 32% vol./vol.
5% of the *Daphnia* were immobilized at 18% vol./vol.
No *Daphnia* were immobilized at 10% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Less than 19% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: Cell 3, 29.06.09

Tox. Ref. No.: 09T070-4

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	74.8	1.3	n/a	Binomial
5 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*
100% of the *Daphnia* were immobilized at 100% vol./vol.
No *Daphnia* were immobilized at 56% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Less than 5% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: Cell 9, 29.06.09

Tox. Ref. No.: 09T070-5

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

	Test Results			
Test Parameter	**Concentration % vol./vol.**	**Toxic Units**	**95% Confidence Limits % vol./vol.**	**Method of Calculation**
48 h EC_{50} to *Daphnia magna*	31.9	3.1	27.0-39.1	Moving Average
5 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*
100% of the *Daphnia* were immobilized at 56% vol./vol.
25% of the *Daphnia* were immobilized at 32% vol./vol.
10% of the *Daphnia* were immobilized at 18% vol./vol.
5% of the *Daphnia* were immobilized at 10% vol./vol.
No *Daphnia* were immobilized at 5.6% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Less than 21% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: VP2

Tox. Ref. No.: 09T070-6

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

	Test Results			
Test Parameter	**Concentration % vol./vol.**	**Toxic Units**	**95% Confidence Limits % vol./vol.**	**Method of Calculation**
48 h EC_{50} to *Daphnia magna*	>100	<1	n/a	n/a
5 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*
No *Daphnia* were immobilized at 100% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Less than 11% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

TEST RESULTS

Customer: Cork City Council

Customer sample description: Tramore River, 29.06.09

Tox. Ref. No.: 09T070-7

Test Date: 30.06.09 – *Daphnia magna*
01.07.09 – *Vibrio fischeri*

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	>100	<1	n/a	n/a
5 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*
No *Daphnia* were immobilized at 100% vol./vol.

5,15 min EC_{50} to *Vibrio fischeri*
Less than 4% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-2 Ver 2.2

SAMPLE INFORMATION

	SATL	Customer	Other
Sampled by:	☐	✓	☐
Collected by:	☐	✓	☐

Tox Ref. No.	09T070-1	09T070-2
Sampling procedure	n/a	n/a
Date of analysis	30.06.09	30.06.09
Storage conditions (°C)	3±3	3±3
Temperature (°C)	21.0	21.1
pH	7.4 (at 21.1 °C)	7.4 (at 21.2 °C)
Dissolved oxygen (mg/l)	3.9	<1
Dissolved oxygen (% saturation)	44	<10
Conductivity	5.2 (mS/cm at 25°C)	11.3 (mS/cm at 25°C)
Salinity (ppt at 20°C)	2.7	6.4

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-2 Ver 2.2

SAMPLE INFORMATION

	SATL	Customer	Other
Sampled by:	☐	✓	☐
Collected by:	☐	✓	☐

Tox Ref. No.	09T070-3	09T070-4
Sampling procedure	n/a	n/a
Date of analysis	30.06.09	30.06.09
Storage conditions (°C)	3±3	3±3
Temperature (°C)	21.3	21.4
pH	7.6 (at 21.4 °C)	7.2 (at 21.4 °C)
Dissolved oxygen (mg/l)	4.8	5.4
Dissolved oxygen (% saturation)	54	61
Conductivity	4.2 (mS/cm at 25°C)	3.8 (mS/cm at 25°C)
Salinity (ppt at 20°C)	2.2	1.9

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-2 Ver 2.2

SAMPLE INFORMATION

	SATL	Customer	Other
Sampled by:	☐	✓	☐
Collected by:	☐	✓	☐

Tox Ref. No.	09T070-5	09T070-6	09T070-7
Sampling procedure	n/a	n/a	n/a
Date of analysis	30.06.09	30.06.09	30.06.09
Storage conditions (°C)	3±3	3±3	3±3
Temperature (°C)	21.4	21.4	21.3
pH	7.5 (at 21.4 °C)	7.6 (at 21.5 °C)	7.6 (at 21.5 °C)
Dissolved oxygen (mg/l)	5.6	7.2	8.8
Dissolved oxygen (% saturation)	64	82	99
Conductivity	4.6 (mS/cm at 25°C)	3.4 (mS/cm at 25°C)	409 (µS/cm at 25°C)
Salinity (ppt at 20°C)	2.4	1.6	<1

Toxicity Test Methods and Procedures

1. Freshwater Crustacean
Method 6.1 based on ISO 6341:1996/Cor.1:1998: 'Water quality – Determination of the inhibition of the mobility of *Daphnia magna* Straus (Cladocera, Crustacea) – Acute toxicity test'

2. Marine Bacterium
Method 6.2 based on BS EN ISO 11348-3:1999: 'Water quality - Determination of the inhibitory effect of water samples on the light emission of *Vibrio fischeri* (Luminescent bacteria test) – Part 3: Method using freeze-dried bacteria'

3. Marine Copepod
Method 6.3 based on ISO 14669:1999: 'Water quality – Determination of acute lethal toxicity to marine copepods (*Copepoda, Crustacea*)'

4. Marine Algae
Method 6.4 based on ISO 10253:2006: 'Water quality - Marine algal growth inhibition test with *Skeletonema costatum* and *Phaeodactylum tricornutum'*

5. Freshwater Algae
Method 6.5 based on ISO 8692:2004 : 'Water quality – Freshwater algal growth inhibition test with unicellular green algae' [*Pseudokirchneriella subcapitata*]

6. Freshwater Plant
Method 6.6 based on ISO 20079:2005: 'Water quality – Determination of the toxic effect of water constituents and waste water to duckweed (*Lemna minor*) – Duckweed growth inhibition test'

7. Marine Fish
Method 6.7 based on OECD 1992: Guideline 203: - 'Fish, acute toxicity test'

8. Freshwater Fish
Method 6.8 based on OECD 1992: Guideline 203: - 'Fish, acute toxicity test'

9. Estuarine Crustacean
Method 6.9 based on MAFF SOP No. BEG/030:1996: 'Brown Shrimp (*Crangon crangon*) 96 h acute toxicity for liquid effluents and wastes'

10. Marine Amphipod
Method 6.10 based on ICES, No. 28, 2001: 'Biological effects of contaminants: *Corophium* sp. sediment bioassay and toxicity test'

11. Eluate Generation
Procedure 4.7.8. "Eluate Generation" based on DIN 38 414 part 4, 1984: – 'Sludge and Sediments (Group S) – Determination of leachability by water (S4)'

ENTERPRISE IRELAND

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CONFIDENTIAL REPORT
SHANNON AQUATIC TOXICITY LABORATORY

Front Cover Report Sheet

Dept. Toxicity
Sheet no. 1 of 12 sheets

Tox F020 Ver. 2.2

Customer
Cork City Council
Kinsale Road Landfill Site
Landfill Office
Cork

Title
Toxicological analysis of 8 samples

Attn: Mr. Kevin Ryan

Report reference: 10T091

Order no.: N/A

Report by: Kathleen O' Rourke KORourke

Date received: 16.08.10

Approved by: Robert Hernan

Copies to: R.6. Files

Date of issue: 26.08.10

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Test report relates only to the sample(s) tested

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: Raw, 16.08.10

Tox. Ref. No.: 10T091-1

Test Date: 17.08.10

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	18.2	5.6	15.7-21.1	Maximum Likelihood - Probit
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

100% of the *Daphnia* were immobilized at 32% vol./vol.
40% of the *Daphnia* were immobilized at 18% vol./vol.
5% of the *Daphnia* were immobilized at 10% vol./vol.
No *Daphnia* were immobilized at 5.6% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

Less than 32% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: Raw Active, 16.08.10

Tox. Ref. No.: 10T091-2

Test Date: 17.08.10

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	2.5	40.0	2.3-2.6	Trimmed Spearman-Karber
15 min EC_{50} to *Vibrio fischeri*	1.9	52.6	n/a	Microtox

Comments:

48 h EC_{50} to *Daphnia magna*

100% of the *Daphnia* were immobilized at 5.6% vol./vol.
95% of the *Daphnia* were immobilized at 3.2% vol./vol.
No *Daphnia* were immobilized at 1.8% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

Vibrio test report is presented on the next page.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

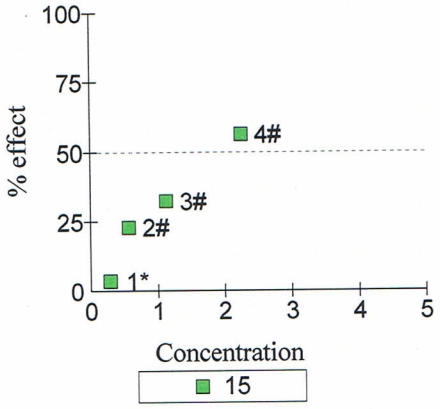
Vibrio Test Report

ENTERPRISE IRELAND

Date: 17/08/2010 02:01 PM

Test Protocol: Basic Test
Sample: 10T091-2
Toxicant: -
Reagent Lot no.:
Test description:
Data File: 10T091-2a.K15;

Plot of %Effect vs Concentration



15 Mins Data:

Sample	Conc	Io	It	Gamma	% effect
Control	0.000	95.05	78.78	0.8288 #	
1	0.2813	99.65	79.60	0.0376 *	3.623%
2	0.5625	111.62	71.34	0.2968 #	22.89%
3	1.125	108.70	60.90	0.4794 #	32.40%
4	2.250	114.15	41.25	1.294 #	56.40%

- used in calculation; * - invalid data; D - deleted from calcs.

Calculations on 15 Mins data:
EC50 Concentration:1.875% (95% confidence range: 0.2725 to 12.90)
95% Confidence Factor: 6.880
Estimating Equation:LOG C =0.9050 x LOG G +0.2729
Coeff. of Determination (R^2):0.9611
Slope: 1.062
Correction Factor: 0.8288

Signature: kORourke 17-8-10

Printed: 17/08/2010 02:11 PM

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: Cell 1, 16.08.10

Tox. Ref. No.: 10T091-3

Test Date: 17.08.10

	Test Results			
Test Parameter	**Concentration % vol./vol.**	**Toxic Units**	**95% Confidence Limits % vol./vol.**	**Method of Calculation**
48 h EC_{50} to *Daphnia magna*	18.5	5.4	16.2-21.0	Trimmed Spearman - Karber
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

100% of the *Daphnia* were immobilized at 32% vol./vol.
45% of the *Daphnia* were immobilized at 18% vol./vol.
No *Daphnia* were immobilized at 10% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

Less than 20% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: Cell 3, 16.08.10

Tox. Ref. No.: 10T091-4

Test Date: 17.08.10

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	70.7	1.4	65.5-76.3	Trimmed Spearman-Karber
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

100% of the *Daphnia* were immobilized at 100% vol./vol.
10% of the *Daphnia* were immobilized at 56% vol./vol.
No *Daphnia* were immobilized at 32% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

Less than 11% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: Cell 9, 16.08.10

Tox. Ref. No.: 10T091-5

Test Date: 17.08.10

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	12.7	7.9	10.8-14.9	Maximum Likelihood - Probit
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

100% of the *Daphnia* were immobilized at 32% vol./vol.
80% of the *Daphnia* were immobilized at 18% vol./vol.
30% of the *Daphnia* were immobilized at 10% vol./vol.
No *Daphnia* were immobilized at 5.6% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

Less than 25% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: VP2, 16.08.10

Tox. Ref. No.: 10T091-6

Test Date: 17.08.10

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	>100	<1	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

No *Daphnia* were immobilized at 100% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

No light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

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TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: N4, 16.08.10

Tox. Ref. No.: 10T091-7

Test Date: 17.08.10

	Test Results			
Test Parameter	**Concentration % vol./vol.**	**Toxic Units**	**95% Confidence Limits % vol./vol.**	**Method of Calculation**
48 h EC_{50} to *Daphnia magna*	>100	<1	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

No *Daphnia* were immobilized at 100% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

No light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-1 Ver 2.1

TEST RESULTS

Customer: Cork City Council

Customer sample description: Tramore River, 16.08.10

Tox. Ref. No.: 10T091-8

Test Date: 17.08.10

Test Parameter	Test Results		95% Confidence Limits % vol./vol.	Method of Calculation
	Concentration % vol./vol.	Toxic Units		
48 h EC_{50} to *Daphnia magna*	>100	<1	n/a	n/a
15 min EC_{50} to *Vibrio fischeri*	>45	<2.2	n/a	n/a

Comments:

48 h EC_{50} to *Daphnia magna*

No *Daphnia* were immobilized at 100% vol./vol.

15 min EC_{50} to *Vibrio fischeri*

Less than 5% light inhibition occurred at 45% vol./vol.
- compared to the control.

Test Method(s): (see Appendix on back of page 12)
Method 1: *Daphnia magna*
Method 2: *Vibrio fischeri*

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-2 Ver 2.2

SAMPLE INFORMATION

	SATL	Customer	Other
Sampled by:	☐	✓	☐
Collected by:	☐	✓	☐

Tox Ref. No.	10T091-1	10T091-2	10T091-3	10T091-4
ampling procedure	n/a	n/a	n/a	n/a
Date of analysis	16.08.10	16.08.10	16.08.10	16.08.10
torage conditions (°C)	3±3	3±3	3±3	3±3
emperature (°C)	19.8	19.3	19.3	19.0
pH	7.3 (at 18.6°C)	7.5 (at 18.7°C)	7.7 (at 18.5°C)	7.1 (at 18.2°C)
issolved oxygen (mg/l)	4.2	<1	6.4	4.8
Dissolved oxygen % saturation)	47	3	70	53
Conductivity	5.8 (mS/cm at 25°C)	14.5 (mS/cm at 25°C)	4.6 (mS/cm at 25°C)	4.4 (mS/cm at 25°C)
alinity (ppt at 20°C)	3.1	8.4	2.4	2.3

SHANNON AQUATIC TOXICITY LABORATORY

ENTERPRISE IRELAND

TOXICOLOGICAL ANALYSIS REPORT

Form No.: ToxF035-2 Ver 2.2

SAMPLE INFORMATION

	SATL	Customer	Other
Sampled by:	☐	✓	☐
Collected by:	☐	✓	☐

.ox Ref. No.	10T091-5	10T091-6	10T091-7	10T091-8
ampling procedure	n/a	n/a	n/a	n/a
Date of analysis	16.08.10	16.08.10	16.08.10	16.08.10
torage conditions (°C)	3±3	3±3	3±3	3±3
emperature (°C)	19.0	19.3	19.1	18.8
pH	7.6 (at 18.3°C)	7.2 (at 18.7°C)	7.2 (at 18.6°C)	7.5 (at 17.9°C)
issolved oxygen (mg/l)	<1	6.5	2.8	7.6
Dissolved oxygen % saturation)	6	71	31	82
onductivity	5.5 (mS/cm at 25°C)	4.4 (mS/cm at 25°C)	3.9 (mS/cm at 25°C)	430 (µS/cm at 25°C)
alinity (ppt at 20°C)	2.9	2.3	2.0	<1

Toxicity Test Methods and Procedures

1. Freshwater Crustacean
Method 6.1 based on ISO 6341:1996/Cor.1:1998: 'Water quality – Determination of the inhibition of the mobility of *Daphnia magna* Straus (Cladocera, Crustacea) – Acute toxicity test'

2. Marine Bacterium
Method 6.2 based on BS EN ISO 11348-3:1999: 'Water quality - Determination of the inhibitory effect of water samples on the light emission of *Vibrio fischeri* (Luminescent bacteria test) – Part 3: Method using freeze-dried bacteria'

3. Marine Copepod
Method 6.3 based on ISO 14669:1999: 'Water quality – Determination of acute lethal toxicity to marine copepods (*Copepoda, Crustacea*)'

4. Marine Algae
Method 6.4 based on ISO 10253:2006: 'Water quality - Marine algal growth inhibition test with *Skeletonema costatum* and *Phaeodactylum tricornutum*'

5. Freshwater Algae
Method 6.5 based on ISO 8692:2004 : 'Water quality – Freshwater algal growth inhibition test with unicellular green algae' [*Pseudokirchneriella subcapitata*]

6. Freshwater Plant
Method 6.6 based on ISO 20079:2005: 'Water quality – Determination of the toxic effect of water constituents and waste water to duckweed (*Lemna minor*) – Duckweed growth inhibition test'

7. Marine Fish
Method 6.7 based on OECD 1992: Guideline 203: - 'Fish, acute toxicity test'

8. Freshwater Fish
Method 6.8 based on OECD 1992: Guideline 203: - 'Fish, acute toxicity test'

9. Estuarine Crustacean
Method 6.9 based on MAFF SOP No. BEG/030:1996: 'Brown Shrimp (*Crangon crangon*) 96 h acute toxicity for liquid effluents and wastes'

10. Marine Amphipod
Method 6.10 based on ICES, No. 28, 2001: 'Biological effects of contaminants: *Corophium* sp. sediment bioassay and toxicity test'

11. Eluate Generation
Procedure 4.7.8. "Eluate Generation" based on DIN 38 414 part 4, 1984: – 'Sludge and Sediments (Group S) – Determination of leachability by water (S4)'

APPENDIX 2

Standard Methods for Laboratory Analysis

APPENDIX 2

Standard Methods for Laboratory Analysis

Parameter	**Standard Method/Other***	**Standard Method Number / Other Number***
Alkalinity	Titration Method	2320-B
Ammonium	Selective Electrode Method	4500-D
BOD_5	5 Day BOD Test	5210-B
Chloride	Argentometric Method	4500-CL-B
Conductivity	Ion Selective Electrode Method	2510-A
COD	*Closed Reflux Colorimetric Method (Hach)	*Hach Procedure Manual for Odyssey DR/2500 Spectrophotometer Method 8000 – Reactor Digester Method
Methane	Liquid – Liquid Extraction Gas Chromatographic Method	6-36
Nitrite	*Closed Reflux Colorimetric Method (Hach)	*Hach Procedure Manual Method 8153 – Ferrous Sulphate Method
Suspended Solids	Total Suspended Solids	2540-B
pH	Electrometric Method	450-B
Phosphorus	Ascorbic Acid Method	4500-P E
Metals		
Cadmium Chromium Copper Iron Lead Magnesium Manganese Mercury Nickel Sodium	Metals by Electrothermal Atomic Absorption Spectrometry	3113-A
Potassium	Air/Acetylene Flame Method	3111-C
Total Coliforms and *E. coli*	Standard Methods Most Probable Number (MPN) model.	Idexx Quanti-Tray®/2000 and Idexx Colilert®-18
All in ‘‘Standard Methods for the Examination of Water and Wastewater, 1998. 20th Edition, Eds. Clesceri, L.S., Greenbury, A.E., Eaton, A.D., American Public Health Association, Washington D.C.’’ unless indicated otherwise		

External Laboratory Testing		
Parameter	**Standard Method/Other**	**Standard Method Number / Other Number**
Total Oxidised Nitrogen (TON)	Devarda's Alloy Reduction Method	419 F, in APHA Standard Methods, 14th Edition
Boron	EM130 ICP-MS	
Mercury	EM130 ICP-MS	
List I/II Substances		
Volatile Organic Compounds	EO 025 Purge and Trap/GC/MS	
SVOC-Pesticides/PAHs Screen	EO 129 By SPE, GC/MS Detection	
Toxicity Testing		
Freshwater Crustacean	Method 6.1 ISO 6341:1996/Cor.1:1998: 'Water quality – Determination of the inhibition of the mobility of *Daphnia magna* Straus (Cladocera, Crustacea) – Acute toxicity test'	
Marine Bacterium	ISO 11348-3:2007: 'Water quality - Determination of the inhibitory effect of water samples on the light emission of *Vibrio fischeri* (Luminescent bacteria test) – Part 3: Method using freeze-dried bacteria'	