Aspects of the ecology of a constructed reedbed within herb-rich grassland

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ASPECTS OF THE ECOLOGY OF A CONSTRUCTED REEDBED WITHIN HERB-RICH GRASSLAND

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ABSTRACT

A horizontal-flow reedbed was constructed in December 1996, at the Central Area Transmission System Terminal, Seal Sands, Teesside (NZ518 247), to provide tertiary treatment for site sewage and surface water. A monitoring programme was required to determine the performance of the reedbed in the treatment of wastewater and its ecological impact within the site. The development of such a biological and chemical monitoring system between October 1996 and July 1997, formed the basis of this project which could be repeated on a long-term basis by Durham University undergraduates.

Performance of the reedbed was tested by planting one-half with reeds transplanted from a local natural reedbed, and the other with commercially grown reeds. Wastewater was chemically analysed to show the changes in water quality as it passed through both sections of the reedbed system.

Nitrogen and phosphorus inputs to the system were studied in terms of 1) nutrient transformation and 2) their effect on growth and development of the reeds themselves.

The ecological impact of the constructed reedbed system upon the surrounding herb-rich grassland was studied using a number of monitoring techniques providing base-line information for future comparison, including pitfall trapping for terrestrial invertebrates, sweep-net sampling for aquatic invertebrates, Longworth trapping of small mammals, and a Common Bird Census.

A 5 year management plan has been designed to ensure the efficient treatment performance of the reedbed, and to maintain the conservation value of the site.

The research has provided important information on the development of biological processes in a newly constructed reedbed system during the first seven months of operation.

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Plate 1. Locally transplanted *Phragmites australis* flowering at the CATS Terminal constructed reedbed, August 1997.

CHAPTER ONE

1. INTRODUCTION

1.1. Background to the project

As part of the planning process for AMOCO's Central Area Transmission System (CATS) Gas Processing Plant at Seal Sands, North Tees (NZ518 247), English Nature and Industry Nature Conservation Association (INCA) were consulted in an attempt to reduce the environmental impact of the development. It was decided to construct a horizontal-flow reedbed to provide a 'natural' tertiary treatment system after conventional treatment for effluent and surface water at the site. Durham University became involved in order to undertake an integrated study and monitoring programme which would determine the performance of the reedbed in the treatment of wastewater and its ecological impact within the site. The development of such a biological and chemical monitoring system between October 1996 and July 1997, formed the basis of this project which could be repeated on a long-term basis by Durham University undergraduates.

The site lies on land reclaimed from the Tees Estuary in 1974. The northern part of the site although within the boundary of the Seal Sands Site of Special Scientific Interest (SSSI), was set aside for industrial development. Figure 1 shows the location of the CATS Terminal site in relation to the Tees Estuary.

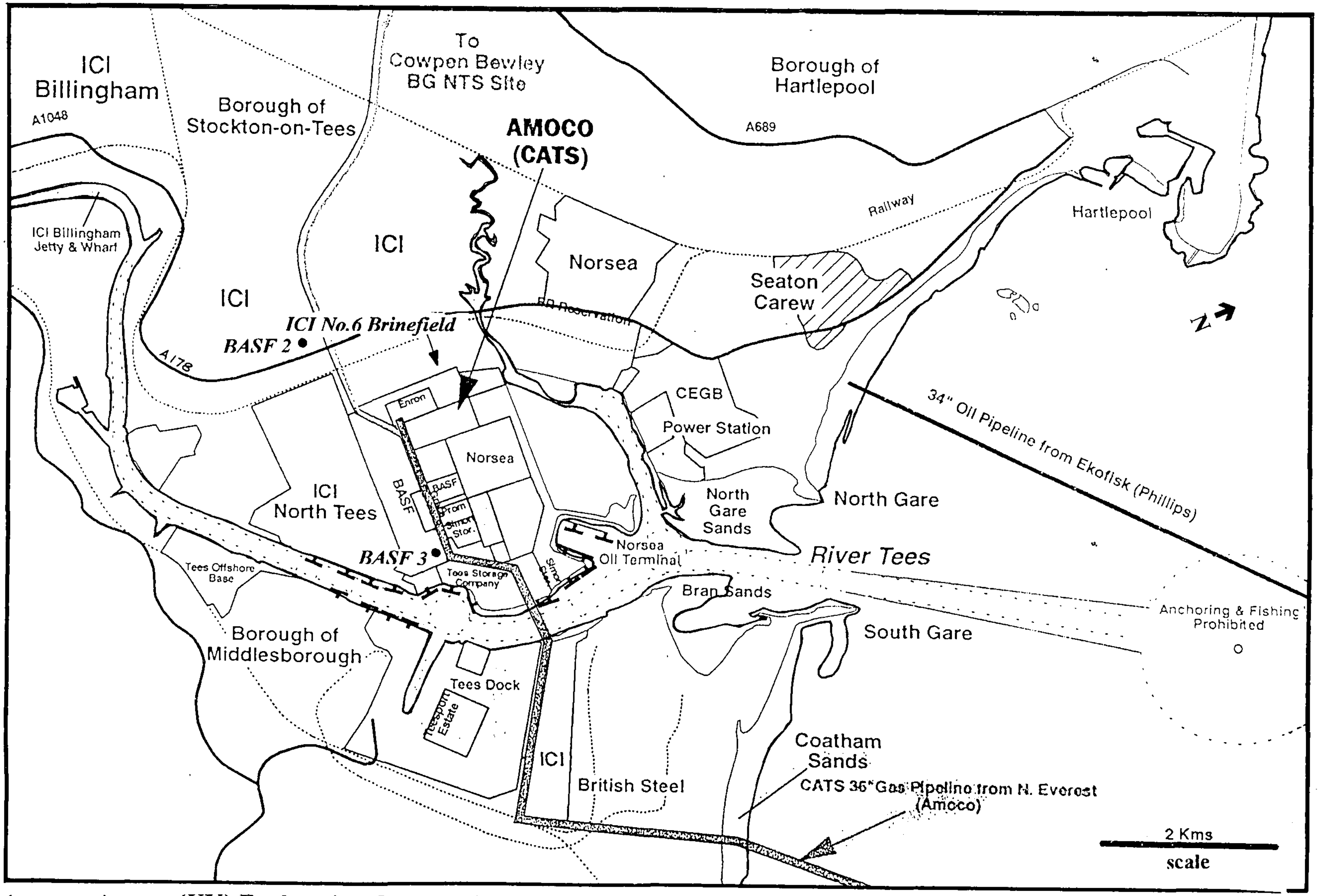
The reedbed was constructed in an area to the north-west of the CATS Terminal site which was not required for development (Plate 2).

1.2. Wastewater treatment

1.2.1. Why treat wastewater ?

Between December 1996 to 9th July 1997, wastewater entering the reedbed was predominantly construction site sewage, with smaller contributions from food preparation and personal washing, consisting mainly of natural organic and

Figure 1. Amoco CATS Terminal location plan



(source, Amoco (UK) Exploration Company)

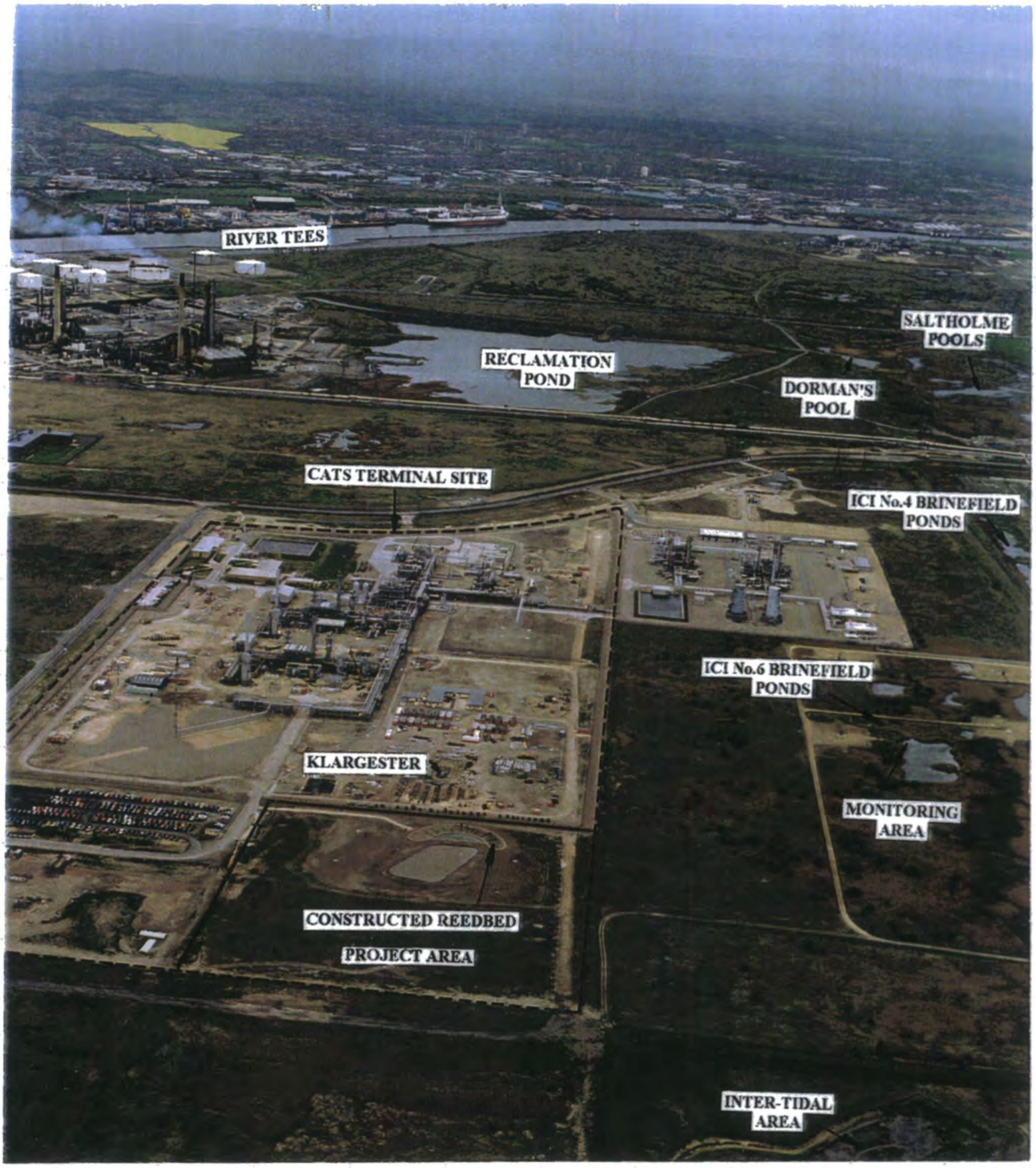


Plate 2. The Amoco CATS Terminal site, April 1997, showing the constructed reedbed and surrounding wetlands.

inorganic materials. Sewage requires treatment to kill pathogenic bacteria and to degrade organic matter and pollutants, converting it into stable oxidised end-products which can be discharged into the local watercourse without any adverse ecological effects (Gray, 1989). Sewage effluent contains micro-organisms which utilize the organic matter for growth and metabolism, using up oxygen in the process. The requirement for oxygen by such organisms is called the Biochemical Oxygen Demand (BOD) (section 1.2.2). The Biochemical Oxygen Demand test (BOD_5) is an empirical measurement of the amount of oxygen consumed in 5 days at a temperature of 20°C, in the dark, by the biological oxidation of any biodegradable organic matter present (Gray, 1989).

Approximately 60% of the organic load of domestic sewage is in the form of particulate or suspended matter (suspended solids, SS) (Grant *et al.*, 1996). Suspended solids can block fish gills, and cause turbidity, preventing light reaching the lower levels of the water, reducing photosynthetic activity, and subsequently oxygen levels.

Nitrogen compounds in organic matter are of concern in wastewater because of their oxygen demand, their toxicity to aquatic invertebrate and vertebrate species, and in their role in eutrophication of receiving waters. Similarly, if phosphorus compounds present in wastewater are not removed, eutrophication of receiving waters may occur.

Organic matter that is not physically removed by sedimentation and filtration is naturally degraded by micro-organisms in the presence of oxygen. The amount of organic matter that a watercourse can naturally assimilate is limited by the availability of dissolved oxygen (Gray,1989). Therefore, in order to prevent the de-oxygenation of receiving waters and to minimise the adverse effects of the wastewater on the environment, it must first be treated and converted into stable end-products.

The amount of treatment required depends on the quality objectives for the water and the amount of dilution available in the receiving water (Mason, 1991). The regulatory authority, the Environment Agency, uses the determinands of BOD_5 and SS to set dischage standards to be achieved by small sewage treatment systems. The Environment

Agency authorised Amoco (UK) Exploration, to discharge on-site effluent through the reedbed not exceeding BOD_5 100 mg O_2 l^{-1} and SS 50 mg l^{-1}. Wastewater entering the reedbed is required by the Environment Agency, to be analysed for BOD_5 and SS every three months. The reedbed can be judged to successfully treat site effluent if these determinands are within the required consent limits. Once the reedbed has been demonstrated to effectively reduce the BOD_5 and SS levels of site wastewater, the consent standards will be reviewed and may be reduced to 20 mg O_2 l^{-1} BOD_5, 30 mg l^{-1} SS from the outlet pipe of the reedbed system into the Outfall Pond soakaway (R.Hudson, Environment Agency, personal communication).

1.2.2. Microbiology of sewage treatment

The treatment of sewage effluent largely depends on bacterial activity. Heterotrophic bacteria are those that require organic carbon as a source for cell synthesis:-

$$\text{Organic matter} + \text{Bacteria} + O_2 \rightarrow \text{New cells} + CO_2 + H_2O + NH_3$$

Oxygen is required as the electron acceptor in the breaking of bonds which link carbon atoms, releasing energy and thus creating an oxygen demand.

In the absence of dissolved oxygen, degradation of organic material can also occur by anaerobic heterotrophic bacteria which convert organic material into new cells, organic acids and alcohols. According to Cooper *et al.*(1996), methane-forming bacteria continue the oxidation using some of the organic matter to synthesise new cells, but convert the remainder to CO_2 and methane:-

$$\text{Organic matter} + \text{Bacteria} \rightarrow \text{New cells} + \text{Alcohols} + \text{Acids} + \text{Bacteria}$$
$$\rightarrow \text{New cells} + CH_4 + H_2S + NH_3 + CO_2$$

Some of the products of anaerobic degradation of organic material are toxic to organisms adapted to aerobic conditions, and some are noxious gases, such as hydrogen sulphide and methane.

Aerobic degradation of organic material is much faster than anaerobic degradation (Gray, 1989). The end-products of aerobic decomposition are odorless, non-toxic and water soluble. The process occurs naturally when organic matter is discharged into a water course, however it may severely deplete the dissolved oxygen of the receiving waters.

Efficient bacterial treatment of sewage requires an adequate supply of oxygen. At the CATS Terminal, a Klargester G11 Bio-disc Rotating Biological Contactor (RBC) (Klargester Environmental Engineering Limited, Aylesbury) has been installed as a pre-treatment system before discharge into the reedbed. The aerobic environment within the Klargester facilitates the degradation of organic material in the wastewater.

Other bacteria and micro-organisms also utilize oxygen during the transformation of the nitrogen compounds present in wastewater. In fresh domestic sewage, nitrogen is mainly present as organic forms in faeces and urine which are rapidly mineralised to ammonium nitrogen (NH_4^+) during the process of ammonification.

$$\text{Organic nitrogen} \leftrightarrow NH_4^+$$

Ammonification involves the breakdown by bacteria of organic tissues containing amino-acids, and by the hydrolysis of urea (Kadlec & Knight, 1995). At the normal pH of fresh sewage (pH 6-8), ammonium ions predominate (at pH >8, it exists in aqueous solutions as ammonia). Whilst passing through the Klargester, most of the organic forms of nitrogen present in the site wastewater will have been transformed to ammonium before reaching the reedbed system

In the aerobic conditions of the Klargester, ammonium is oxidised by bacteria in the two stage process of nitrification. In the first stage, ammonium is oxidised to nitrite using CO_2 as a carbon source for new cells by the bacteria *Nitrosomonas.*

$$NH_4^- + CO_2 + O_2 \rightarrow Cells + NO_2^- + H_2O$$

(*Nitrosomonas*)

In the second stage, CO_2 is also used as a carbon source for new cells by the bacteria *Nitrobacter* which oxidise nitrite to nitrate.

$$NO_2^- + CO_2 + O_2 \rightarrow Cells + NO_3^-$$

(*Nitrobacter*)

A high rate of nitrification reduces the pH of the water. Further nitrification occurs in the aerobic root zone areas of the reedbed. Dissolved oxygen concentrations above 1 mg l^{-1} are required otherwise oxygen becomes the limiting factor for growth (Cooper *et al.* 1996). However, nitrification will still occur down to dissolved oxygen concentrations of about 0.3 mg l^{-1} (Reddy and Patrick, 1984, Kadlec & Knight, 1996). There is competition for attachment sites between nitrifying bacteria and the heterotrophic bacteria responsible for carbon oxidation. As a consequence, nitrification does not proceed until BOD levels are reduced to approximately the same level as ammonium nitrogen (Kadlec & Knight, 1996).

Nitrate is reduced in anaerobic areas of the reedbed by bacteria to N_2 and N_2O in the process of dentrification. Nitrate is initially reduced to nitrite, which is further reduced to nitric oxide, nitrous oxide and nitrogen gas which are released into the atmosphere.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_20 \rightarrow N_2$$

The heterotrophic bacteria involved in the process include *Achromobacter, Aerobacter, Bacillus, Lactobacillus, Pseudomonas* and *Spirillum*. Alkalinity is increased during the process resulting in a rise in pH. Dentrification was expected to occur in the anaerobic zones of the reedbed, away from the aerobic root zones. However, as the process is mediated by heterotrophic bacteria, nitrogen removal in a tertiary treatment reedbed system may be limited by insufficient organic carbon.

1.2.3. Conventional wastewater treatment

Most wastewater treatment systems utilize the physical process of sedimentation to remove solids and sludge (Primary treatment), and the biochemical action of micro-organisms on dissolved and colloidal organic material in an aerobic environment (Secondary treatment). Primary treatment may remove 60 % of the suspended solid content of the wastewater, and 35 % of the BOD_5. Conventional secondary treatment systems are either those where the micro-organisms are attached to a fixed surface (e.g. gravel percolating filters), or those where the micro-organisms move freely within the wastewater (e.g. activated sludge) (Gray, 1989). Merritt (1994) reports that sewage effluent leaving a secondary treatment system will typically have reduced its initial BOD_5 by 95 %, 90 % of its suspended solids, and 85 % of its ammonia concentration. According to Mason (1991), the minimum requirement for an effluent, which should be achieved with secondary treatment, is the Royal Commission Standard for Effluent of 30 mg l^{-1} SS and 20 mg l^{-1} BOD_5. The main water treatment removal mechanisms are outlined in the following table.

Table1. The physical, chemical and biological processes involved in the treatment of wastewater.

Wastewater constituent	Removal mechanism
Suspended solids	Sedimentation-Gravitational settling of solids. Filtration.
Soluble organics	Aerobic microbial degradation Anaerobic microbial degradation
Nitrogen	Ammonification followed by microbial nitrification and dentrification. Adsorption onto the treatment bed matrix. Ammonia volatisation-conversion to ammonia gas at pH >8
Phosphorus	Sedimentation. Adsorption onto the treatment bed matrix. Chemical precipitation with Al, Fe, Ca and clay materials in the bed matrix.
Metals	Adsorption and cation exchange Complexation Precipitation Microbial oxidation/reduction
Pathogens	Sedimentation Filtration Natural die-off UV irradiation

(Wood & McAtamney, 1994; Cooper *et al.*, 1996)

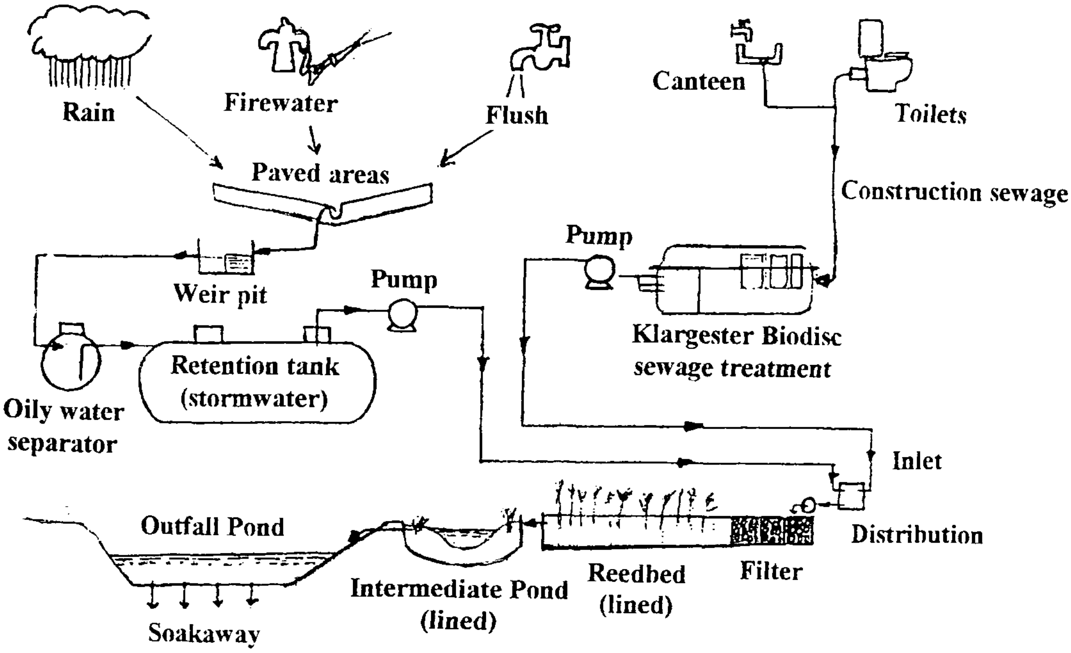
1.2.4. Wastewater treatment at the CATS Terminal

As the CATS Terminal site is not attached to the Northumbrian Water sewerage system, a Klargester G11 Bio-disc Rotating Biological Contactor (RBC) provided primary settlement, and biological treatment and secondary settlement for the construction workforce effluent. RBC principles of operation and effluent treatment are detailed in Tchobanoglous *et al.* (1991) and Anon (1994a). Plate 2 shows the location of the Klargester in relation to the reedbed. The unit was configured to produce a final effluent quality of 20 mg O_2 l^{-1} BOD_5, 30 mg l^{-1} suspended solids and 20 mg l^{-1} ammonium.

Sewage treatment plants generally discharge secondary treated water. Tertiary treatment involves further physical, biological or chemical processes in order to produce high quality effluent. The horizontal-flow constructed reedbed provided tertiary treatment of site effluent from December 1996, and monitoring of the performance of the system began in January 1997.

The final effluent passes into the unlined Outfall Pond which acts as a soakaway where it eventually seeps into the Tees estuary. A diagrammatic representation of the source of the reedbed influent is shown in Figure 2.

Figure 2. Sources of influent wastewater to the CATS Terminal reedbed.



(P. Weiner, 1997, Parsons Group International Ltd., personal communication)

Water quality was monitored in the reedbed system between January 1997 until 9th July 1997, when all wastewater entering the reedbed was secondary treated effluent from the Klargester. From 10th July 1997, the site surface water retention tanks (capacity 120 m^3) were periodically emptied through the reedbed system. Surface water run-off and firewater pond overflow from the CATS Terminal 'live site', previously discharged into Greatham Creek, were discharged through the reedbed system from July 1997 (Figure 2). The reedbed therefore, changed from a tertiary treatment to a combined tertiary and surface wastewater system. This must be considered when comparing the 1997 water quality results with those from future monitoring periods.

The construction of a tertiary treatment reedbed at the site was beneficial to AMOCO for the following reasons:-

- Wastewater discharged from the reedbed system into the Tees estuary should consistently fall within the discharge consent limits, reducing the likelihood of clean up charges and fines from the Environment Agency, if standards were breached.

- Accidentally high discharges from the site should be ameliorated by the reedbed.

- The reedbed could receive and treat non-sewage, surface wastewater from the 'live site', previously discharged into Greatham Creek which had more stringent discharge consent standards (20 mg O_2 l^{-1} BOD_5, 30 mg l^{-1} SS). The Environment Agency authorised the discharge of the 'live plant' surface water run-off, and firewater pond overflow through the reedbed within the limits of BOD_5 100 mg O_2 l^{-1} and SS 50 mg l^{-1}, further reducing the likelihood of clean up charges and fines from the Environment Agency, if standards were breached.

- The 'natural' treatment system would create a wetland habitat, which should increase the biological diversity of the site.

1.3. Reedbed water treatment systems

1.3.1. Background.

McEldowney *et al.*(1993) suggested that natural reedbeds act as effective substrate-plant microbial filters, whereby oxygen-demanding materials present in wastewater discharged into natural wetlands are immobilized and degraded by the physical and biological processes which operate in such ecosystems. In the USA, Canada and Australia, natural wetlands supporting *Phragmites australis* *(Cav.) Trin. ex Steudel (common reed) and other aquatic macrophytes, have been utilized to provide tertiary treatment for large scale water treatment systems for towns and cities. The capacity for wastewater purification by such natural wetlands has been well documented by Athie & Cerri (1987), Reddy & Smith (1987), Hammer (1989), Moshiri (1993) and Kadlec & Knight (1996).

Constructed reedbeds have been used as effective water purifying systems following work by Seidal in the late 1960's and later developments by Kickuth in the 1970's in Germany (Haberl *et al.*, 1995). Constructed reedbeds are widely used in Europe to provide secondary or tertiary treatment of domestic sewage for small populations (Cooper *et al.*, 1996). They provide a more controlled environment which can be designed to meet specific pollutant removal requirements.

The UK Water Industry became interested in Reedbed Treatment Systems (RBTS) in 1985 following a visit to Germany (Boon, 1985). Since 1985, the use of constructed reedbeds to treat domestic, industrial and agricultural wastewaters has been investigated by the Water Services Association Reedbed Treatment Systems Co-ordinating Group in the UK, and by the European Community Expert Contact Group on Emergent Hydrophyte Treatment Systems (EHTS) which receives information from nine EU countries. Their efficiency has been discussed at numerous International Conferences on

* Nomenclature of higher plants follows that of Clapham, Tutin & Moore (1989)

Wetland Systems for Water Pollution Control. The 5th conference was held in Vienna, Austria during September 1996. Conference proceedings and publications concerning the principles of operation and the use of constructed reedbeds in water pollution control have been produced by Cooper (1990), Green & Upton (1994), Brix (1994), Wood & McAtamney, (1994), and Cooper *et al.*(1996).

The majority of European systems use rooted emergent macrophytes such as *Phragmites australis* in constructed, sub-surface horizontal or vertical flow systems. Constructed reedbeds have proved to be effective for consistent reduction of Biochemical Oxygen Dermand (BOD_5), Suspended Solids (SS),Chemical Oxygen Demand (COD), for oxidising ammonia, reducing nitrate and removing phosphorus (Knight, 1993). The use of constructed reedbeds as a tertiary polishing stage to further reduce BOD_5, SS and COD has been well documented (Green, 1993; Green & Upton, 1994; Cooper *et al.*, 1996).

Northumbrian Water PLC. have installed tertiary treatment reedbeds at Garrigill (NY744 415), at Winston (NZ140 167), and at Moorsholm (NZ689 144). All were installed because secondary treatment systems were not achieving discharge consents (M.Woolley, Northumbrian Water PLC, personal communication). However, Severn Trent Water PLC have installed constructed reedbeds for tertiary and tertiary/storm overflow treatments at over 160 wastewater treatment facilities (Green *et al.*, 1997).

1.3.2. Vertical and Horizontal flow sub-surface reedbeds.

Wetlands constructed for wastewater treatment can either mimic natural treatment wetlands where wastewater flows over the surface of the bed (Overland flow), or they can be designed to allow wastewater to flow just below the surface of the reedbed, either vertically or horizontally, through the root zone of the plants (Subsurface flow).

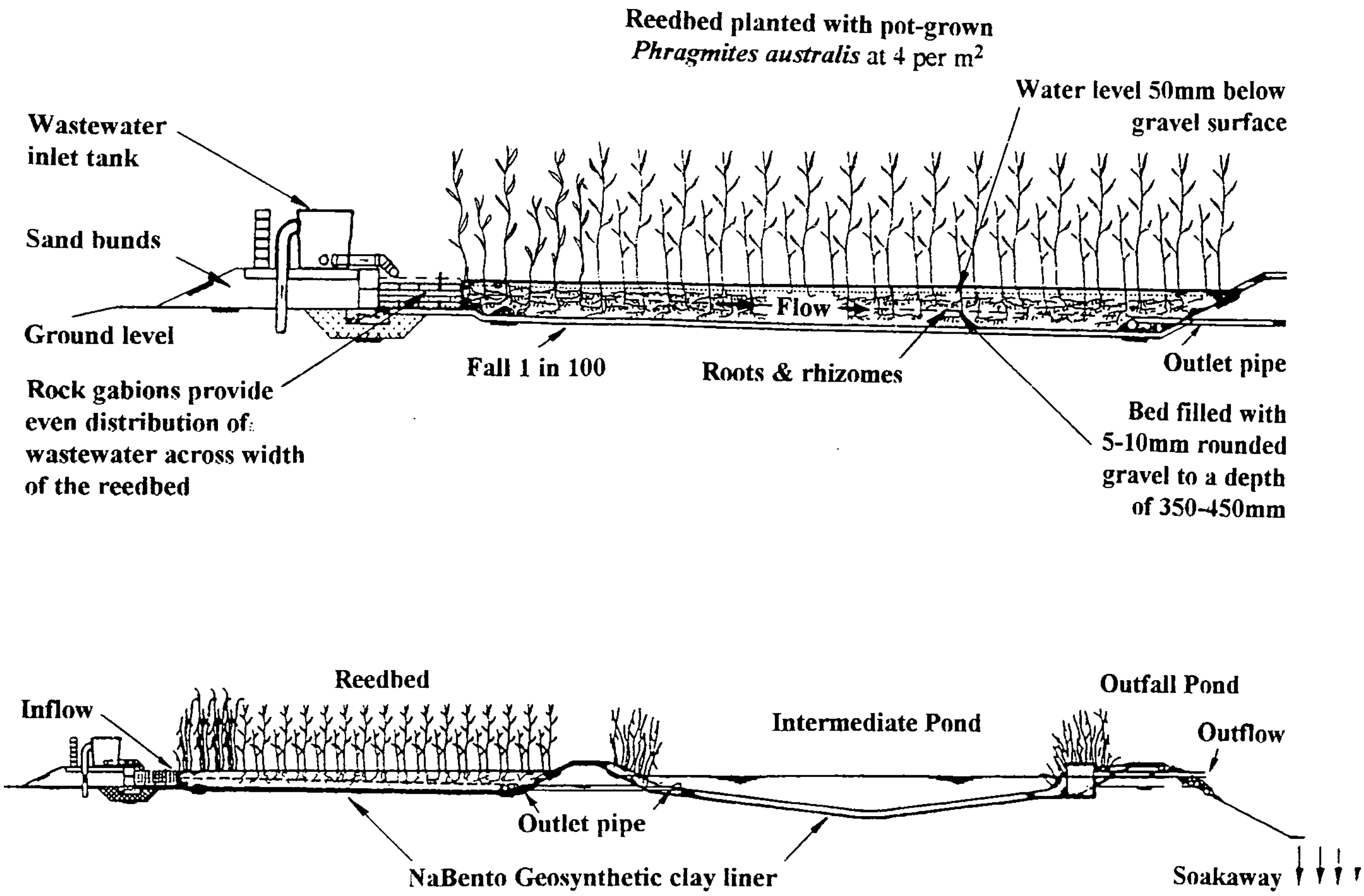
In vertical-flow reedbeds, wastewater is introduced onto the surface of the bed and percolates down through the substrate and macrophyte root zone, and passes out at the base of the bed. The beds are fed intermittently, and the dosing onto the bed introduces oxygen throughout the bed, providing ideal conditions for nitrification to occur. As wastewater is treated as it passes through the deep root zone, vertical-flow reedbeds do not require large surface areas (compared to horizontal-flow reedbeds). However, they are less efficient at suspended solids removal and are often followed by a horizontal-flow reedbed (Cooper *et al.*, 1996) as part of a combined system, such as at Larchfield Farm, Middlesbrough (NZ503 134) (J.Jenkins, personal communication), and at the Centre for Alternative Technology, Wales (Grant *et al.*, 1996).

In horizontal-flow systems, wastewater is evenly distributed at the inlet and flows horizontally, through a shallow (generally 0.3-0.6 m depth) gravel or soil filled bed, planted with aquatic macrophytes, until it overflows at the outlet. As the wastewater passes through the root zone, organic material is degraded and nitrogen sources are transformed, by complex physical, chemical and biological processes.Watson & Danzig (1993) suggest that shallow, horizontal-flow gravel-filled reedbeds are more effective than deeper systems for nitrification because the wastewater flow is restricted to the most effective portion of the plant root zone, as most root biomass in gravel beds typically occurs in the top 30 cm.

In recent years, there has been a move towards vertical-flow systems because horizontal-flow systems may fail to remove ammonium because they are oxygen limited (Cooper *et al.*, 1996). However, as the CATS Terminal horizontal-flow reedbed has been installed as a tertiary treatment system, ammonification would be expected to occur during pre-treatment in the Klargester. Also, the nitrate produced would be further transformed by dentrification in the low-oxygen environment within the reedbed. Any ammonium remaining would be oxidized to nitrate in the aerobic environment of the Intermediate Pond.

Early problems were experienced in constructed reedbeds with soil-based horizontal-flow systems due to channeling and surface flow. Graded gravel, which allows even filtration and movement of wastewater with a high hydraulic conductivity, is now the preferred medium (Cooper & Green, 1995), and has been used in the CATS Terminal reedbed. A horizontal-flow reedbed was appropriate at the CATS Terminal because it was the simplest system to construct, the larger land requirement was not a problem, and the main treatment requirements were for BOD_5 and SS reduction. Figure 3 shows a cross-section of the reedbed system built at the Terminal.

Figure 3. Cross-sections through the CATS Terminal horizontal subsurface-flow reedbed system



Plates 3 and 4 show the reedbed inlet tank and wastewater distribution system.

Plate 3. Wastewater inlet tank at the CATS Terminal reedbed, January 1997, showing secondary treated effluent entering the system from the Klargester.

Plate 4. Wastewater inlet sections of the CATS Terminal reedbed, January 1997.(One month after planting, pot-grown *Phragmites australis* can be seen in the foreground, local transplanted *Phragmites australis* in the background).

1.3.3. How reedbeds improve water quality

As in conventional waste water treatment systems, the most important removal processes in Reedbed Treatment Systems are based on physical, chemical and microbial processes. The role of macrophytes in the treatment processes has therefore been questioned. Numerous studies measuring wastewater treatment with and without plants (Reddy, 1984; Sikora *et al.*, 1985; Ulrich & Burton, 1985; Athie & Cerri, 1987; Reddy & De Busk, 1987; Brix & Schierup, 1989; Surrency, 1993, and Brix, 1997), have concluded that performance is usually higher when plants are present.

Aquatic macrophytes accelerate the 'purification' of wastewater by the following methods:-

1) Aquatic macrophytes provide a surface area for microbial growth.

As on the gravel in conventional systems, the roots and rhizomes provide a substrate for the attached growth of micro-organisms which break down the wastewater into simpler compounds.

2) Physical effects.

The roots and rhizomes of the plants provide filtration of suspended matter and electrostatic attraction of small particles. The presence of roots and rhizomes reduces the velocity of the wastewater. This creates better conditions for the sedimentation of suspended solids. Reduced water velocity also increases the contact time with the root and rhizome surface areas. The litter layer produced by the plants insulates the bed during cold periods, providing wind and frost protection. Insulation also serves to ameliorate the temperature within the bed beneficial for microbial transformations which are temperature-dependent.

3) Aquatic macrophytes transport oxygen to the root zone.

Wetland plants have physiological adaptations that allow for growth in low oxygen environments. Certain aquatic plants, such as *Phragmites australis* have developed aerenchyma tissues (containing large, extracellular air spaces) in roots and stems which allow the diffusion of oxygen from above ground parts of the plant into the roots, and to remove gases such as carbon dioxide The oxygen is required for root respiration, and growth. It is also required to oxidise toxic compounds in the rhizosphere which may inhibit plant growth (Cooper *et al.*, 1996). Wastewater entering a constructed reedbed has both a carbonaceous and nitrogenous oxygen demand. Dissolved oxygen is further depleted to meet the respiration requirements of plants and organisms within the reedbed. According to Kadlec and Knight (1996), wastewater loading may be sufficient to drive the dissolved oxygen level down to 1-2 mg l^{-1} , and in horizontal sub-surface flow reedbeds with continuous flow, oxygen levels may fall below 1.0 mg l^{-1}. Oxygen leaked from the roots results in aerobic microzones around the plant roots and anaerobic zones away from them, whereby aerobic and anaerobic bacteria present will breakdown organic material and transform nitrogen by nitrification and dentrification in aerobic and anaerobic zones of the reedbed.

Oxygen is required to sustain nitrification and is often the limiting factor in nitrogen removal from constructed reedbeds. There have been studies to examine the ability of some aquatic macrophytes to pass a supply of oxygen into the rhizosphere of constructed reedbed treatment systems. The ability of *Phragmites australis* to transfer oxygen to the roots has been demonstrated by Armstrong *et al.*,(1988), but the rate of oxygen transfer is not clear. Brix and Schierup (1990), have measured oxygen transport into the root zone of *Phragmites australis* as 2.08 g O_2 m^{-2} d^{-1}, and Armstrong *et al.*(1990b) measured 5 - 12 g O_2 m^{-2} d^{-1} in *Phragmites* grown in gravel beds. Aerobic breakdown (nitrification) of organic matter is faster than anaerobic breakdown (Gray, 1989), and a continued supply of oxygen is essential in order to achieve nitrification (Cooper *et al.*, 1996). Brix (1990), Armstrong and Armstrong (1990a) and Haberl & Perfler (1990), have shown that the roots of *Phragmites* do leak oxygen into the rhizosphere, but much less than needed for nitrification.

Due to the inability to supply sufficient oxygen through the reeds there has been an increasing interest in vertical-flow systems, where more oxygen is provided by entrapment in intermittently-dosed beds (Cooper & Green, 1995).

4) Plants take up nitrogen and phosphorus during the growing season.

Aquatic macrophytes take up nutrients such as nitrate and phosphate, which are required for growth and reproduction, through their root systems. The effect of macrophytes on the temporary removal of nitrate and phosphate from wastewater treatment systems has been well documented (Reddy, 1984; Ulrich & Burton, 1985; Athie & Cerri, 1987; Reddy & DeBusk, 1987; Brix & Schierup, 1989; Sikora *et al.*, 1995). Reddy and DeBusk (1987) suggest that if nitrate and phosphate removal is important, systems should be designed which optimize conditions for plant uptake. Considerable amounts of nutrients can be removed from the wastewater by plants during the growing season, but the nutrients are only removed if the plants are harvested before translocation to the storage organs (roots and rhizomes) which occurs during the autumn. Harvesting only removes the nutrients present in the above-ground areas of the plant. Plants also return nutrients into the wastewater upon decomposition. According to Kadlec & Knight (1996), plant uptake is generally of minor importance compared to the microbial and physical transformations which occur in reedbeds.

1.3.4. Emergent macrophyte species used in reedbed treatment systems

The commonest species used in UK and European constructed reedbeds is *Phragmites australis* (Cav.) Trin. ex Steudel (common reed). The distribution, morphology and life history characteristics of *Phragmites australis* have been documented by Haslam (1972), and van der Werff (1991). Briefly, *Phragmites* is a tall perennial reed, with annual cane-like shoots and an extensive rhizome system. It grows in Britain between April and September, to an average height of 2 m. The reed is common in temperate latitudes, growing in low-lying wetland habitats which are intermittently or permanently flooded with shallow, still, water (Haslam, 1972), often forming monodominant stands. The ability of *Phragmites* to transport oxygen into the root zone (an adaptation to flooding), has been exploited by its use in macrophyte wastewater treatment systems. Also its deep and extensive root and rhizome system provides a large surface area for attached bacteria. *Phragmites* has been also been used in macrophyte treatment systems because productivity and biomass levels are generally high, due to its ease of propagation from rhizomes and because of its robustness.

Many other macrophytes have been evaluated and successfully used. Yorkshire Water PLC have been experimental in their use of macrophytes at their reedbed treatment systems, using a range of species in different locations (Merritt, 1994). Burka & Lawrence (1990), researching at Oaklands Park, Gloucestershire, identified that *Phragmites* and *Scirpus* (club-rush) species provided greater oxygenation and root proliferation, whilst species such as *Typha* (reedmace) tended to have higher short-term productivities, but limited root proliferation (Burka & Lawrence, 1990).

1.3.5. Advantages of constructed reedbeds in the treatment of wastewater.

Constructed reedbeds provide a controlled environment which can be designed to meet specific pollutant removal requirements, with the following advantages:-

- They have a simple construction design, with low cost materials.
- They provide a cost effective wastewater treatment system for small communities (<2000 population), with low operational and maintenance costs, despite relatively high construction costs.
- They do not require a power supply.
- They are capable of handling a large variation in daily flow, and can buffer shock loads.
- They can provide a tertiary treatment stage following conventional treatment systems, providing consistent, high quality effluent.

- They provide a 'natural' treatment system with wildlife habitat value.

1.4. The ICI No.6 brinefield site.

The development of the reedbed and its performance in treating wastewater can be understood properly only by comparing it with a naturally occurring system. Similarly, concentrations of phosphorus and nitrogen in plants growing in natural stands can provide base-line estimates of nutrient assimilation. The reeds of different provenance in the CATS Terminal reedbed were compared with reeds which have naturally become established in the slightly brackish pools of the adjacent ICI No.6 Brinefield site. The ICI No.6 brinefield site (NZ516 246) is bordered to the west by the slag wall known as Long-drag, to the south by the Enron Gas Processing Plant, to the north by the inter-tidal area, and to the east by a strip of ICI owned land comprising rough grassland with *Salix* spp.(Willow) and *Betula* spp.(Birch) scrub. Plate 5 shows the brinefield pool from which plants of *Phragmites australis* were monitored for height and leaf tissue nutrient content. Aquatic invertebrates were sampled in order to compare the species composition and diversity of the pool with the recently created CATS Terminal pools.

1.5. Atmospheric Nitrogen deposition

The Seal Sands area receives atmospheric nitrogen deposition from the Teesside conurbation and from nearby industrial processes which may affect reed growth. Dry deposition of atmospheric nitrogen was monitored at both the No.6 brinefield site and the CATS Terminal reedbed site (Plates 5 and 6).

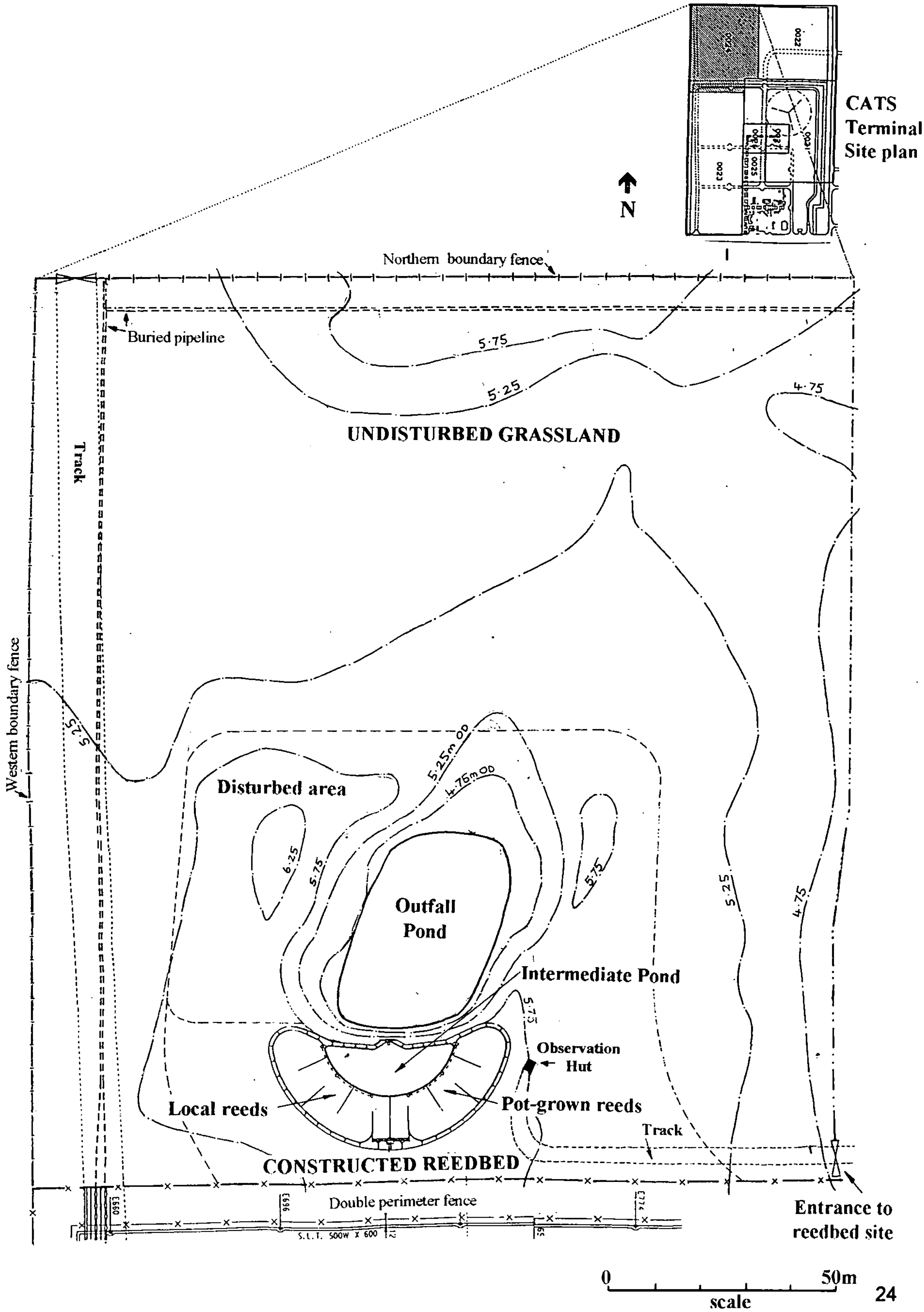
Plate 5. The ICI No.6 brinefield pond, March 1997, showing the NO_2 passive diffusion tube samplers.

Plate 6. NO_2 passive diffusion tube samplers at the CATS Terminal, adjacent to the constructed reedbed.

1.6.The Herb-rich Grassland

The reedbed was constructed in an area of the north-west of the CATS Terminal site which was not required for development (Figure 4). The area to the north of the Outfall Pond was regarded as suitable for retention as a natural grassland by English Nature. The area has developed naturally since it was reclaimed from the estuary in 1974, resulting in a herb-rich grassland with plants characteristic of dry calcareous soils. The re-introduction of a wetland habitat should introduce wetland species to the site, whilst the area disturbed during the excavation of the Outfall Pond and the construction of the reedbed, should introduce species that are early successional colonisers. A baseline survey of the botanical composition of the grassland site between October 1996 and July 1997 can be used in the future to be able to identify changes in species composition, and it may also identify any uncommon species that may be present. The north-west area of the CATS Terminal which includes the grassland and the reedbed, shown in Figure 4 and Plate 2, provided the project monitoring area for the baseline study of, invertebrates, birds and small-mammals that use the site, and whose species composition may be altered by the introduction of the reedbed and wetland system. Plate 2 also shows the other wetlands in the immediate vicinity of the site.

Figure 4. CATS Terminal constructed reedbed and grassland site.
(Adapted from CATS Terminal Project drawing no.7983-15/00/00/40/252/0024)



1.7. Monitoring programme

A monitoring programme was set up to provide baseline information in order to quantify changes which result from the construction of the reedbed system. According to Spellerberg (1994), good baseline data, assembled as part of the monitoring programme, are an important prerequisite for successfull biological monitoring. The biological and chemical monitoring system was designed to determine the performance and ecological impact of the constructed reedbed with the following considerations in mind:-

- The measurement techniques should be simple and reliable in order that future studies by different investigators can be compared with confidence.

- Standard methods should be used and carefully documented, as should the timing and frequency of measurement techniques. All methods used should be reproducable, and capable of being undertaken by a single operator.

- Any additional monitoring requirements, and variations to the initial techniques should be documented for future studies.

- The results from all parameters monitored during this study should be tabulated (Microsoft EXCEL version 5 for Windows formatted disc, included with this dissertation), so that they are comparable from year to year.

1.8. Aims & objectives

The overall aim of the study was to develop a biological monitoring system to determine the performance and ecological impact of a newly constructed reedbed for the treatment of wastewater within a herb-rich grassland.

The specific objectives were:-

1.To describe the methods and processes used to establish and develop the reedbed during the first six months after planting.

2. To determine how the water chemistry entering the reedbed alters as it passes through the reedbed system during the monitoring period, and indicate reasons for these changes.

3. To assess the performance of reeds of different provenance in the treatment of wastewater.

4. To assess the relationship between inputs of nitrogen and phosphorus from treated effluent and inputs of nitrogen from the atmosphere, and their influence upon reed growth and development.

5. To provide a baseline survey of the soils, plants, invertebrates, birds and mammals that use the site, in order to be able to quantify changes which may result from the reedbed construction.

6. To suggest a future management strategy for the site.

CHAPTER TWO

2. THE ESTABLISHMENT AND DEVELOPMENT OF THE REEDBED

2.1. The design and construction of the reedbed system

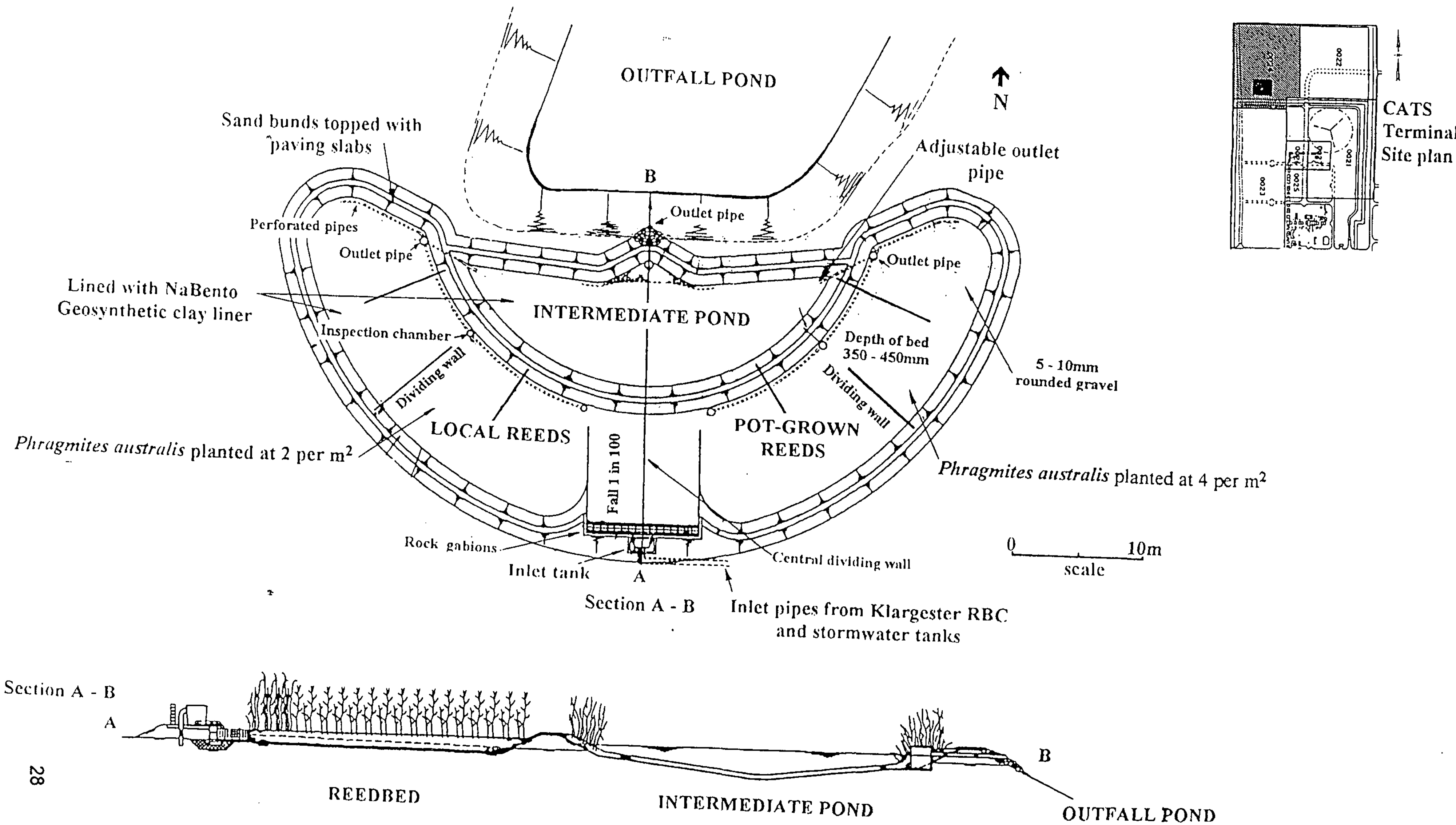
The principles of the design and construction of the reedbed follow those detailed by Cooper (1990), in the European Design and Operations Guidelines, but with modifications specific to the site by Dr. Chris Weedon of Weedon Water Systems, Bridgewater, and Mr. Philip Weiner of Parsons Group International Ltd.

The horizontal flow, sub-surface, tertiary treatment reedbed was designed to reduce the total BOD_5 from 20 mg O_2 l^{-1} (Klargester discharge) to 5 mg O_2 l^{-1} , when effluent was discharged from the Klargester at a rate of 0.006 kg m^3 day (6 m^3 per hour). This was originally based on 500 construction workers and a discharge at 60 litres of wastewater per day, giving a total of 30 m^3 wastewater at 20 mg O_2 l^{-1} BOD_5 (P.Weiner, personal communication).

A reedbed with a volume of 100 m^3 would have been adequate to reduce the BOD_5 loading down to the required 5 mg O_2 l^{-1}, especially as the construction workforce was on average 350. However, the reedbed was constructed with a capacity of 170 m^3, allowing it to reduce the loading of not 30 m^3, but 50 m^3 per day. The average discharge of 60 litres per day from a workforce of say 350, would result in a discharge from the Klargester to the reedbed of 21 m^3 per day. The reedbed was therefore generously sized. However, the reedbed was also designed to treat periodic discharges from the site stormwater tanks and wastewater from the live terminal which until July 1997, was discharged through a pipeline to Greatham Creek. The reedbed would be expected to cope with wastewater if the optimum low flow-rate of 6 m^3 per hour was not breached. Increasing the flow and total throughput would reduce the efficiency of the reedbed.

The reedbed was constructed during the autumn / winter of 1996 according to the CATS Terminal Project drawing numbers 7983-15/00/00/40/252/0040 and 0041. A less detailed, but annotated plan of the reedbed is shown in Figure 5.

Figure 5. CATS Terminal horizontal subsurface flow reedbed system
(Adapted from CATS Terminal project drawing no. 7983-15/00/00/40/252/0040)



The reedbed was designed with two identical halves so that, at six monthly intervals, each half could be pumped out in turn while the other half remained operational, in order to introduce oxygen into the beds. It was decided to plant each half of the reedbed with *Phragmites australis* (common reed) from two different provenances. The environmental conditions at the site were harsh (chapter five), and the reedbed situation was elevated (to avoid groundwater infiltration) and exposed, and some difficulties in establishing good plant growth had been reported elsewhere by Parr (1990) and Boar *et al.*(1991). The Institute of Terrestrial Ecology (ITE) recommended that pot-grown seedlings could successfully produce a dense stand of reeds in only four months (Cooper and Green, 1995). However, Kadlec and Knight (1996) reported that field-harvested plants were more likely to be adapted to local climatic conditions including their phenology and genetic tolerance to the area. Van der Toorn (1982), also commented on the successful growth of rhizome transplants in their native habitats.

The reedbed was planted with *Phragmites australis* on 5th and 6th of December 1996. 1000 pot-grown reeds were planted in one half of the reedbed at a density of 4 per m^2. Clumps of naturally growing reed from a wildlife pond at nearby Wilton ICI were split and planted in the remaining half of the reedbed at a density of 2 per m^2.

The reedbed overflows pass into the lined Intermediate Pond. In order to oxygenate the Intermediate Pond and to provide further substrates for water purification, the margins of the pond were planted with pot-grown native aquatic plants on 10th April 1997. The following plants were deemed the most suitable taking into account the pH of the water and the size of the pond.

15 x Water mint - *Mentha aquatica* L.

10 x Water plantain - *Alisma plantago-aquatica* L.

10 x Arrowhead - *Sagittaria sagittifolia* L.

10 x Spiked water-milfoil - *Myriophyllum spicatum* L.

10 x Water crowfoot - *Ranunculus aquatilis* L.

40 x Marsh marigold - *Caltha palustris* L.

40 x Yellow flag - *Iris pseudacorus* L.

10 x Common water starwort - *Callitriche verna* L.

10 x Curled leaf pondweed - *Potamogeton crispus* L.

The plants were not monitored systematically but, apart from several Yellow Flag plants which were grazed by birds, the aquatic plants grew well during the summer following establishment and spread around and within the Intermediate Pond (Plate 7). *Tripleurospermum maritimum* (L.) Koch (Sea Mayweed), and *Epilobium hirsutum* L. (Great Willow-herb) have seeded and developed in the gravel and have not been removed. Plants should be removed if they obstruct the outlet pipes from the reedbed or the pipe to the Outfall Pond.

Outfall Pond margins were not planted, and were left to develop a natural flora by colonisation (Plate 8).

2.2. The development of the planted reeds

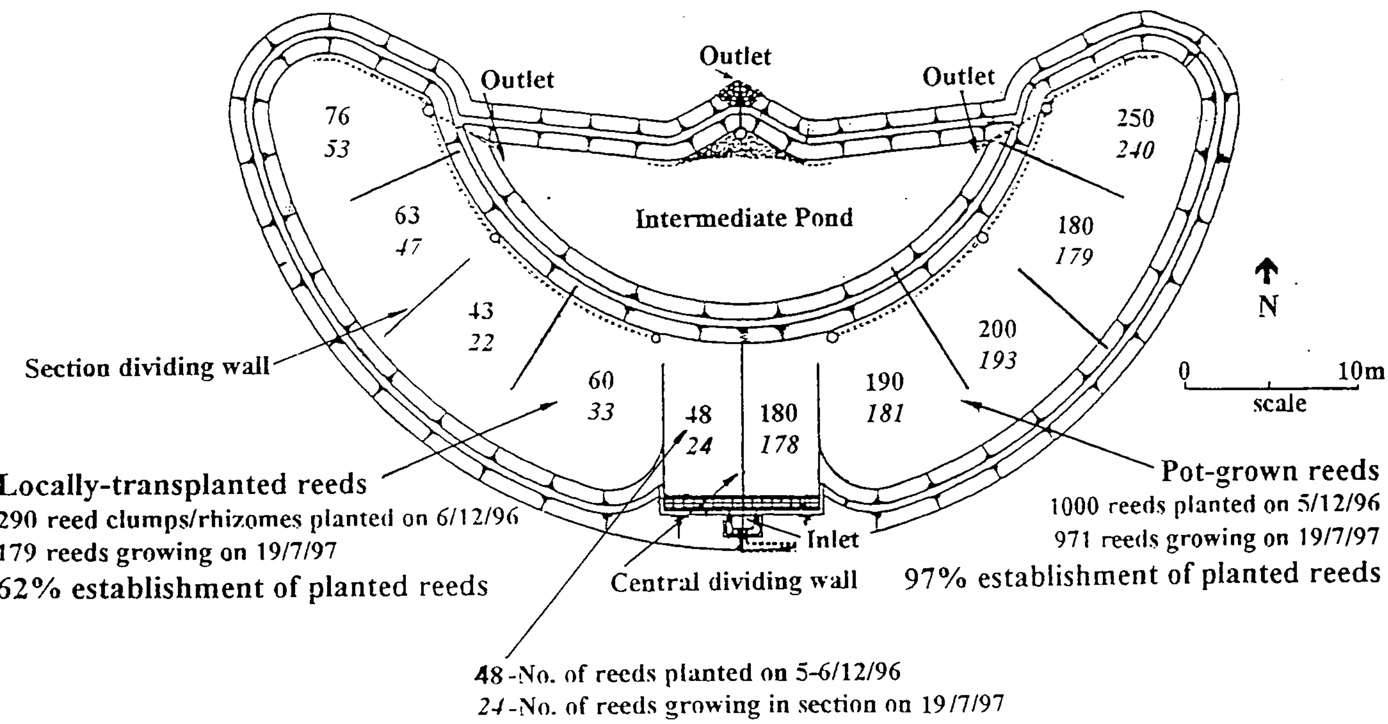
Following inclement weather during the spring, pot-grown reed plugs which were frequently disturbed by wind and ice-heave were re-planted when required. Re planting was necessary until April when root development secured the reeds in the gravel substrate. Above ground, shoot growth commenced from April, 1997. By 15th April, 95 % of the pot-grown reeds had produced new shoots, compared to 25 % of the locally transplanted reeds. Although hares were present on the site, there was no evidence of grazing damage to the emerging reed shoots. Some of the locally transplanted reed shoots emerging during April were damaged by strong winds. This problem declined when the shoot density increased during May.

Plate 7. Aquatic marginal plants around the CATS Terminal reedbed system Intermediate Pond, August 1997.
(Pot-grown section of the reedbed to the left, local reed section to the right)

Plate 8. Natural colonisation of marginal vegetation around the CATS Terminal reedbed system Outfall Pond, August 1997.
(Southern margin of pool showing outlet from Intermediate Pond)

Of the 1000 pot-grown reeds planted in one half of the reedbed on 5th December 1996, 971 plants were alive and growing on 19/7/97, amounting to 97 % establishment of planted reeds. Of the 290 local reed clumps / rhizomes planted in the remaining half of the reedbed on 6th December, 1996, 179 were alive and growing on 19/7/97, amounting to 62 % establishment of local reeds. The 2 sections and 10 areas of the reedbed detailing the planted and remaining reeds are shown in Figure 6.

Figure 6. Plan of *Phragmites australis* planted at the CATS Terminal reedbed on 5/12/96, showing the number of reeds growing on 19/7/97.



2.2.1. Percentage cover of the reedbed

In order to determine the establishment of the reeds in terms of ground cover, a visual estimate of the percentage cover within each section was made looking down on the vegetation. When the constructed reedbed was planted with reeds on 5th and 6th of December 1996, percentage cover over all areas of the pot-grown section of the reedbed was approximately 1 % (Plate 9). Percentage cover over the local reed section was approximately 2 %. Percentage cover values for the reedbed estimated on two further occasions are listed in Table 2.

Table 2. Percentage cover of *Phragmites australis* in 10 sections of the CATS Terminal reedbed on 16/12/96, 19/7/97 and 12/8/97.

Area in reedbed	**% cover**		
	16/12/96	19/7/97	12/8/97
Pot-grown reeds 1 (inlet)	1	40-50	95
Pot-grown reeds 2	1	30-40	80-90
Pot-grown reeds 3 (middle)	1	30-40	60-70
Pot-grown reeds 4	1	30	40-50
Pot-grown reeds 5 (outlet)	1	20	25-30
Local reeds 1 (inlet)	2	10	25
Local reeds 2	2	10-15	25-30
Local reeds 3 (middle)	2	10	20
Local reeds 4	2	15	25
Local reeds 5 (outlet)	2	15-20	25

Plates 10 to 12 show the development of the pot-grown section of the reedbed between May and August 1997.

Reed height was measured in order to compare reed growth between the different sections of the reedbed and is discussed in chapter four.

Plate 9. Pot-grown *Phragmites australis* section of the CATS Terminal reedbed, December 1996.

Plate 10. Pot-grown *Phragmites australis* section of the CATS Terminal reedbed, early May 1997.

Plate 11. Pot-grown *Phragmites australis* section of the CATS Terminal reedbed, late July 1997.

Plate 12. Pot-grown *Phragmites australis* section of the CATS Terminal reedbed, late August 1997. (Local reed inlet section in the foreground showing less successful establishment of planted reeds)

The Water Research Council commisioned a study by the Institute of Terrestrial Ecology (ITE) on the establishment of reed growth in 81 reedbed treatment systems. It was found that reed establishment in the beds (1 to 3 years old) was disappointing. In theory, it should be possible for a reedbed to have 100 % cover within two years. In practice, only 18 out of the 81 reedbeds studied supported satisfactory reed growth (Parr, 1990). It was also found that beds planted with rhizomes and clumps of reeds took a long time to spread and cover the whole bed. The study found that pot-grown seedlings, planted at a density of 4 plants m^2, would give the most reliable establishment and cover (Cooper & Green, 1995). Within the CATS Terminal reedbed, the 97 % establishment and 25 to 95 % cover in the first eight months after planting of the pot-grown reeds, supports the ITE results.

Despite the lower percentage cover, it was decided to allow the local reed section to expand naturally rather than increasing the density with pot-grown reeds. The technique of 'layering', as described by Hawke and Jose (1996) could be used to increase reed density. Overground runners were produced by some of the local reeds, and if covered by gravel, roots and side shoots could develop at the nodes. This method was advised for the CATS Terminal reedbed (chapter ten). Meanwhile, the variation in structural density between both sections of the reedbed should increase the habitat diversity for birds and invertebrates (chapters seven and eight).

'Weeds' growing in the pot-grown section were predominantly windblown grass and broadleaved 'weeds' associated with the grassland such as *Tussilago farfara* L. (Coltsfoot), and *Taraxacum* spp.(Dandelion). However, 'weeds' appearing in the local reed section were wetland species which had been transplanted with the local reeds. For example *Typha latifolia* L. (Greater Reedmace) and *Epilobium hirsutum* (Great Willowherb). 'Weeds' were removed weekly from the reedbed until July, 1997, after which weeding on a monthly basis was agreed with the site maintenance team.

During the summer of 1997, it became apparent that the depth of gravel in the reedbed was less than originally specified (the design required 350 mm depth at the inlet and 450 mm at each outlet). This would result in reduced wastewater retention time and treatment performance. Dr. Chris Weedon (Weedon Water Systems) advised that the reeds should be cut back during late March 1998, before raising the gravel to the specified level. Although cutting back the reeds will reduce the habitat value of the reedbed for wildlife during the spring and early summer of 1998, the reeds should remain unharvested following this remedial work.

2.3. The performance of the reedbed in ameliorating a major accidental discharge

The high rainfall over the site during May and June which culminated in a deposit of 41 cm on 30/6/97, resulted in localised flooding of the site, of greatest consequence in the hollow where the Klargester was situated (Plate 2). The Klargester was innundated with excess groundwater with a high suspended silt content. The Klargester began to discharge into the reedbed a continuous flow of groundwater and re-suspended sludge from the settlement tanks for a period of at least 6 hours. The performance of the reedbed was monitored and the results are summarised in the table following.

Table 3. Dairy of events following an accidentally high discharge of effluent from the Klargester RBC into the CATS Terminal reedbed on 1/7/97.

TIME	OBSERVATION
1/7/97 - 5.50 am	Strong smell observed when approaching the reedbed. On inspection, the discharge pipe from the Klargester was releasing a higher than specified, continuous flow of dark brown liquid to an already flooded reedbed. The level of the liquid in the reedbed was 9 cm above the surface of the gravel. The discharge had reached the intermediate pond which contained cloudy, brown water.
	The reedbed had been checked at 8.30pm the previous evening when small mammal traps were positioned throughout the site. Although the surrounding grassland was very wet, no irregular discharges were exuded from the Klargester.
1/7/97 - 6.00 am	Water samples were taken from the Klargester discharge pipe and also from the intermediate pond discharge chamber, and taken to ITS Testing Services (UK) Ltd. Middlesbrough for analysis of BOD_5 and SS.

1/7/97 - 10.30 am	Continuous flow ceased and the Klargester pump resumed control of the discharge, which remained dark grey in appearance with a high suspended sediment content. The wastewater in the reedbed was 11cm above the surface of the gravel. The colour of the wastewater was dark grey in the two inlet sections and cloudy brown in the remaining areas of the reedbed.
1/7/97 - 10.50 am	The level of the wastewater had dropped to 8 cm above the level of the gravel. The regulated flow from the Klargester was a cloudy brown colour. Water samples were taken at the inlet and outlets for ammonium, nitrite and nitrate.
1/7/97 - 14.00 (Plate 13)	The wastewater level in the reedbed had fallen, but remained above the surface of the gravel. Rock gabions were visible, however, a layer of dark brown/grey sludge was deposited over the gabions and the surface of the inlet sections of the reedbed. The intermediate pond continued to discharge cloudy, light brown wastewater rapidly into the outfall pond, where the level had been raised due to the discharge and the heavy rain.
1/7/97 - 16.00	The wastewater level was 4 cm above the level of the gravel. The areas of dark sludge were restricted to the inlet sections of the reedbed, the section dividing walls appear to have successfully preventing short-circuiting of the flow.
1/7/97 - 21.00	The dark/grey sludge covering the reedbed inlet sections contained some red coloured sediment. The intermediate pond, although a cloudy-brown colour, had started to become more clear, although discharging rapidly into the outfall pond.
2/7/97 - 06.00	The wastewater level in the reedbed was 2 cm above the surface of the gravel. 75% of the inlet sections were covered with a thick sludge deposit which contained a small amount of red sediment. The gravel in the sections of the reedbed next to the inlet sections were coated with brown sediment, some remaining in suspension. The gravel in the remaining sections of the reedbed were coated with a light-brown sediment,however the wastewater above the surface was relatively clear. The smell from the reedbed was less noticeable. The upper 10 cm of the intermediate pond was clear, with no surface scum.
2/7/97 - 10.00	The upper 15 cm of the intermediate pond had cleared. Gravel samples were taken at the inlet and outlet areas of the reedbeds for invertebrates.
2/7/97 - 14.30	Discharge from the Klargester was very clear, with little discernable colour or sediment content. (Clearer than any samples taken since January). The wastewater in the reedbed had fallen to the level of the gravel.
3/7/97 - 09.00	The sludge covering the inlet sections of the reedbed was at least 1 cm thick. The surface of the sludge exposed to the air, had developed cracks due to decomposition. Pied Wagtails were feeding over the surface of the sludge. Water in the intermediate pond had cleared, almost to the bottom where a thin layer of pale brown sediment had covered the gravel. Relatively clear effluent was trickling from the intermediate pond into the outfall pond.
3/7/97 - 4/7/97	The exposed sludge in the inlet sections of the reedbed continued to decompose. Pied Wagtail and Meadow Pippit were regularly feeding in the reedbed. The smell from the reedbed was hardly noticeable.

The reedbed demonstrated its capacity to successfully buffer the heavily loaded discharge from the Klargester. The re-suspended sludge quickly settled in the inlet sections of the reedbed (Plate 14). Lowering the water level in the reedbed allowed

Plate 13. Flooded rock-gabions and pot-grown *Phragmites australis* inlet section of the CATS Terminal reedbed, 14.00 hours, 1/7/97.

Plate 14. Sludge deposited within the pot-grown *Phragmites australis* section of the CATS Terminal reedbed, 2/7/97.

aerobic decomposition to proceed. The sludge contained an abundance of Chironomid larvae (chapter seven) attracting feeding *Motacilla alba* ** L. (Pied Wagtail) and *Anthus pratensis* L. (Meadow Pippit). Although effluent passing through the reedbed was not treated with respect to nitrogen transformations due to short retention times (chapter three), the BOD_5 and SS levels passing out of the reedbed were within the consent limits.

	Consent limit (mg l^{-1})	Reedbed inlet mg l^{-1} 1/7/97- 06.00hours	Reedbed outlet mg l^{-1} 1/7/97- 06.00 hours
BOD_5	100	114	6.3
TSS	50	488	45

(results from ITS Testing Services (UK) Ltd. Middlesbrough)

The Klargester was designed to produce effluent not exceeding BOD_5 20mg O_2 l^{-1}, and SS 30 mg l^{-1}, which were well within the consent limits, however the flooding event of 1/7/97 would have resulted in a fine and would have severely depleted the dissolved oxygen content of the Outfall Pond. The reedbed coped well with the abnormal loading, providing an effective buffer before discharge to the natural watercourse with only a minimal effect on the overall treatment process.

* Nomenclature of birds follows that of Cramp, S *et al.* (1980)

CHAPTER THREE

3. THE PERFORMANCE OF THE REEDBED IN TREATING SITE EFFLUENT

Chemical and biological methods of water analysis were undertaken from mid-January to 9th July 1997 in order to assess the changes in water quality as effluent passed through the reedbed treatment system. As mentioned earlier, the Environment Agency authorised Amoco (UK) Exploration, to discharge on-site effluent through the reedbed not exceeding BOD_5 100 mg O_2 l^{-1} and SS 50 mg l^{-1}. The reedbed can be judged to successfully treat site effluent if these determinands are met. However, an analysis of how the wastewater changes as it passes through the reedbed provides a more thorough evaluation of the performance of the system.

The performance and ecological impact of the reedbed will benefit from long-term monitoring of the site. Documented procedures and results will allow future monitoring to be directly comparable. Where standard procedures have been followed, references to the method are given, with any variations outlined in the text. Methods which are less readily available are given in more detail.

3.1. Methods

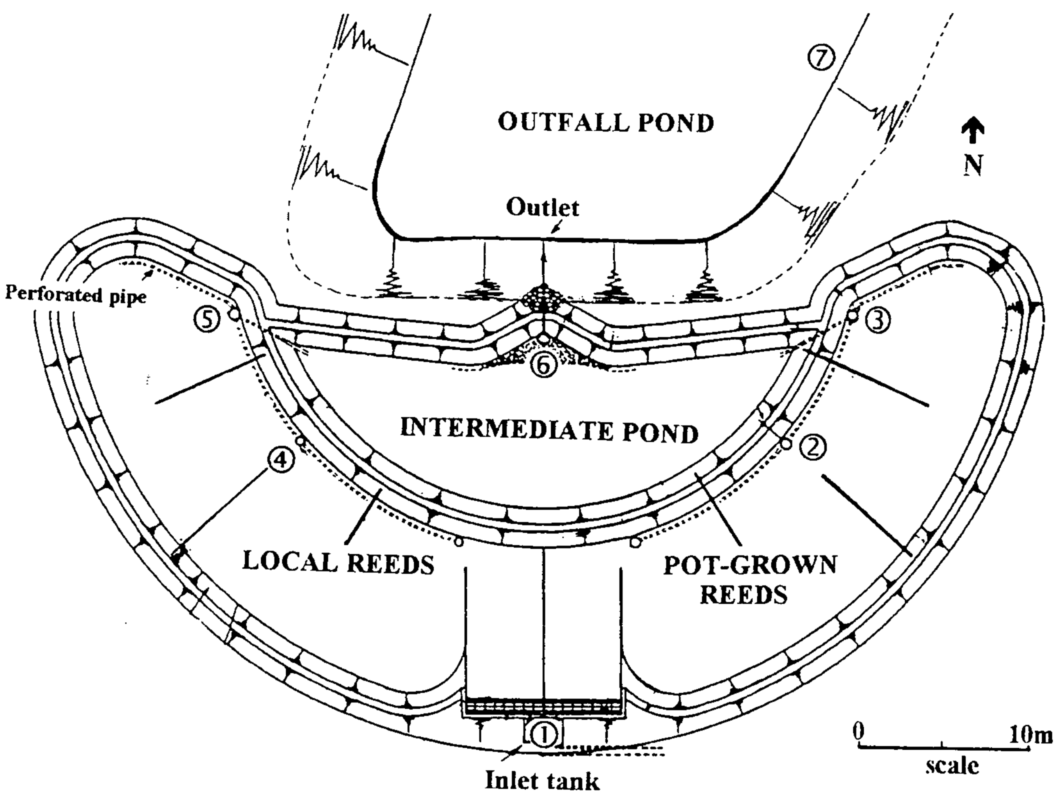
3.1.1. Collection and preparation of samples.

All glassware and polyethylene bottles used in sample collection and laboratory analysis of water, soil and tissue samples were washed with phosphate-free detergent (Decon 90), acid washed (10 % HCl), and rinsed with tap and finally deionized water. All chemicals and reagents were made freshly as required or stored in the dark at 4 °C.

3.1.1.1. Collection of water samples

Water samples were taken from sampling points as shown in Figure 7. Containers were rinsed three times with the water to be sampled before collection. Samples were taken in triplicate at a depth of 15 cm below the surface, in 500 cm^3 polyethylene bottles, was taken to exclude air from the bottles. Samples were taken from the site on the day of analysis at approximately 9.00 am, taken to University College Stockton, and analysed within 4 hours of collection. Samples for phosphate and nitrate determination by the SKALAR Auto-analyser (SAN^{PLUS}, SKALAR, Breda, The Netherlands) were frozen until the analyser was operational.

Figure 7.CATS Terminal reedbed system water sampling points



REED BED SAMPLE POINTS
1.Klargester/stormwater inlet tank.
2.Pot-grown reed bed inspection chamber.
3.Outlet chamber from pot-grown reed bed.
4.Local reed bed inspection chamber.
5.Outlet chamber from local reed bed.
6.Outlet chamber from intermediate pond.
7.Outfall pond.

3.1.2. Biochemical Oxygen Demand (BOD_5)

Measurements were determined using the standard Department of the Environment method (DoE, 1988). Efficient BOD_5 determinations required samples to be prepared and incubated on the day of collection. The number of determinations (taken in triplicate) meant that it was not practical to take samples from the middle areas of the reedbed.

270 cm^3 capacity, ground glass-stoppered incubation bottles were used in the test. The water samples generally required dilution. The dilution factors (DF) varied depending on the quality of the sample, and were as follows:

Reedbed inlet (area 1.)	DF=10 or 5
Pot-grown reed outlet (area 3)	DF=3 or 2
Local reed outlet (area 5)	DF=3 or 2
IntermediatePond (area 6)	DF=3 or 2
Outfall Pond	undiluted

Dilution waters were prepared freshly on the morning of each test according to the standard method. Where algae were present the water, samples were filtered and were shown in the results. 2.0 mg l^{-1} of 0.10 % Allyl thiourea solution was added to all samples in order to supress nitrification. All results were therefore quoted as BOD_5 (ATU). Two blank samples containing dilution water were determined during each test to provide a check on the validity of the method and quality of the dilution water.

A standard solution of glucose/glutamic acid with a BOD_5 of 220 mg O_2 l^{-1} was determined with each test run as an analytical quality control. The water samples did not require seeding, however the glucose/glutamic standard did require seeding. 5 cm^3 of inlet area sample was added to 1l of dilution water, 20 cm^3 of which was added to the standard. Dissolved oxygen concentrations of the prepared BOD_5 samples were determined using the Winkler titration as detailed in the standard Department of the Environment method

(DoE, 1979). The modified Pomeroy-Kirschman-Alsterberg reagent was used as the preferred alkaline iodide-azide solution as it gave a more accurate titrimetic end point.

The prepared BOD_5 samples were incubated for five days at 20 °C, using a LMS cooled incubator, after which the dissolved oxygen content of the samples were taken and BOD_5 calculations determined.

3.1.3. Dissolved Oxygen

Dissolved Oxygen concentrations were determined for all areas of the reedbed, using a Hanna 9071 portable dissolved oxygen meter (Hanna Instrumemnts Ltd., Leighton Buzzard, Bedfordshire), and calibrated with sodium sulphite as described in the operating manual. Measurements of samples were taken at 20 °C in the laboratory.

3.1.4. Chemical Oxygen Demand.

Chemical Oxygen Demand was determined by the Dichromate Reflux Method using colourimetric determination method 8230 (mg O_2 l^{-1}), using a Hach Direct Reading Spectrophotometer, Model DR/2000 (Camlab, Cambridge). Efficient COD determinations require samples to be prepared on the day of collection.The number of determinations (in triplicate) meant that it was not practical to take samples from the middle areas of the reedbed.

As the expected COD range was between 0-800 mg O_2 l^{-1} , 10 cm^3 of sample was required for each test. A standard solution of potassium acid phthalate with a COD of 500 mg O_2 l^{-1} was determined with each test run as an analytical quality control.

3.1.5. Suspended solids

Suspended Solids were determined by the Photometric Method 8006 (0-750 mg l^{1}) (also called nonfilterable residue), using the Hach Direct Reading Spectrophotometer.

3.1.6. pH

pH measurements were taken at the site using a Hanna HI 9025C portable pH meter (Hanna Instrumemnts Ltd., Leighton Buzzard, Bedfordshire) with temperature compensation between 20/1/97 to 13/3/97. However, in order to standardise water analysis methods, subsequent measurements were taken at a standard 20 °C in the laboratory, using a Jenway 3020 pH meter (Jenway Ltd., Dunmow, Essex), taken to two decimal places. Results analysed did not therefore include measurements taken between 20/1/97 to 13/3/97. Standard buffer solutions of pH 4, 7 and pH 10 were used for calibration.

3.1.7. Conductivity

Conductivity measurements were taken at the site using a Hanna HI 93300 portable conductivity meter (Hanna Instrumemnts Ltd., Leighton Buzzard, Bedfordshire) with temperature compensation between 20/1/97 to 20/3/97. However, in order to standardise water analysis methods, subsequent measurements were taken at a standard 20 °C in the laboratory, using a Jenway 4010 conductivity meter (Jenway Ltd., Dunmow, Essex). Results analysed did not therefore include measurements taken between 20/1/97 to 20/3/97. Prior to use the meter was calibrated to 1413 $\mu S\ cm^{-1}$ using 0.01M KCl.

3.1.8. Ammonium.

Ammonium nitrogen (NH_4^+-N) was measured using a Merck Reflectoquant RQflex. (Merck KGaA, Darmstadt, Germany). According to the principle of remission photometry, reflected light from a test strip is measured using the difference in intensity of emitted and reflected light.

The Ammonium test range selected was between 0.2 - 7.0 mg l^{-1} NH_4^+. and samples were diluted where necessary to fall within the range. The procedure was as follows:-

10 drops of reagent NH_4-1 were added to 5 cm^3 of sample followed by one level microspoon of reagent NH_4-2. After swirling the sample, an anaylitical test strip was placed in the solution for eight minutes. The test strip was shaken to remove excess liquid and immediately inserted into the strip adapter of the reflectoquant. The concentration of NH_4^+ was shown on the display. This amount of NH_4^+ was multiplied by 0.777 to give the result as NH_4^+-N. In this method, NH_4^+ ions reacted with a chlorinating agent to form monochloramine. This in turn reacted with a phenol compound to form a blue indophenol derivative, the concentration of which was determined reflectometrically.

3.1.9. Nitrite.

Nitrite nitrogen (NO_2^--N) was measured using the Merck Reflectoquant RQflex. The nitrite test range selected was between 0.5 to 25.0 mg l^{-1} NO_2^-. The amount of NO_2^- was multiplied by 0.304 to give the results as NO_2^--N. The procedure was as follows:- An analytical test strip was placed in the sample solution for two seconds and the timer of the reflectoquant activated for a 15 second period. Five seconds before the end of the reaction time, the test strip was inserted into the strip adapter. The concentration of NO_2^- was shown on the display.This amount of NO_2^- was multiplied by 0.304 to give the results as NO_2^--N. In this method, in the presence of an acidic buffer, nitrite reacted with an aromatic amine to form a diazonium salt, which in turn reacted with N-(1-napthyl)-ethylene-diamine to form a red-violet azo dye, the concentration of which was determined reflectometrically.

3.1.10. Nitrate

Nitrate nitrogen (NO_3^--N) was also measured using the Merck Reflectoquant RQflex. The nitrate test range selected was between 3 - 90 mg l^{-1} NO_3^- and samples were diluted where necessary to fall within the range. The procedure was as follows:-

An analytical test strip was placed in the sample solution for two seconds and the timer of the reflectoquant activated for a 60 second period. Five seconds before the end of the reaction time, the test strip was inserted into the strip adapter.The concentration of NO_3^- was shown on the display.This amount of NO_3^- was multiplied by 0.226 to give the results as NO_3^--N. In this method, Nitrate was reduced to nitrite by a reduction agent, and as in the nitrite test, a red-violet azo dye was produced, the concentration of which was determined reflectometrically. In samples where the nitrite concentration was higher than 0.5 mg l^{-1}, interfering nitrite ions were eliminated by adding 5 drops of a 10 % aqueous amidosulfonic acid solution to each 5 cm^3 of sample. To check the equipment and procedure, a 30 mg l^{-1} NO_3^- standard solution was analysed during each sampling period. Samples that displayed values below 1 mg l^{-1} were frozen and concentrations were later analysed, undiluted, by the SKALAR Segmented Flow Analyser which became operational during August of 1997.

The segmented flow analyser was an automatic continuous flow method of chemical analysis in which a stream of reagents and samples, segmented with air bubbles was pumped through a manifold to undergo treatment before entering a flow cell to be detected. The determination of nitrate was based on the cadmium reduction method; the sample was passed through a column containing granulated copper-cadmium to reduce the nitrate to nitrite. The nitrite was determined by diazotizing with sulfanilamide and coupling with α-naphthylethylenediamine to form a coloured azo dye which was measured by a photometric detector at 540 nm.

3.1.11. Phosphate

Reactive phosphorus present as phosphate was determined between 6/3/97 to 30/4/97, by the Ascorbic Acid method 8048 (0 - 2.50 mg l^{-1} PO_4^{3-}), using a Hach Direct Reading Spectrophotometer, Model DR/2000. Samples were diluted to fall within the range and the method validated with a 2 mg PO_4^{3-} l^{-1} standard solution during each sampling period. The concentrations were divided by 3 to give the results as PO_4^{3-}-P. Phosphate present in ICI No.6 brinefield water samples could not be detected by method 8048, and it was decided that from 20/5/97, samples from the ICI site and the reedbed system would be frozen for later analysis by the SKALAR segmented flow analyser. ICI samples were analysed undiluted, reedbed inlet samples were diluted by 10, and the remaining reedbed samples were diluted by a factor of 3. The determination of phosphate by the SKALAR analyser was based on the following reaction; ammonium molybdate and potassium antimony tartrate reacted in an acidic medium with diluted solutions of phosphate to form an antimony-phospho-molybdate complex. This complex was reduced to a blue coloured complex by ascorbic acid and measured by a photometric detector at a wavelength of 880 nm.

3.1.12. Chloride.

Chloride levels were determined between 14/2/97 to 2/4/97, using a Jenway 3040 Ion analyser (Jenway, Dunmow, Essex) with a chloride ion selective electrode ELIT 261. The electrode was calibrated with a set of standard Cl^- solutions prepared freshly for each sampling period with the following concentrations:

1) 100 mg l^{-1} Cl^- 2) 500 mg l^{-1} Cl^- 3) 1000 mg l^{-1} Cl^- 4) 5000 mg l^{-1} Cl^-

Measurements taken on 2/4/97 were inconsistent although measurements of the standard solutions were constant. Interference by undetermined factors within the samples prompted analyses by a different method. Determination of chloride by titration with standard silver nitrate was undertaken (APHA, 1992), using potassium chromate as an indicator, and chloride standards of 100 mg l^{-1} Cl^-, 200 mg l^{-1} Cl^- and 300 mg l^{-1} Cl^- were titrated for validation of the method.

3.1.13. Reedbed air/water temperature.

The temperature of the inlet water was taken for each sampling point during each sampling period using the portable pH meter temperature probe. Between 13/6/97 to 10/7/9 reedbed water temperatures were measured at the site using a GRANT 1200 Squirrel logger (Grant Instruments, Cambridge) at hourly intervals. Daily air temperatures between 15/1/97 to 10/7/97 were supplied by ICI Chemicals & Polymers and were taken at the Billingham site (NZ 475 221).

3.1.14. Rainfall.

Mean daily rainfall figures between January to July were supplied by the Environment Agency, West Hartlepool monitoring station (NZ508 334).

3.2. Results

In order that long-term monitoring of the reedbed and associated grasslands can be directly comparable with this study, the results from all monitored parameters are tabulated in an EXCEL version 5 for Windows 3.11 formatted disc accompanying this dissertation.

3.2.1. Reedbed water analysis-Interpretation of results

Mass balance and removal efficiency calculations could not be calculated without accurate flow measurements. Due to ongoing technical and administration problems at the CATS Terminal site, the flow meter, expected during January, 1997 was not installed during the project. Concentration, rather than loading, therefore forms the basis for the performance evaluation of the reedbed.

With reference to detailed results from several Severn Trent Water PLC tertiary treatment reedbeds, it became apparent that daily fluctuations in effluent quality are commonplace and could be expected. Seasonal or even yearly averages were taken for the required monitored parameters. The performance of the CATS Terminal reedbed must initially be assessed on the basis of less than six months data from fortnightly or monthly spot samples. Spot samples (taken in triplicate), taken at each section of the reedbed did not relate exactly to each other as the water takes approximately two days to pass through the system. With these constraints in mind, it was still possible to monitor changes in water quality as it passed through the reedbed. Mean values for the main water quality determinands have been calculated for the period of study, and are presented in the following table.

Table 4. Mean concentration (±SE) and purification efficiency for the main water quality determinands at the CATS Terminal reedbed between January-July 1997.

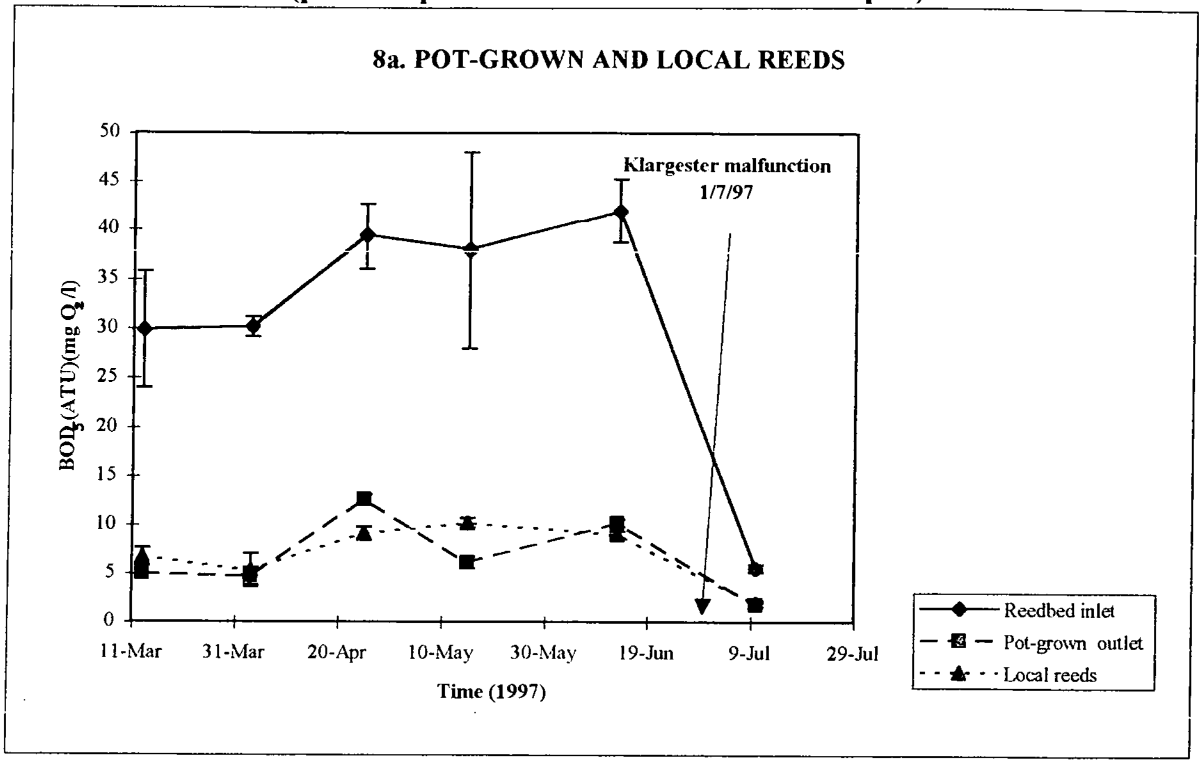
Area of reedbed	BOD_5 (mg l^{-1})	COD (mg l^{-1})	SS (mg l^{-1})	*NH_4^+ (mg l^{-1})	NO_3^- (mg l^{-1})	*Ing.-N (mg l^{-1})	PO_4^{3-}-P (mg l^{-1})
Pot-grown inlet	30.8 (5.5)	254.6 (45.8)	78.0 (18.7)	1.5 (1.0)	16.4 (3.1)	17.7 (2.8)	11.3 (2.3)
Pot-grown middle	-	-	9.0 (1.1)	9.5 (4.2)	1.1 (0.4)	6.4 (1.0)	2.5 (0.3)
Pot-grown outlet	6.7 (1.6)	93.0 (11.4)	7.6 (0.9)	8.0 (3.1)	1.1 (0.6)	6.0 (0.5)	2.1 (0.3)
% difference (inlet to outlet)	**-78 %**	**-63 %**	**-90 %**	**433 %**	**-93 %**	**-66 %**	**-81 %**
Local reed inlet	30.8 (5.5)	254.6 (45.8)	78.0 (18.7)	1.5 (1.0)	16.4 (3.1)	17.7 (2.8)	11.3 (2.3)
Local reed middle	-	-	13.3 (3.5)	6.5 (3.0)	1.3 (0.6)	4.7 (0.4)	3.1 (0.5)
Local reed outlet	7.0 (1.3)	106.0 (19.0)	18.4 (5.5)	8.0 (3.1)	1.2 (0.4)	6.1 (0.5)	3.0 (0.3)
% difference (inlet to outlet)	**-77 %**	**-58 %**	**-76 %**	**433 %**	**-92 %**	**-65 %**	**-73 %**
Intermediate pond	8.6 (1.7)	104.2 (16.0)	24.0 (8.8)	0.5 (0.1)	2.0 (0.5)	2.7 (0.6)	2.2 (0.2)
% difference (reedbed inlet to reedbed outlet)	**-72 %**	**-59 %**	**-69 %**	**-66 %**	**-88 %**	**-85 %**	**-80 %**

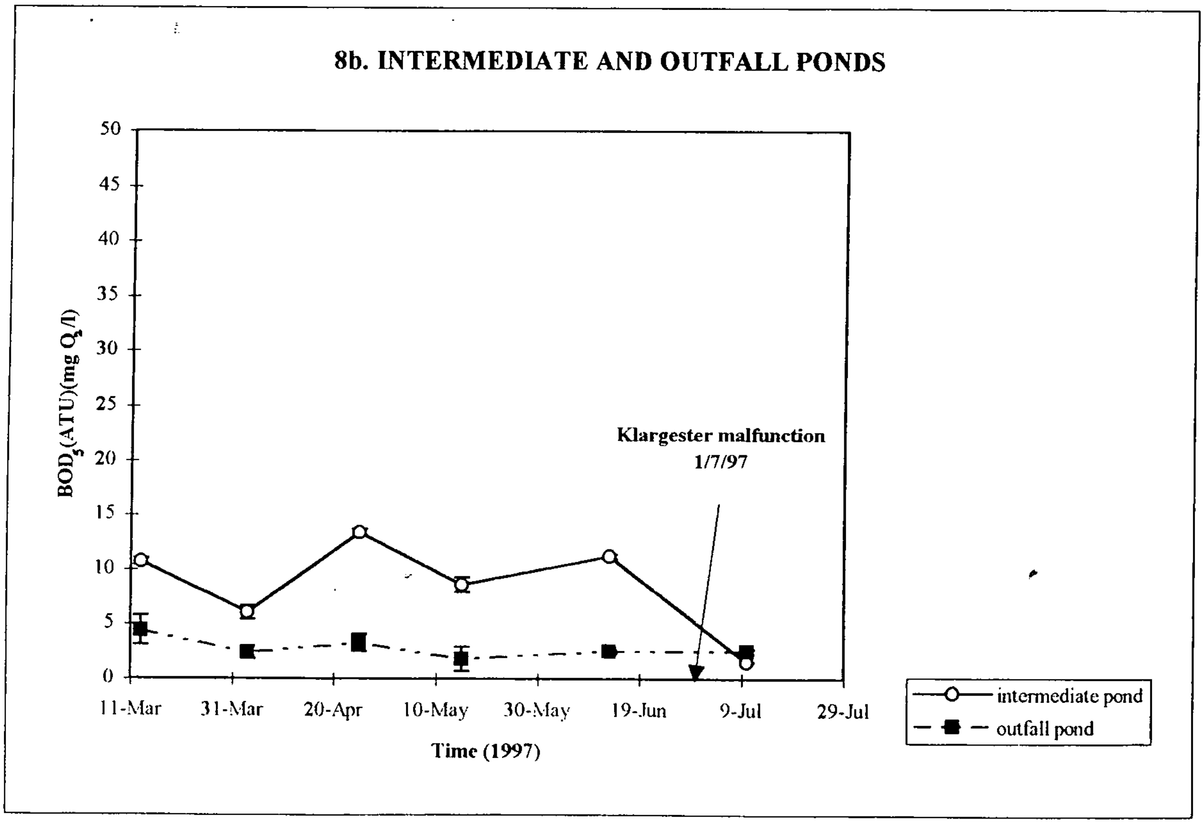
(*NH_4^+, NO_3^- and NO_2^- determinations were sampled on the same day and combined to provide the inorganic-N fraction of the wastewater. An earlier high NH_4^+ determination was not part of the inorganic-N fraction as NO_3^- and NO_2^- were not available at that time)

3.2.2. Biochemical Oxygen Demand (BOD_5 ATU)

The Klargester biodisc was designed to provide an effluent not exceeding 20 mg O_2 l^{-1} BOD_5. The final effluent from the biodisc being discharged into the inlet section of the reedbed, achieved the standard on only one out of 6 monitoring occasions. The BOD_5 of the reedbed influent ranged from 5.5 to 42.0 mg O_2 l^{-1} , with an average of 30.1 mg O_2 l^{-1}. It can be seen from the graph (Figure 8a), that influent levels increased with time until the water was sampled on 10/7/97, following the Klargester discharge of 1/7/97, when a 5.5 mg O_2 l^{-1} BOD_5 was recorded.

Figure 8. Graphs to show the BOD (ATU)(mg O_2 /l) of water samples from the CATS Terminal reedbed between 13/3/97- 10/7/97 (points represent the mean +/- SE of 3 samples)





Pot-grown section

2-way ANOVA indicated that there was a significant reduction in the BOD_5 of water between the inlet and outlet areas of the reedbed ($F_{1,24} = 131.0$, $p < 0.001$). Water leaving the reedbed ranged from between 1.8 to 12.6 mg O_2 l^{-1} BOD_5 with an average of 6.7 mg O_2 l^{-1} BOD_5. The BOD_5 of the outlet water did not increase with time (Figure 8a).

Local reed section

There was a significant reduction in the BOD_5 of water between the inlet and outlet areas of the reedbed ($F_{1,24} = 125.5$, $p < 0.001$). Water leaving the reedbed ranged from between 1.9 to 10.2 mg O_2 l^{-1} BOD_5 ,with an average of 7.0 mg O_2 l^{-1} BOD_5.The BOD_5 of the outlet water did not increase with time (Figure 8a).

Comparison between pot-grown and local reed sections of the reedbed

There was no significant difference in the reduction of BOD_5 between the pot-grown and local reed sections of the reedbed. The average reduction in BOD_5 between the inlet and outlet areas of the reedbed over the monitoring period was 78 % in the pot-grown section, and 77 % in the local reed section.

The Intermediate Pond

BOD_5 in the final polishing pond of the reedbed system ranged between 1.5 to 13.4 mg O_2 l^{-1}, with an average of 8.5 mg O_2 l^{-1} BOD_5. The slight increase in biochemical oxygen demand within the Intermediate Pond was not significant (Figure 8b).

The results clearly show the improved water quality, in terms of BOD_5, following the flushing of the Klargester on 1/7/97. Inlet samples were visibly much clearer, and gave a low BOD_5 of 5.5 mg O_2 l^{-1}. which was further reduced in the reedbed to < 2.0 mg O_2 l^{-1} BOD_5. From mid-July until September, when BOD_5 determinations had ceased, visual inspection of the discharge from the Klargester confirmed that BOD_5 was unlikely to be high.

The results from the first six months operation of the reedbed showed that the system met the Environment Agency standard of 100 mg O_2 l^{-1} BOD_5, 100 % of the time.

3.2.3. Chemical Oxygen Demand (COD)

The COD of the reedbed influent ranged from 121 to 358 mg O_2 l^{-1}, with an average of 254.6 mg O_2 l^{-1}. The highest inlet COD levels were recorded on 21/4/97 and 19/5/97, and reflected the variable nature of the influent content, as shown in Figure 9a.

<u>Pot-grown section</u>

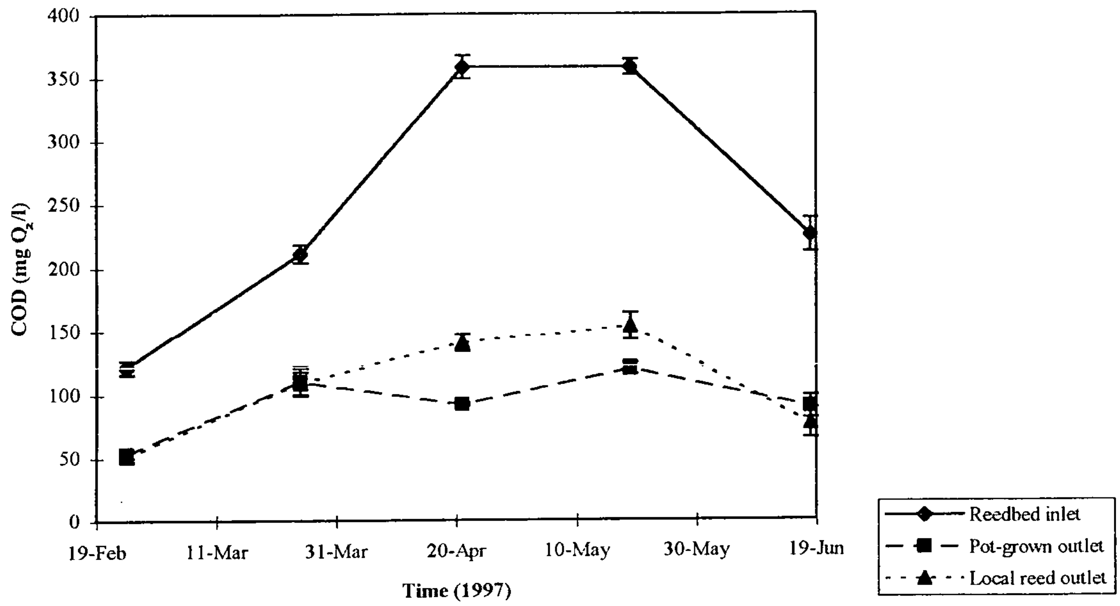
There was a significant reduction in the COD of water between the inlet and outlet areas of the reedbed ($F_{1,20}$=1156.19, p <0.001). Water leaving the reedbed ranged from 55 to 120 mg O_2 l^{-1},with an average of 93 mg O_2 l^{-1}. 2-way ANOVA indicated that there was a significant difference in COD between different sampling periods both at the inlet and outlet of the reedbed ($F_{4,20}$=131.78, p <0.001), reflecting the variable nature of the influent content, as shown in figure 9a. There was also a significant difference between the reduction in COD between different sampling periods ($F_{4,20}$= 66.58, p <0.001), with the highest reduction of 74 % on 21/4/97.

<u>Local reed section</u>

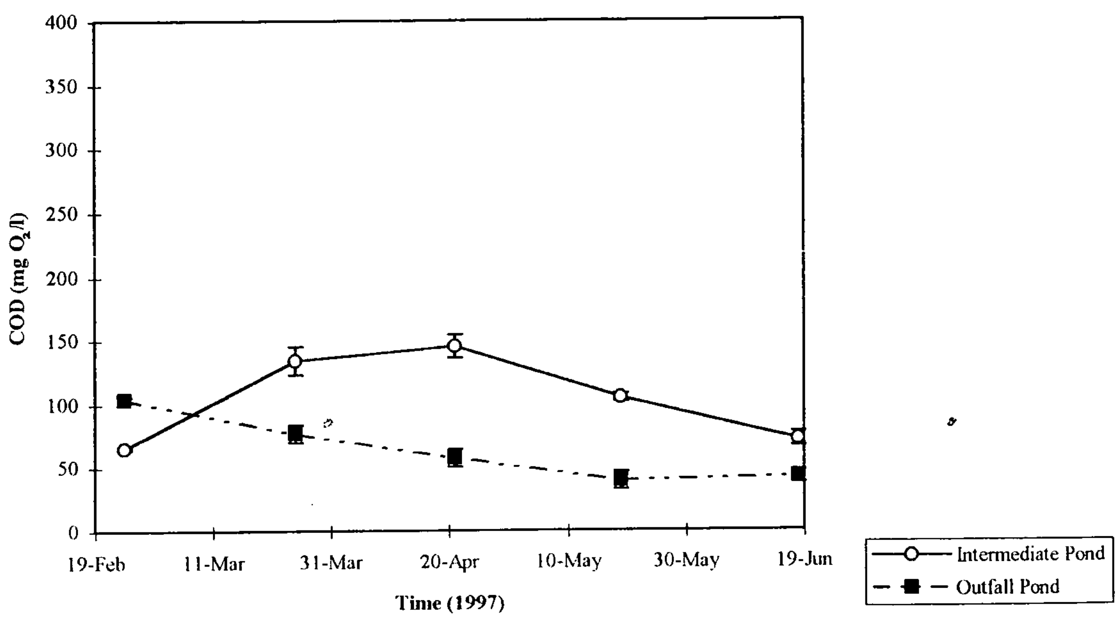
There was a significant reduction in the COD of water between the inlet and outlet areas of the reedbed ($F_{1,20}$=706.04, p <0.001). Water leaving the reedbed ranged from 51 to 153 mg O_2 l^{-1},with an average of 106 mg O_2 l^{-1}. 2-way ANOVA indicated that there was a significant difference in COD between different sampling periods both at the inlet and outlet of the reedbed ($F_{4,20}$ = 131.53, p <0.001), reflecting the variable nature of the influent content, as shown in Figure 9a. There was also a significant difference in the

Figure 9. Graphs to show the COD (mg O_2/l) of water samples from the CATS Terminal reedbed between 25/2/97 - 18/6/97 (points represent the mean +/- SE of 3 samples)

9a. POT-GROWN AND LOCAL REEDS



9b. INTERMEDIATE AND OUTFALL PONDS



reduction in COD between different sampling periods ($F_{4,20} = 26.39$, $p < 0.001$), with the highest reduction of 66 % on 18/6/97.

Comparison between pot-grown and local reed sections of the reedbed

There was a significant difference in the COD of outlet water between the pot-grown and local reed sections of the reedbed ($F_{1,20} = 6.61$, $p < 0.05$), with the pot-grown section discharging lower values (Figure 9a). However, 2-way ANOVA indicated that there was a significant interaction in the reduction in COD between the two types of reed areas during different sampling periods ($F_{4,20} = 5.28$, $p < 0.01$). The average reduction in COD between the inlet and outlet areas of the reedbed over the monitoring period was 63 % in the pot-grown section, and 58 % in the local reed section.

The Intermediate and Outfall Ponds

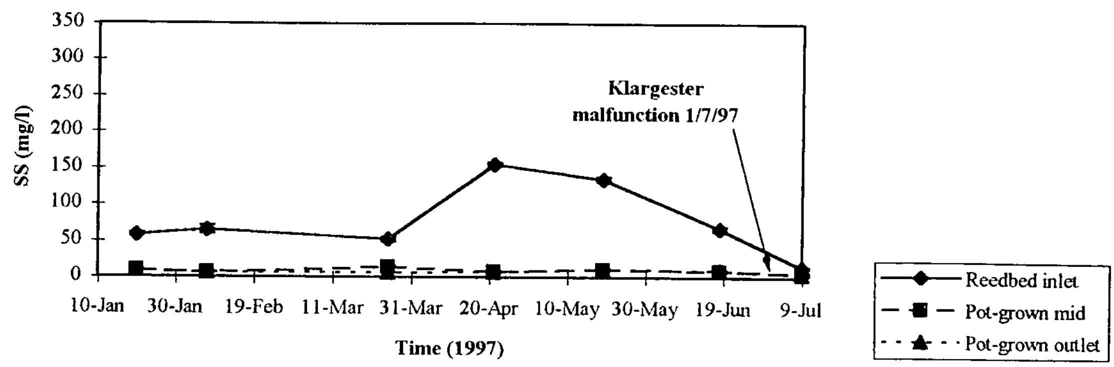
COD in the intermediate pond ranged from 65 to 145 mg O_2 l^{-1}, with an average of 104 mg O_2 l^{-1}. The Intermediate Pond did not reduce the COD of the reedbed water further. The COD of Outfall Pond water samples decreased significantly with time from 104 mg O_2 l^{-1} on 24/2/97 to 39 mg O_2 l^{-1} on 19/5/97 as shown in Figure 9b. The Outfall Pond contained windblown sediment from the area disturbed during construction, which was regraded and seeded during April, 1997. Vegetation became established and air-borne sediment reduced, during May, 1997. Sediment levels in the Outfall Pond settled down following the disturbance, as did COD levels of water samples.

3.2.4. Suspended Solids (SS)

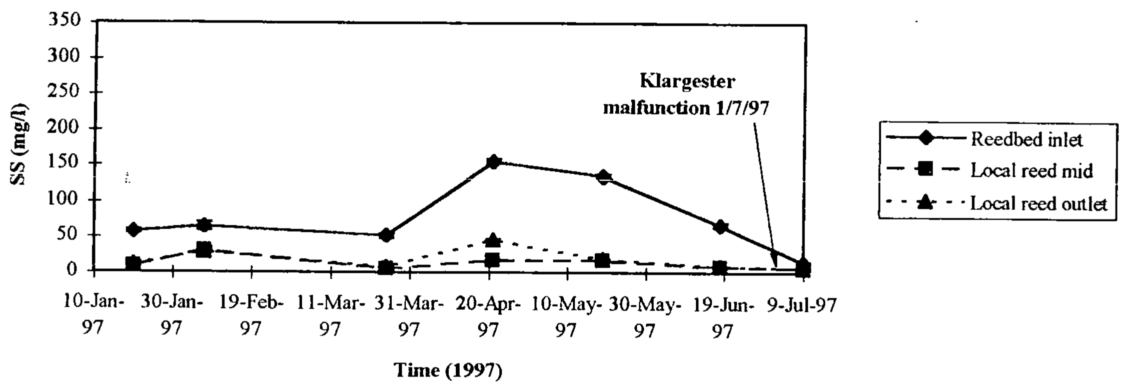
The suspended solid material in the reedbed influent ranged from 14 to 155 mg l^{-1} SS, with an average of 78 mg l^{-1} SS, and reflected the variable nature of the influent content (Figure 10).

FIGURE 10. Graphs to show the Suspended Solids (mg/l) from the CATS Terminal reedbed between 20/1/97 - 9/7/97 (data represent the mean +/- SE of 3 samples)

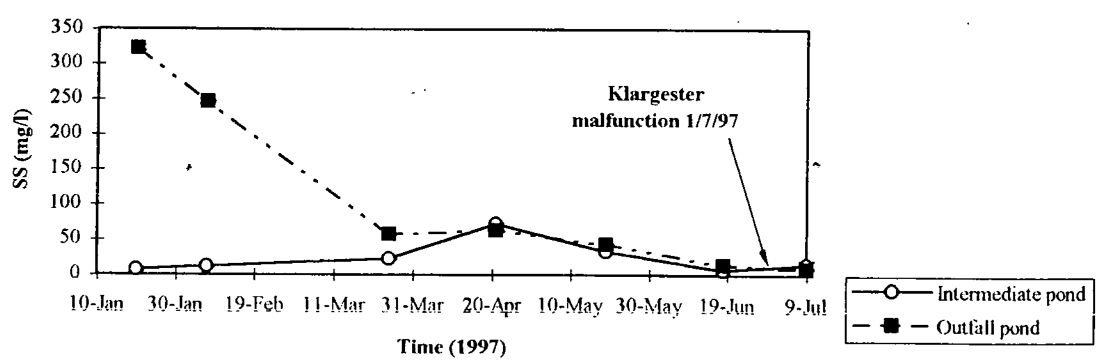
10a. POT-GROWN REEDS



10b. LOCAL REEDS



10c. INTERMEDIATE & OUTFALL PONDS



Pot-grown section

There was a significant reduction in the SS content of water between different areas of the reedbed, most of the suspended material was removed between the inlet and middle areas ($F_{1,28} = 2994.75$, $p < 0.001$). Water leaving the reedbed ranged from 4 to 11 mg l^{-1} SS with an average of 7.6 mg l^{-1} SS. 2-way ANOVA indicated that there was a significant difference in SS content between different sampling periods both at the inlet and outlet of the reedbed ($F_{6,42} = 223.17$, $p < 0.001$), reflecting the variable nature of the influent content, as shown in Figure 10a. There was also a significant difference in the reduction in SS content during different sampling periods ($F_{12,42} = 203.09$, $p < 0.001$), with the highest reduction of 95 % on 21/4/97.

Local reed section

There was also a significant reduction in the SS content of water between different areas of the reedbed planted with local reeds, with most of the suspended material being removed between the inlet and middle areas ($F_{6,42} = 1690.86$, $p < 0.001$). Water leaving the reedbed ranged from 6 to 46 mg l^{-1} SS, with an average of 18.4 mg l^{-1} SS. 2-way ANOVA indicated that there was a significant difference in SS content between different sampling periods both at the inlet and outlet areas of the reedbed ($F_{6,42} = 271.11$, $p < 0.001$), reflecting the variable nature of the influent content, as shown in Figure 10b. There was also a significant difference in the reduction in SS content during different sampling periods ($F_{12,42} = 119.27$, $p < 0.001$), with the highest reduction of 86 % on 19/5/97.

Comparison between Pot-grown and Local reed sections of the reedbed

There was a significant difference in the SS content of outlet water between the pot-grown and local reed sections of the reedbed ($F_{1,28} = 281.88$, $p < 0.001$), with the pot-grown section having lower SS content (Figure 10a). 2-way ANOVA indicated that there was a significant difference in the reduction in SS content between the pot-grown and local reed areas during different sampling periods ($F_{6,28} = 75.53$, $p < 0.001$), as shown in Figure 10b. The average reduction in SS between the inlet and outlet areas during the first six months operation of the reedbed was 90 % in the pot-grown section, and 76 % in the local reed section.

The Intermediate and Outfall Ponds

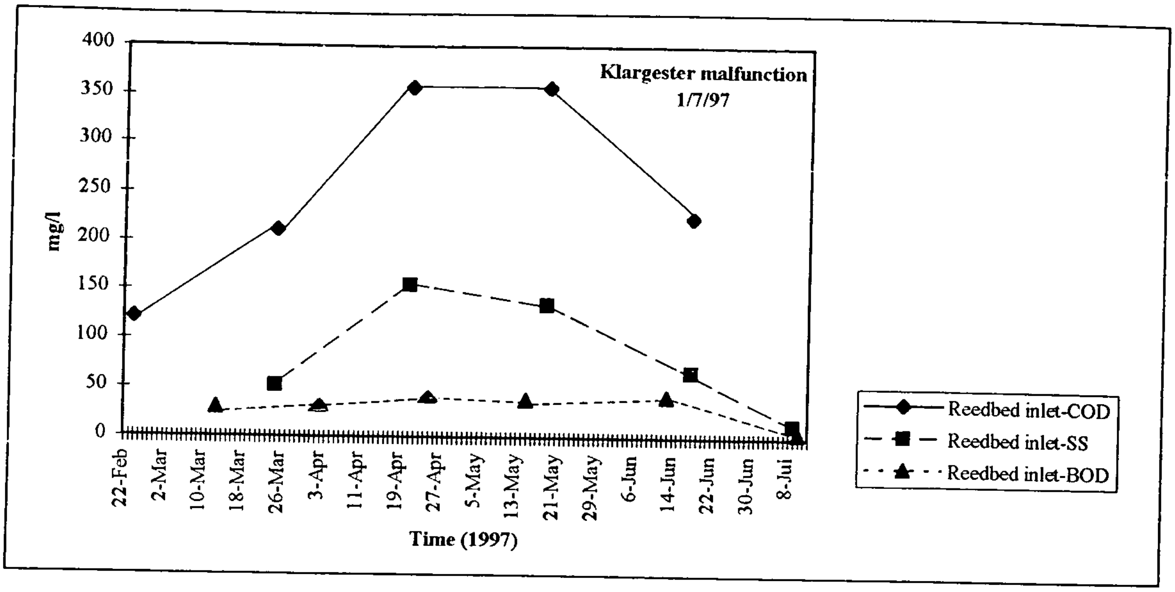
SS in the Intermediate Pond ranged from 6 to 72 mg l^{-1} with an average of 24 mg l^{-1} SS. The Intermediate Pond did not reduce the SS of the reedbed water further. The results showed that during only one sampling period, the final discharge into the receiving waters exceeded the Environment Agency standard of 50 mg l^{-1} SS. The system achieved the required standard 86 % of the time.

Figure 10c shows that the SS of Outfall Pond water samples decreased with time from 322 mg l^{-1} SS on 20/197 to 57 mg l^{-1} SS on 25/3/97. The Outfall Pond contained windblown sediment from the area disturbed during construction, which was later regraded and seeded. Vegetation became established and air-borne sediment reduced, during May,1997. Sediment levels in the Outfall Pond settled down following the disturbance, as did SS levels of water samples.

The relationship between SS, BOD_5 and COD

The sewage effluent from the Klargester comprised biodegradable organic matter in suspension. Figure 11 shows a comparison between SS, BOD_5 and COD for the inlet area with time, where it can be seen that the inlet fluctuations of SS are mirrored by fluctuations in BOD_5 and COD.

Figure 11. Graph to show the relationship between SS, BOD_5 & COD (mg/l) of inlet water samples from the CATS Terminal reedbed between 25/2/97-10/7/97



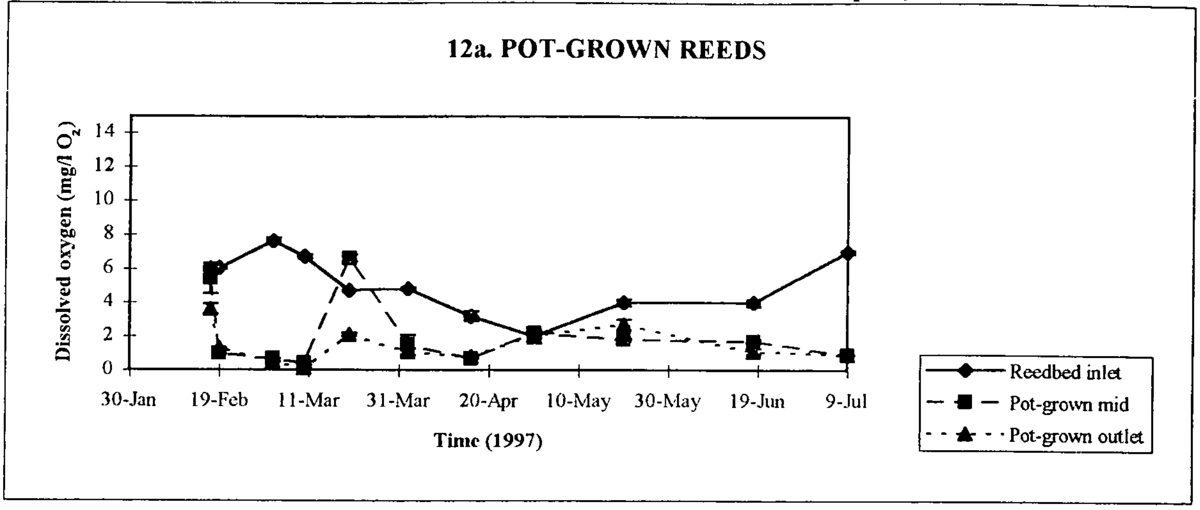
3.2.5. Dissolved Oxygen (DO)

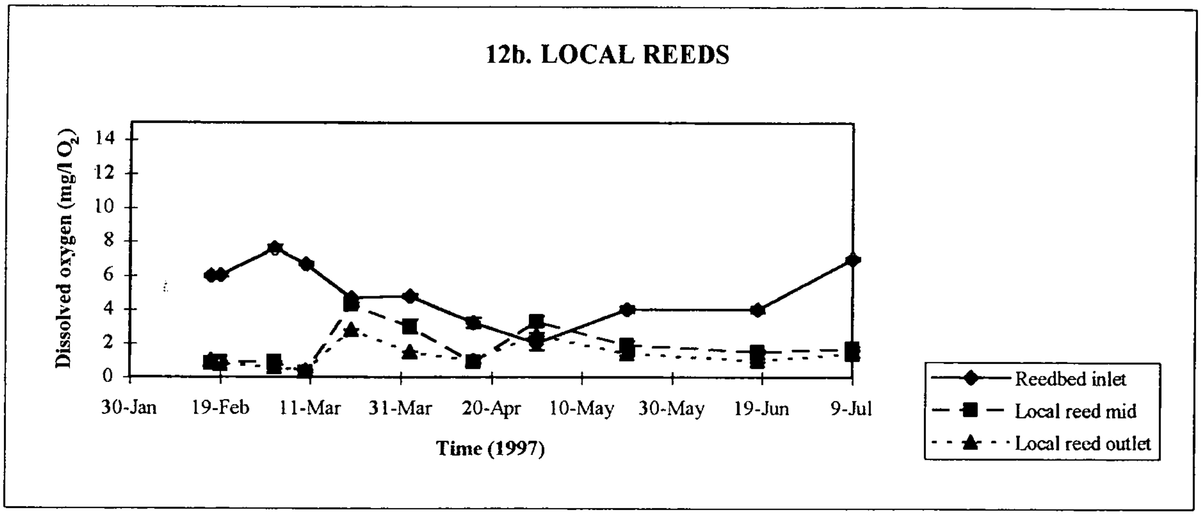
Figure 12 shows the DO content of water samples in the pot-grown and local reed sections of the reedbed. The water entering the reedbed from the Klargester had DO concentrations which ranged from 2.0 to 7.6 mg l^{-1} O_2 during the monitoring period. Inlet concentrations declined until 30/4/97, after which concentrations increased with time.

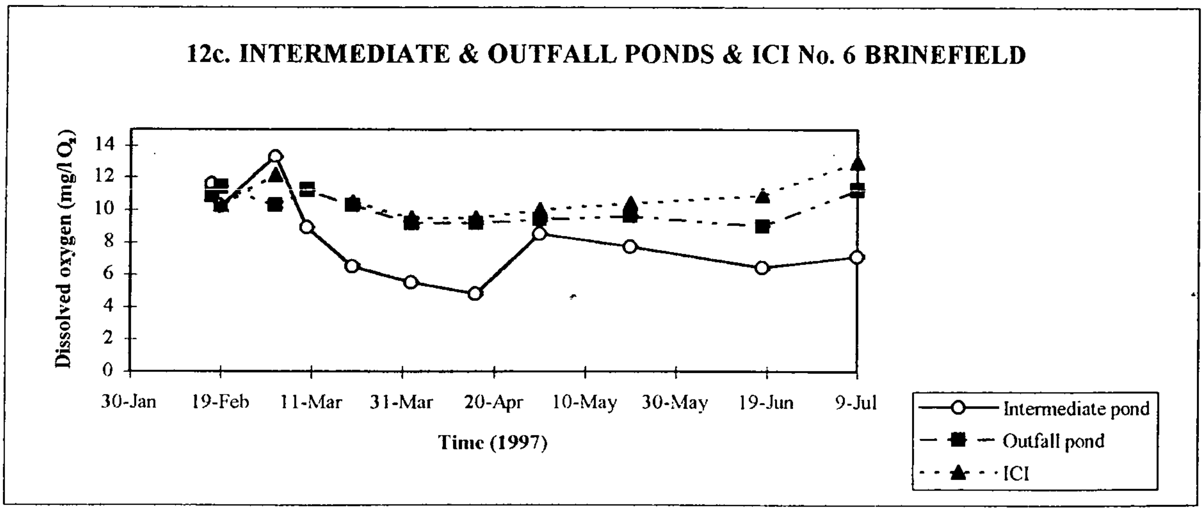
<u>Pot-grown section</u>

There was a significant reduction in the DO content of water between different areas of the reedbed, with the most significant reduction occuring between the inlet and outlet areas ($F_{2,60}$ = 569.32, p <0.001) (Figure 12a). DO concentrations from three separate samples were taken at each monitoring period, therefore the raised concentration of 6.6 (± 0.2) mg l^{-1} O_2 recorded on 20/3/97 was representative of the water column and not sampling error. 2-way ANOVA indicated that within the reedbed, the difference in DO concentrations between areas varied significantly with time ($F_{9,60}$ = 56.43, p <0.001), although the difference does not appear to be seasonal. It was also significant that during

Figure 12. Graphs to show the Dissolved oxygen content (mg/l O_2) of water samples from the CATS Terminal reedbed and the ICI No.6 brinefield between 17/2/97-9/7/97 (data represent the mean +/- SE of 3 samples)







different sampling occasions, the middle area contained higher or lower DO than the outlet area. DO concentrations of water leaving the reedbed ranged from 0.1 to 3.6 mg l^{-1} O_2

Local reed section

There was a significant reduction in the DO content of water between different areas of the reedbed, with the most significant reduction occuring between the inlet and outlet areas ($F_{2,60}$ = 1477.73, p <0.001), as shown in Figure 12b. 2-way ANOVA indicated that within the reedbed, the difference in DO concentrations between areas varied significantly with time ($F_{9,60}$ = 46.37, p <0.001), although the difference does not appear to be seasonal. Figure 12b also shows that the DO content of water samples decreases significantly between the middle and outlet areas of the reedbed during each monitoring period ($F_{1,40}$ = 56.10, p <0.001). DO concentrations of water leaving the reedbed ranged from 0.4 to 2.8 mg l^{-1} O_2.

Comparison between pot-grown and local reed sections of the reedbed

There was a significant difference in the DO concentrations of water in the outlet areas of pot-grown and local reeds, with generally lower concentrations being present in the pot-grown section, however, this difference fluctuated between sampling periods ($F_{9,40}$ = 38.86, p <0.001), as shown in Figures 12 a and b.

The Intermediate and Outfall ponds and ICI No.6 brinefield reedbed

DO levels in the intermediate pond ranged from 4.8 to 11.6 mg l^{-1} O_2 as shown in Figure 12c. The site Outfall Pond and the ICI No.6 brinefield reedbed water samples show the same seasonal pattern in DO concentrations, although the ICI concentrations were generally higher, possibly due to the presence of algae in the water throughout the monitoring period.

3.2.6. pH

The pH of water entering the reedbed ranged from 5.70 to 6.44 and decreased with time as shown in Figure 13.

Pot-grown section

There was a significant increase in the pH of water samples between different areas of the reedbed, with the most noticeable increase occuring between the inlet and middle areas ($F_{2,36}$ = 237.81, p <0.001). pH variations with time were significant but do not show a seasonal trend ($F_{5,36}$ = 5.75, p <0.001) (Figure 13a).

Local reed section

There was a significant increase in the pH of water samples between different areas of the reedbed, with the most noticeable increase occuring between the inlet and middle areas ($F_{2,36}$ = 473.52, p <0.001). pH variations with time were significant but do not show a seasonal trend ($F_{5,36}$ = 10.99, p <0.001) (Figure 13b).

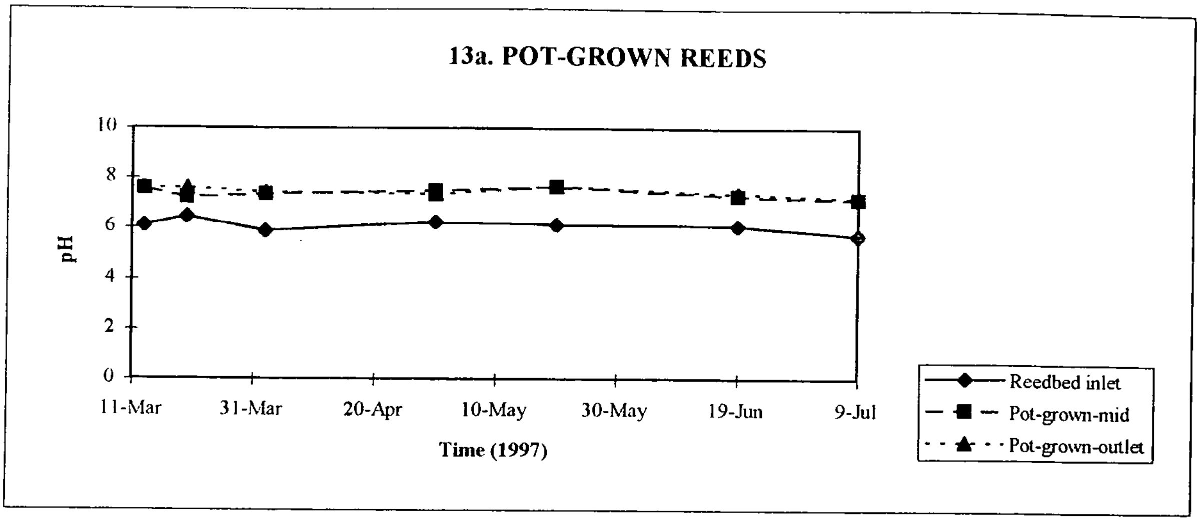
Comparison between pot-grown and local reed sections of the reedbed

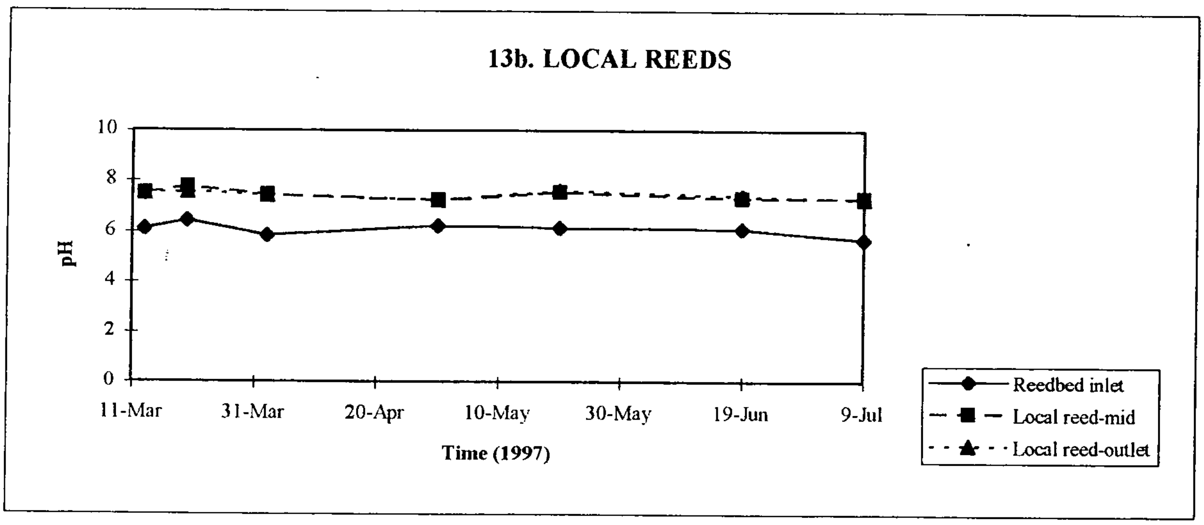
There was no significant difference between the pH of the pot-grown and local reed sections of the reedbed in either the middle or the outlet areas.

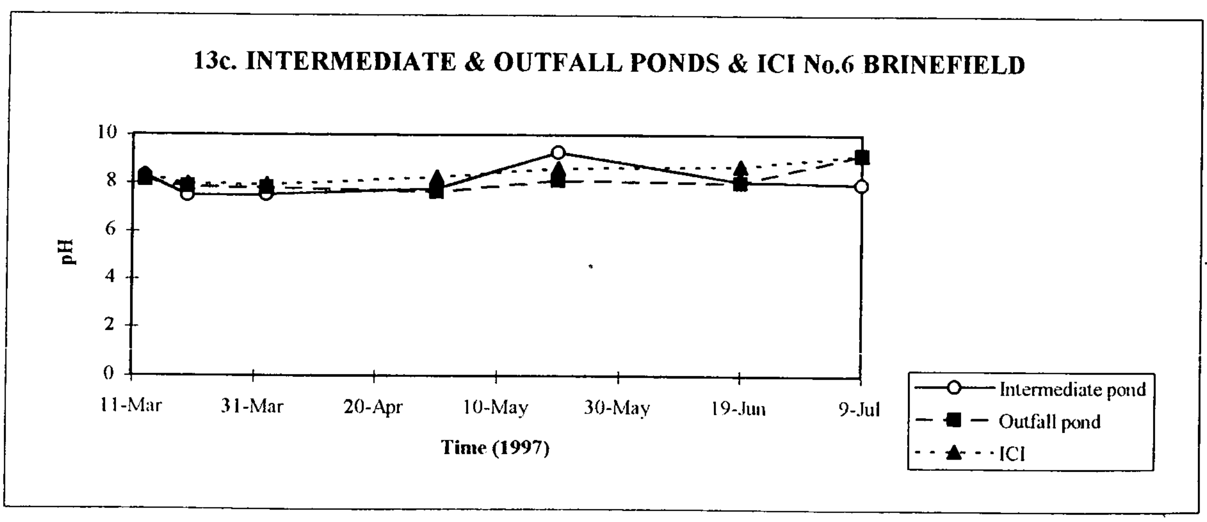
The Intermediate and Outfall Ponds and ICI No.6 brinefield reedbed

The pH of water in the Intermediate Pond ranged from 7.49 to 9.29 (Figure 14c). Algae can raise the pH of wetland waters during periods of high productivity (Kadlec & Knight, 1996). The raised pH value taken on 20/5/97 may have been associated with an increasing amount of algae in the water, which subsequently declined from late May, when the pond became very clear. The pH of water from the ICI No.6 brinefield reedbed ranged from 7.93 to 9.18 and increased with the season. A large amount of filamentous algae was

Figure 13. Graphs to show the pH of water samples from the CATS Terminal reedbed and the ICI No.6 brinefield between 13/3/97 - 9/7/97 (data represent the mean +/- of 3 samples)







present in the water and may have contributed to the elevated pH when compared to the pH of the Outfall Pond where algae was not abundant.

3.2.7. Conductivity

The electrical conductivity, being proportional to the total dissolved solids in water was a measure of the salt content of the wastewater. The conductivity of water entering the reedbed ranged from 1009 to 1988 μS cm^{-1}. and reflected the varible nature of the inlet content, as shown in Figure 14. As water passed through the reedbed the conductivity increased towards the outlet in both sections of the reedbed until late spring. From early-May, conductivity decreased throughout the reedbed system. The conductivity of water leaving the pot-grown section of the reedbed ranged from 802 to 1969 μS cm^{-1}, and water leaving the local reed section ranged from 931 to 1889 μS cm^{-1}.

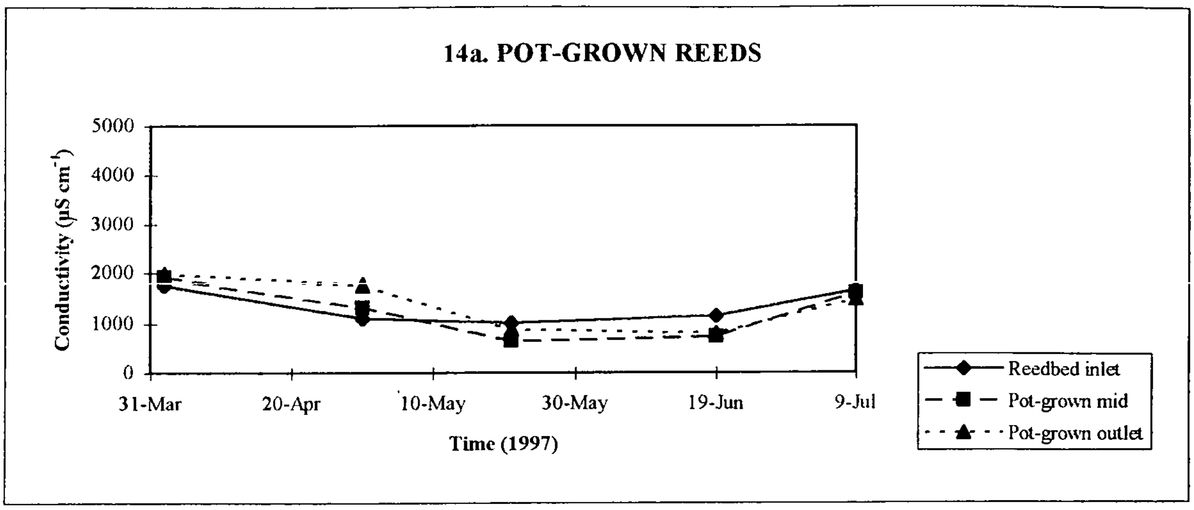
The conductivity of water in the Intermediate Pond ranged from 584 to 1939 μS cm^{-1} and also had fewer dissolved solids after April. All waters in the reedbed system had elevated conductivities in the July sample, following the Klargester discharge on 1/7/97.

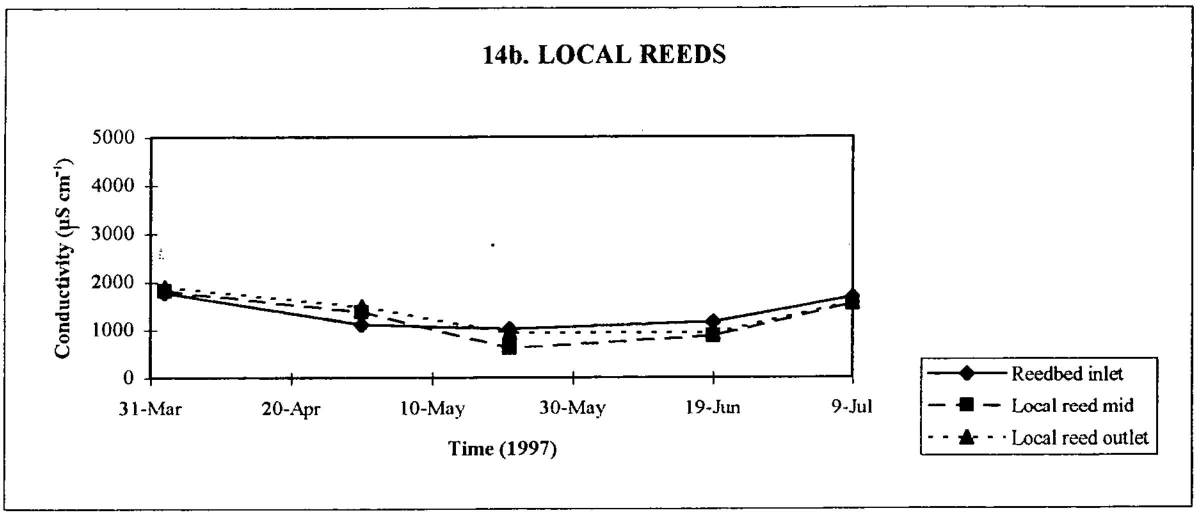
Figure 14c shows the range of conductivity values for the Outfall Pond and the ICI No.6 brinefield sites. The Outfall Pond conductivity declined from 1256 to 671μS cm^{-1} with time, whereas the ICI water conductivity ranged from 3863 to 4457 μS cm^{-1} and shows no seasonal pattern.

3.2.8. Chloride

Humans excrete around 6g of chloride a day in sewage. Treatment plants do not usually remove chloride (Grant *et al.*, 1996). Chloride levels of water entering the reedbed ranged between 125-195 mg l^{-1} Cl^- (Figure 15). A level of 100 mg l^{-1} Cl^- was considered average for the size of the reedbed (P. Griffin, Severn Trent Water PLC, personal communication), but the Klargester at the CATS Terminal was processing waste from predominantly human sewage rather than domestic wastewater, therefore higher than

Figure 14. Graphs to show the Conductivity (µS cm^{-1}) of water samples from the CATS Terminal reedbed and the ICI No.6 Brinefield between 2/4/97-9/7/97 (data represent the mean +/- SE of 3 samples)





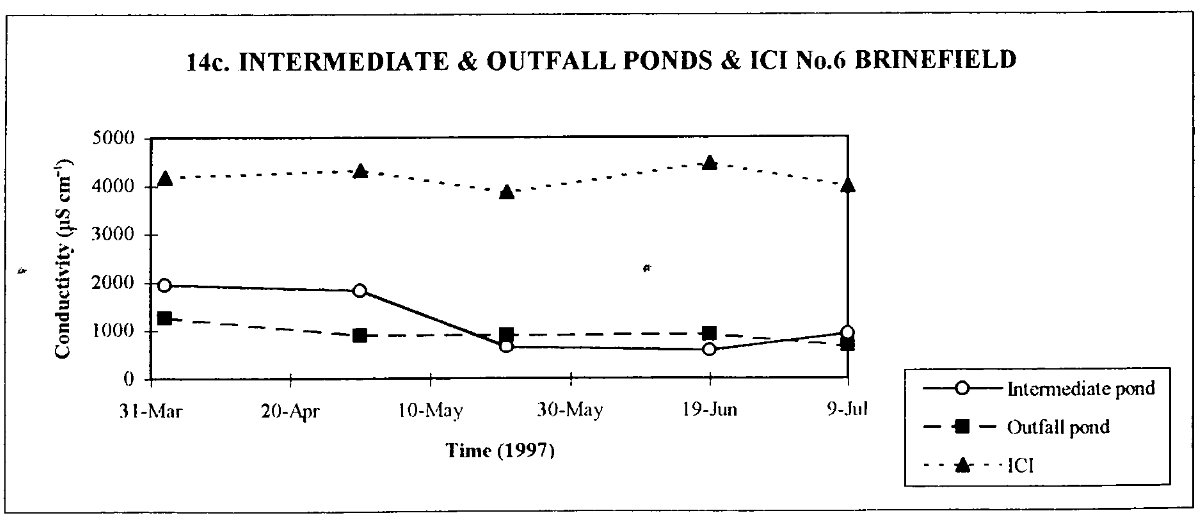
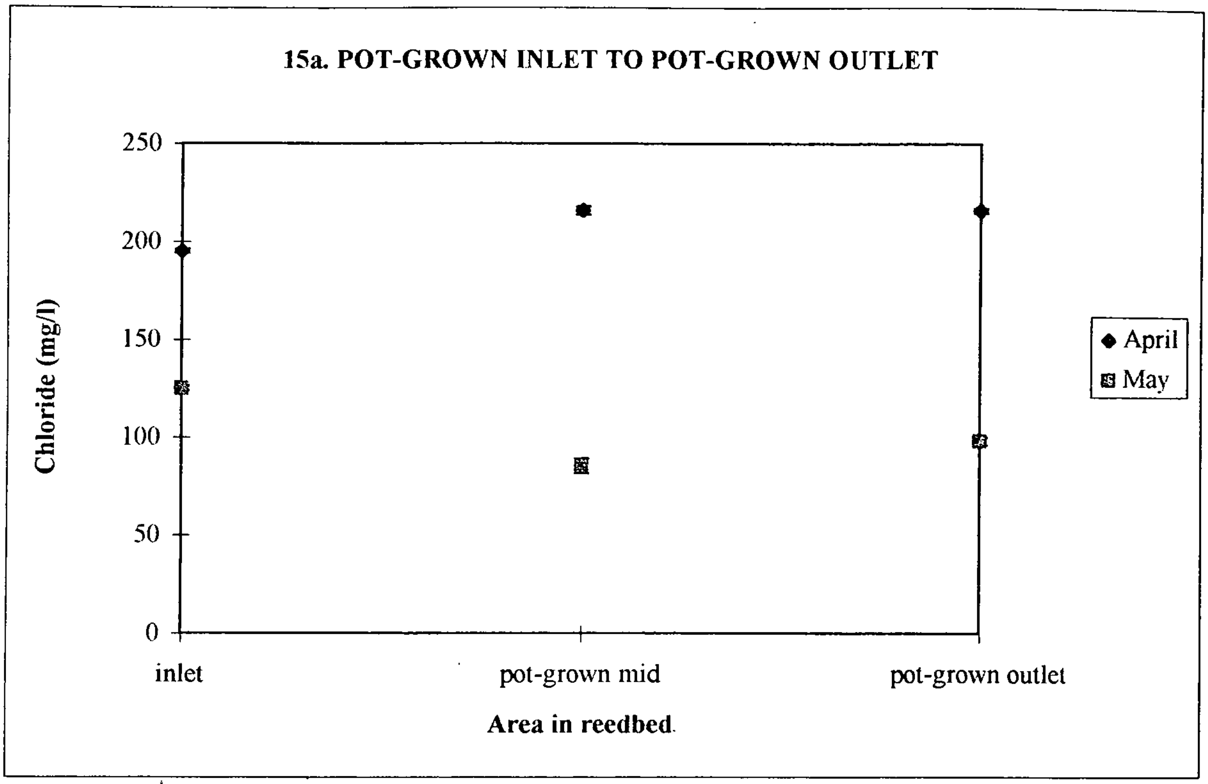
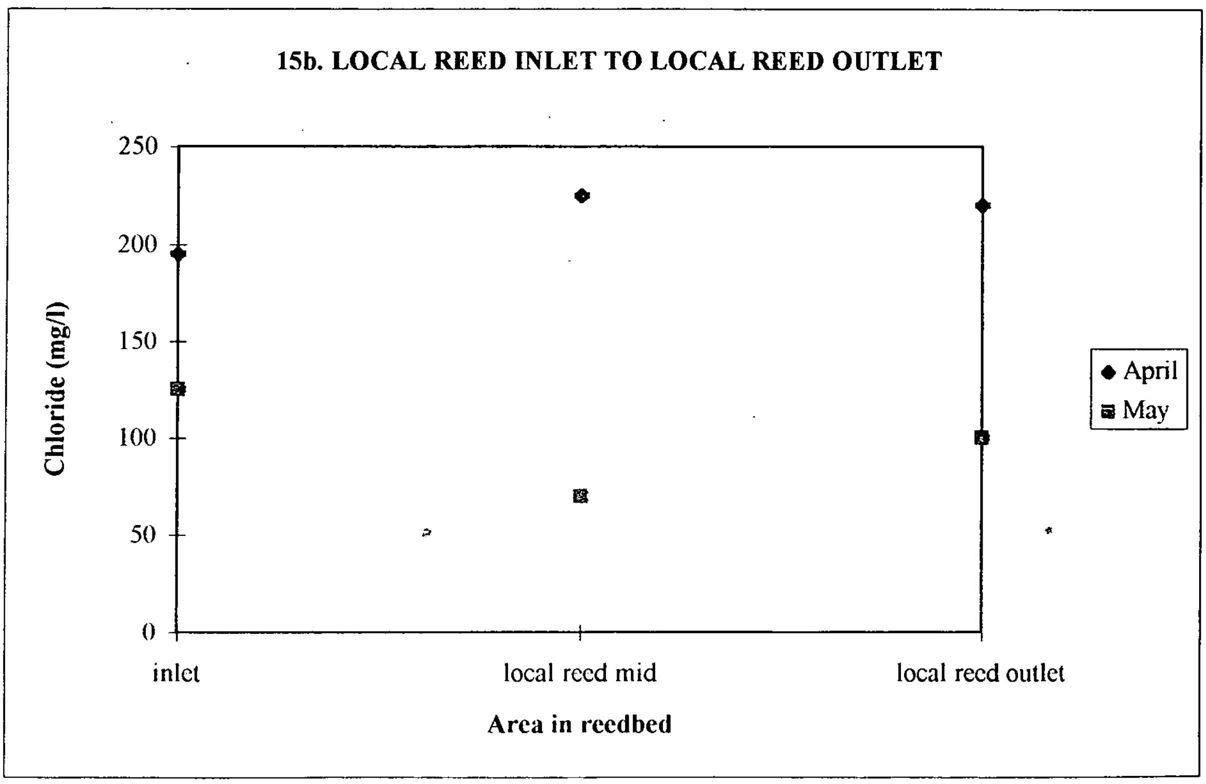


Figure 15. Graphs to show the chloride (mg/l) content of water samples from the CATS Terminal reedbed on 21/4/97 & 21/5/97 (data represent the mean +/- SE of 3 samples)





average levels could be expected. Results from the April samples (Figure 15) indicate that concentrations rose slightly through both sides of the reedbed, either due to evaporation, or simply a reflection of variation in inlet concentrations over a couple of days. The May results indicate that chloride levels decreased away from the inlet, particularly in the middle areas of both sections of the reedbed. Water conductivity shown in Figure 14 show the same trend.

3.2.9. Ammonium nitrogen (NH_4^+-N)

The primary and secondary treatment of site effluent undertaken by the Klargester was designed to achieve a degree of nitrification by the oxidation of ammonia to nitrate-N and therefore, to discharge less than 20 mg l^{-1} NH_4^+-N. The ammonium content of water entering the reedbed from the klargester ranged from 0.26 to 4.53 mg l^{-1} NH_4^+, with an average of 1.54 mg l^{-1} NH_4^+ (Figure 16).

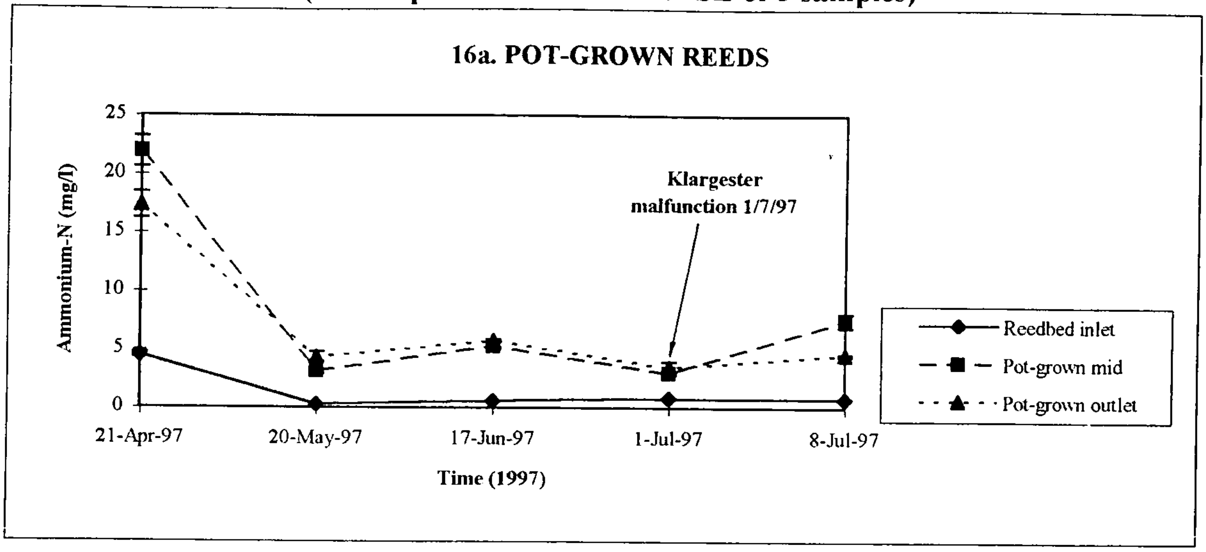
<u>Pot-grown section</u>

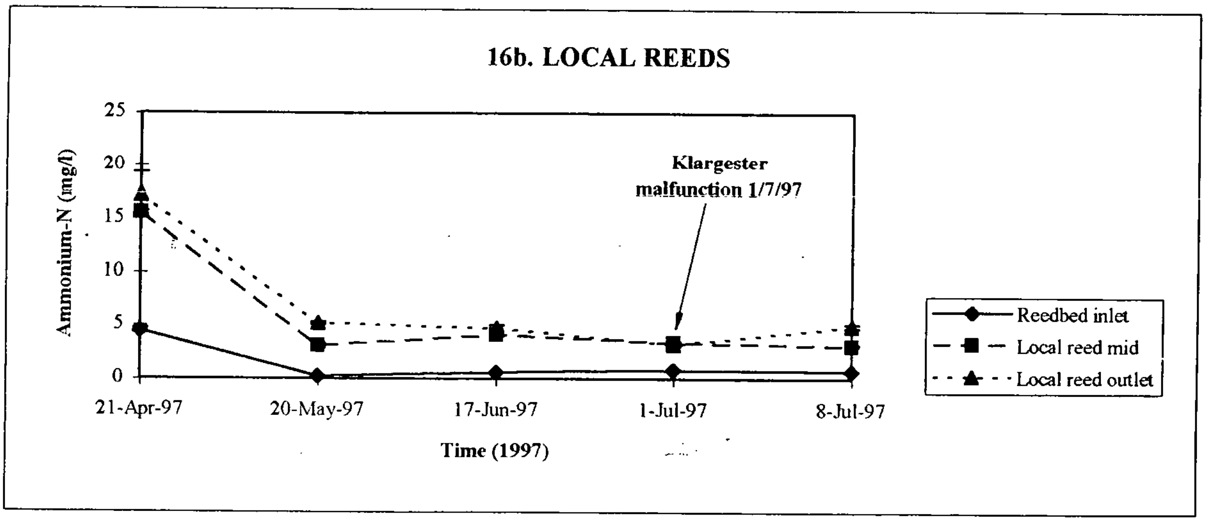
There was a significant increase in the NH_4^+-N content of water between the inlet and outlet areas of the reedbed ($F_{2,24} = 234.41$, $p < 0.001$) as shown in Figure 16a. Water leaving the reedbed ranged from 3.5 to 17.3 mg l^{-1} NH_4^+, with an average of 8.1 mg l^{-1} NH_4^+. 2-way ANOVA indicated that there was a significant difference in NH_4^+-N content between different sampling periods within the reedbed ($F_{3,24} = 304.32$, $p < 0.001$), when significantly higher levels were present in all areas of the reedbed on 21/4/9. There was also a significant interaction in the reduction in NH_4^+-N content between different areas during different sampling periods ($F_{6,24} = 37.26$, $p < 0.001$), as shown in Figure 16a.

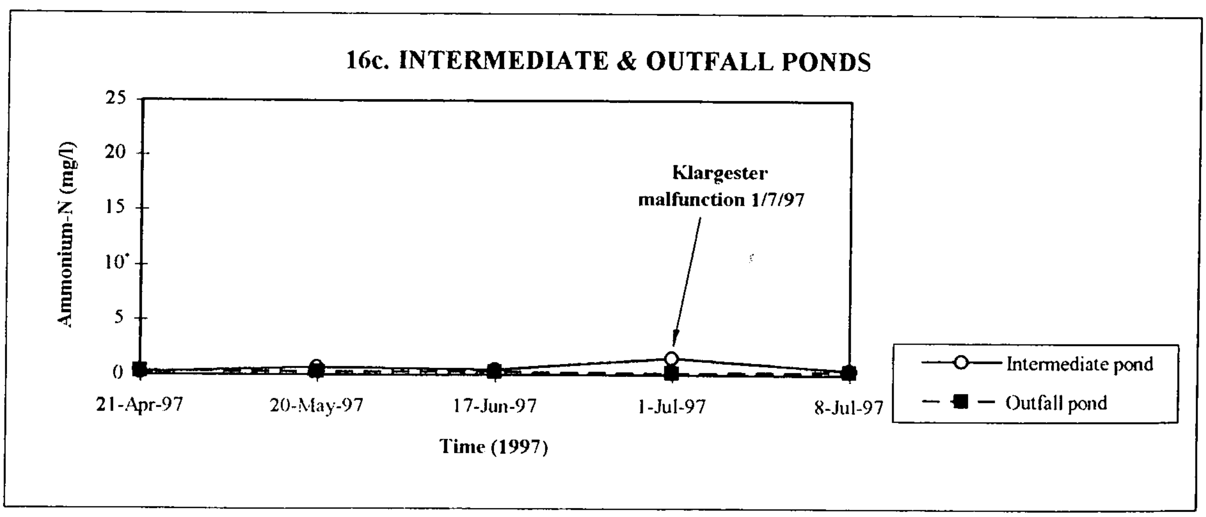
<u>Local reed section</u>

There was a significant increase in the NH_4^+-N content of water between the inlet and outlet areas of the reedbed ($F_{2,24} = 117.38$, $p < 0.001$) as shown in Figure 16b. Water

Figure 16. Graphs to show the ammonium-N (mg/l) content of water samples from the CATS Terminal reedbed between 21/4/97 - 9/7/97 (data represent the mean +/- SE of 3 samples)







leaving the reedbed ranged from 3.19 to 17.2 mg l^{-1} NH_4^+, with an average of 8.0 mg l^{-1} NH_4^+. 2-way ANOVA indicated that there was a significant difference in NH_4^+-N content between different sampling periods within the reedbed ($F_{3,24}$ = 1171.46, p <0.001), when significantly higher levels were present in all areas of the reedbed on 21/4/97.

Comparison between pot-grown and local reed sections of the reedbed

Levels of NH_4^+-N increased as water passed through both sides of the reedbed. Although higher concentrations were sampled at each side of the reedbed during different periods, the difference between the two outlet sections was not significant.

The Intermediate and Outfall ponds

There was a significant decrease in the NH_4^+-N content of the reedbed water within the intermediate pond ($F_{1,16}$ = 202.21, p <0.001). Water leaving the intermediate pond ranged from 0.26 to 1.53 mg l^{-1} NH_4^+, with an average of 0.45 mg l^{-1} NH_4^+. Figure 16c shows that with the exception of the uncharacteristic result on 1/7/97, the levels of NH_4^+-N discharged from the reedbed system were similar to the background levels in the Outfall Pond.

3.2.10. Nitrate (NO_3^--N)

An efficiently operating Klargester should discharge oxidised NH_4^+-N in the form of nitrate-N into the reedbed. During the monitoring period, nitrates were discharged into the reedbed, apart from the occasion of the Klargester malfunction on 1/7/97, when higher than average concentrations of ammonium entered the bed along with lower than average nitrate concentrations (see chapter two). The nitrate content of water entering the reedbed from the Klargester ranged from 4.3 to 22.0 mg l^{-1} NO_3^--N, with an average of 16.4 mg l^{-1} NO_3^--N.

Pot-grown section

There was a significant decrease in the NO_3^--N content of water between the inlet and outlet areas of the reedbed ($F_{2,18} = 2951.56$, $p < 0.001$) as shown in Figure 17a. Water leaving the reedbed ranged from 0.3 to 2.3 mg l^{-1} NO_3^--N, with an average of 1.1 mg l^{-1} NO_3^--N. 2-way ANOVA indicated that there was a significant difference in NO_3^--N content between different sampling periods within the reedbed ($F_{2,18} = 127.43$, $p < 0.001$). There was also a significant interaction in the decrease in NO_3^--N content between the inlet and the middle and outlet areas during different sampling periods ($F_{4,18} = 125.51$, $p < 0.001$), with the most significant reduction occuring on 17/6/97.

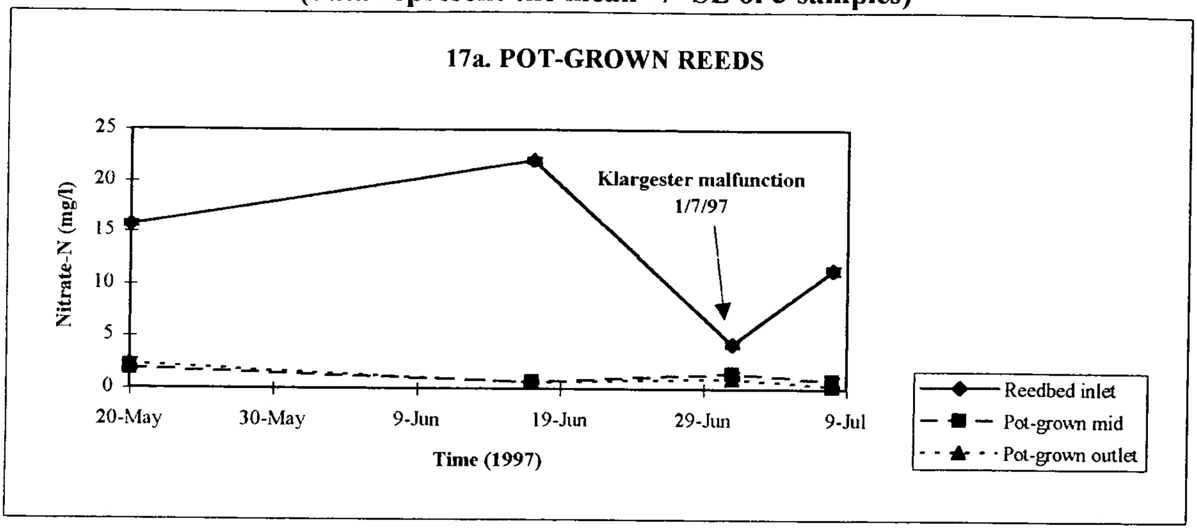
Local reed section

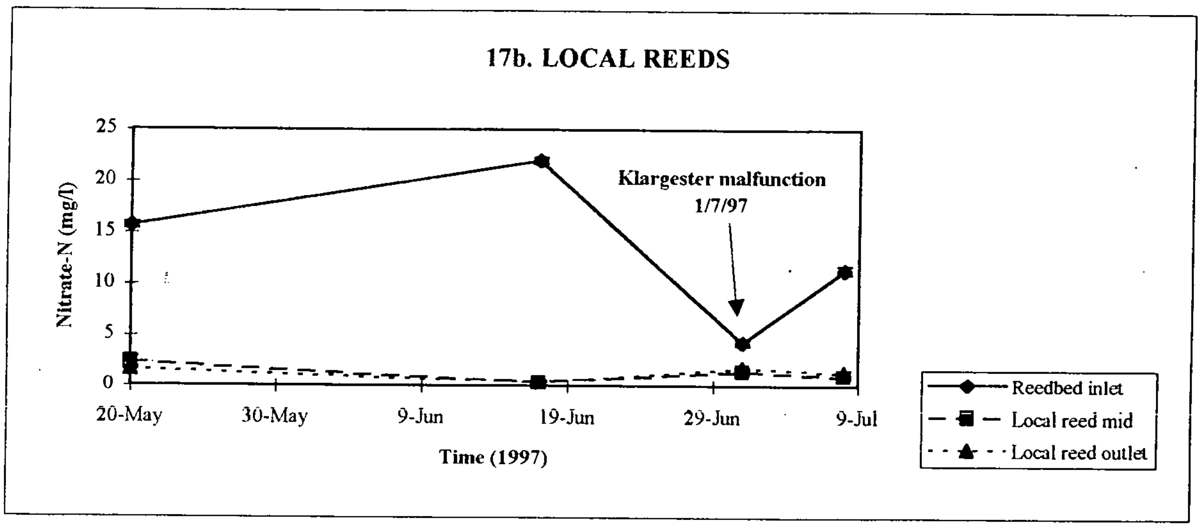
There was a significant decrease in the NO_3^--N content of water between the inlet and outlet areas of the reedbed ($F_{2,18} = 3157.91$, $p < 0.001$) as shown in Figure 17b. Water leaving the reedbed ranged from 0.4 to 1.8 mg l^{-1} NO_3^--N, with an average of 1.2 mg l^{-1} NO_3^--N. 2-way ANOVA indicated that there was a significant difference in NO_3^--N content between different sampling periods within the reedbed ($F_{2,18} = 93.83$, $p < 0.001$). There was also a significant interaction in the decrease in NO_3^--N content between the inlet, and the middle and outlet areas during different sampling periods ($F_{4,18} = 125.51$, $p < 0.001$), with the most significant reduction occuring on 17/6/97.

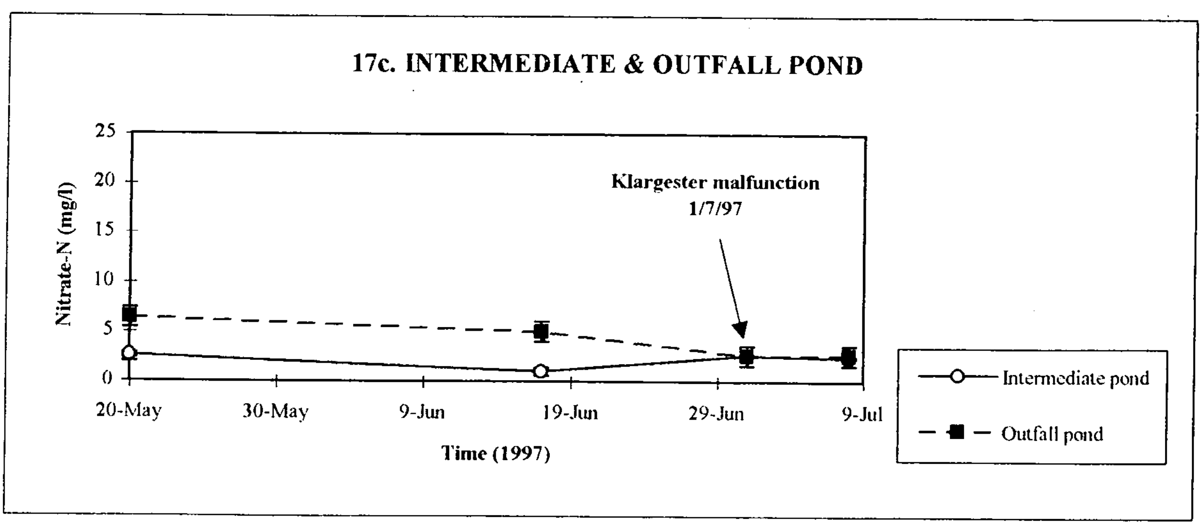
Comparison between pot-grown and local reed sections of the reedbed

Levels of NO_3^--N decreased as water passed through both sides of the reedbed. Although lower concentrations were sampled at each side of the reedbed during different periods, the difference between the two outlet sections was not significant.

Figure 17. Graphs to show the nitrate-N (mg/l) content of water samples from the CATS Terminal reedbed between 20/5/97-9/7/97 (data represent the mean +/- SE of 3 samples)







The Intermediate and Outfall Ponds

Within the Intermediate Pond, nitrate concentrations were higher than the concentrations received from the reedbed and ranged from 1.0 to 2.6 mg l^{-1} NO_3^--N, with an average of 2.0 mg l^{-1} NO_3^--N. Figure 17c shows that with the exception of the uncharacteristic result on 1/7/97, concentrations of nitrate-N discharged from the reedbed system, were lower than the background concentrations in the Outfall Pond.

3.2.11. Nitrite (NO_2^--N)

The NO_2^--N content of the water as it entered the reedbed ranged from < 0.3 to 5.0 mg l^{-1} NO_2^--N (data for 1/7/97 excluded), with an average of 1.8 mg l^{-1} NO_2^--N (Figure 18). It can be seen from the graphs that concentrations of nitrite within both the pot-grown and local reed sections of the reedbed were low from 20/5/97 until monitoring ceased on 9/7/97. Nitrite was present in the Intermediate Pond at detectable levels between 23/4/97 to 17/6/97.

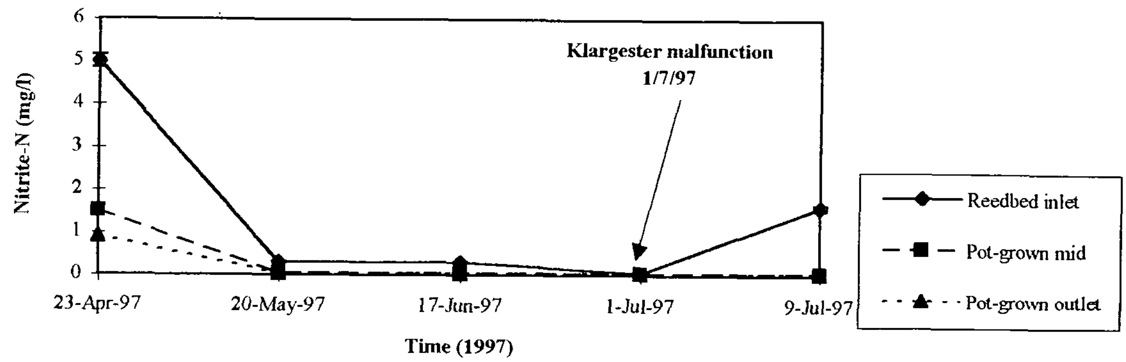
3.2.12. Inorganic nitrogen

Nitrogen entering the reedbed was anticipated to be in the inorganic form of ammonium, nitrate and nitrite, organic nitrogen being previously converted to ammonia in the Klargester. As a measure of the ability of the reedbed to remove nitrogen from the wastewater, the inorganic forms were monitored. Inorganic nitrogen was therefore the sum of the ammonium, nitrate and nitrite concentrations of the wastewater.

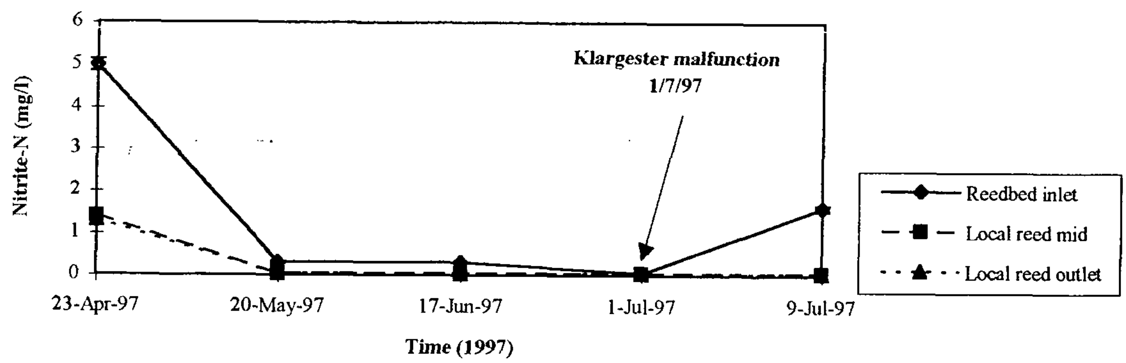
Water samples taken on 1/7/97 were not included in the statistical analyses (2-way ANOVA) for two reasons. Firstly, on 30/6/97, approximately 49.6 mm of rain was recorded for the area, secondly, on 1/7/97, the Klargester discharged an uncharacteristic high sediment and organic loading to the reedbed, at flow rate far higher than suitable for efficient treatment. Therefore, the negligible retention time of the wastewater through the flooded reedbed would provide misleading results. Figure 19 shows that the water passed

Figure 18. Graphs to show the nitrite-N (mg/l) content of water samples from the CATS Terminal reedbed between 23/4/97 - 9/7/97 (data represent the mean +/- SE of 3 samples)

18a. POT-GROWN REEDS



18b. LOCAL REEDS



18c. INTERMEDIATE & OUTFALL POND

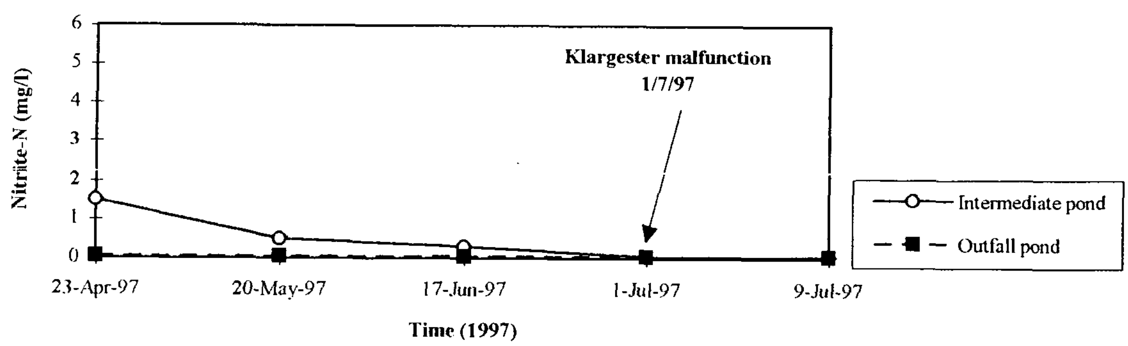
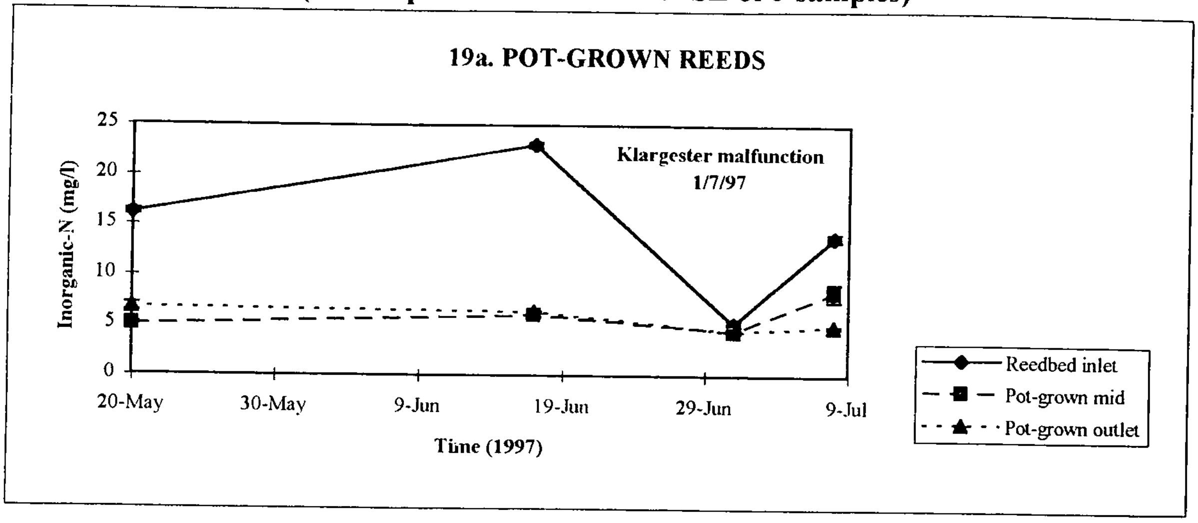
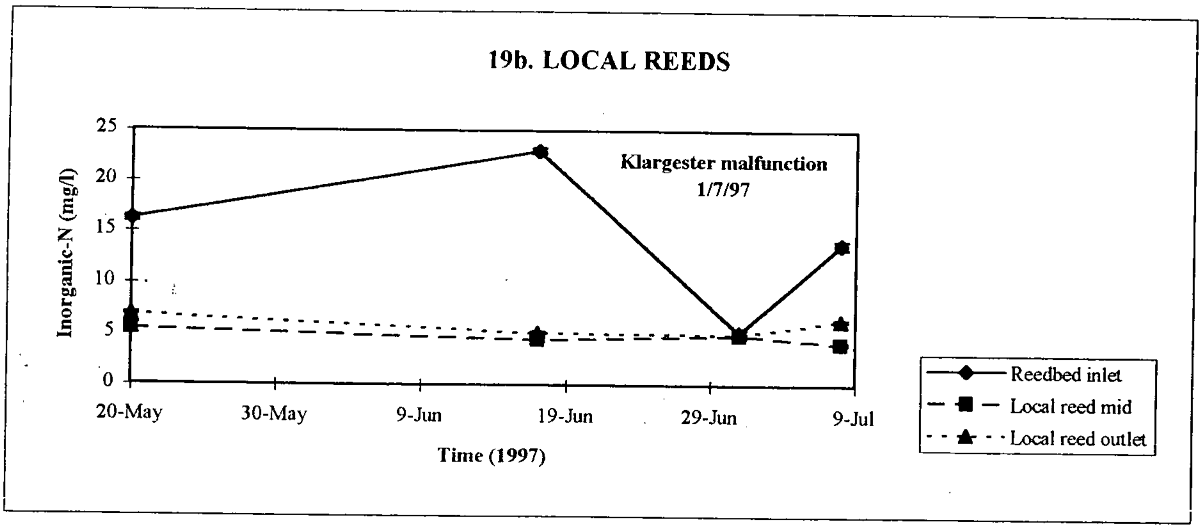
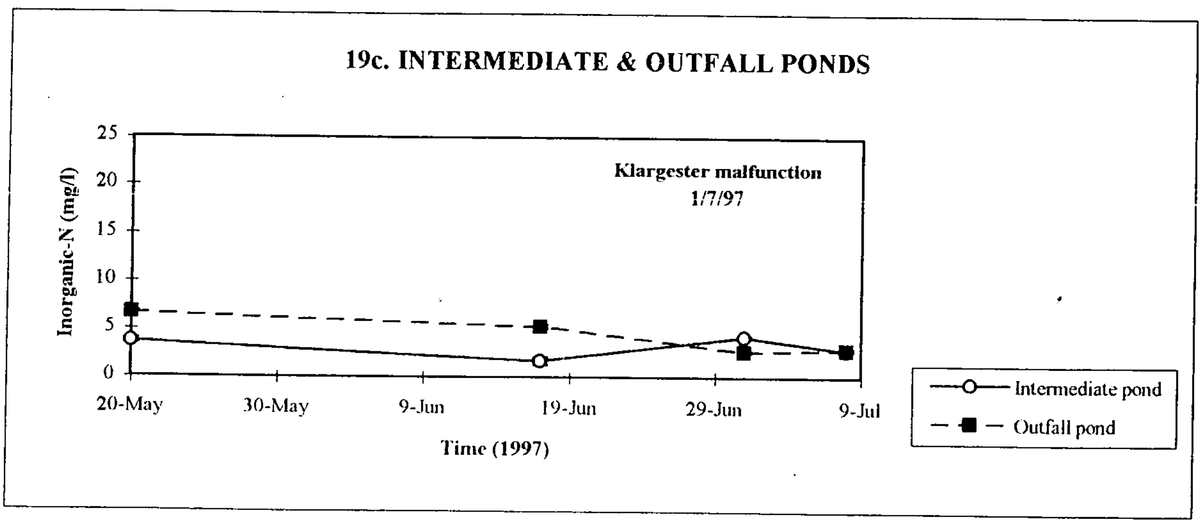


Figure 19. Graphs to show the inorganic-N (mg/l) content of water samples from the CATS Terminal reedbed between 20/5/97-9/7/97 (data represent the mean +/- SE of 3 samples)







through the reedbed on that date with minimal nitrogen transformations occurring. The inorganic nitrogen content of the water as it entered the reedbed ranged from 5.2 to 23.0 mg l^{-1} inorganic-N, with an average of 17.6 mg l^{-1} inorganic-N.

Pot-grown section

There was a significant reduction in the inorganic-N content of water between the inlet and outlet areas of the reedbed ($F_{2,18}$ = 785.99, p <0.001). Water leaving the reedbed ranged from 4.4 to 6.7 mg l^{-1} inorganic-N, with an average of 5.9 mg l^{-1} inorganic-N. 2-way ANOVA indicated that there was a significant difference in inorganic-N between different sampling periods both at the inlet and outlet of the reedbed ($F_{2,18}$ = 41.61, p <0.001), reflecting the variable nature of the influent content, as shown in Figure 19a. There was also a significant difference in the reduction between areas in inorganic-N during different sampling periods ($F_{4,18}$ = 57.84, p <0.001), with the highest reduction of 73 % on 17/6/97.

Local reed section

There was a significant reduction in the inorganic-N content of water between the inlet and outlet areas of the reedbed ($F_{2,18}$ = 2102.36, p <0.001). Water leaving the reedbed ranged from 5.0 to 6.9 mg l^{-1} inorganic-N, with an average of 6.1 mg l^{-1} inorganic-N. There was a significant difference in the reduction between areas in inorganic-N during different sampling periods ($F_{4,18}$ = 126.18, p <0.001), with the highest reduction of 78 % on 17/6/97.

Comparison between pot-grown and local reed sections of the reedbed

The average reduction in inorganic-N between the inlet and outlet areas of the reedbed over the monitoring period was 66 % in the pot-grown section, and 65 % in the local reed section, the difference between the two areas was not significant.

The Intermediate and Outfall Ponds

Inorganic-N in the reedbed wastewater was further reduced in the Intermediate Pond where discharge samples ranged from 1.7 to 3.7 mg l^{-1} inorganic-N, with an average of 2.7 mg l^{-1} inorganic-N, as shown in Figure 19c The graph also shows that with the exception of the uncharacteristic result on 1/7/97, the concentrations of inorganic-N discharged from the reedbed system were lower than the background concentrations in the Outfall Pond.

3.2.13. Phosphate (PO_4^{3-}-P)

The PO_4^{3-}-P of the reedbed influent ranged from 2.7 to 24.4 mg l^{-1} PO_4^{3-}-P, with an average of 11.2 mg l^{-1} PO_4^{3-}-P, and reflected the variable nature of the influent (Figure 20).

Pot-grown section

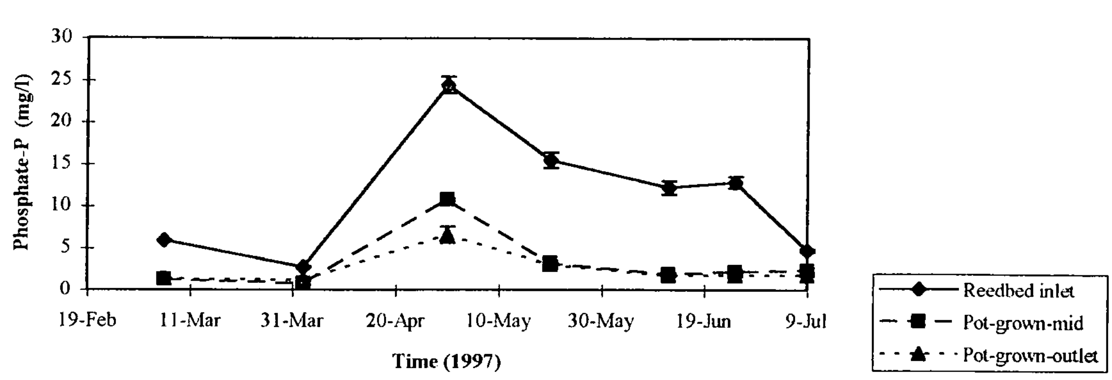
There was a significant reduction in the PO_4^{3-}-P of water between the inlet and outlet areas of the reedbed ($F_{2,,24}$ = 565.34, p <0.001). Water leaving the reedbed ranged from 1.2 to 6.5 mg l^{-1} PO_4^{3-}-P, with an average of 2.5 mg l^{-1} PO_4^{3-}-P. 2-way ANOVA indicated that there was a significant difference in PO_4^{3-}-P between different sampling periods both at the inlet and outlet of the reedbed ($F_{3,24}$ = 48.13, p <0.001), reflecting the variable nature of the influent content, as shown in Figure 20a. There was also a significant difference in the reduction between areas in PO_4^{3-}-P during different sampling periods ($F_{6,24}$ = 32.75, p <0.001), with the highest reduction of 87 % on 25/6/97.

Local reed section

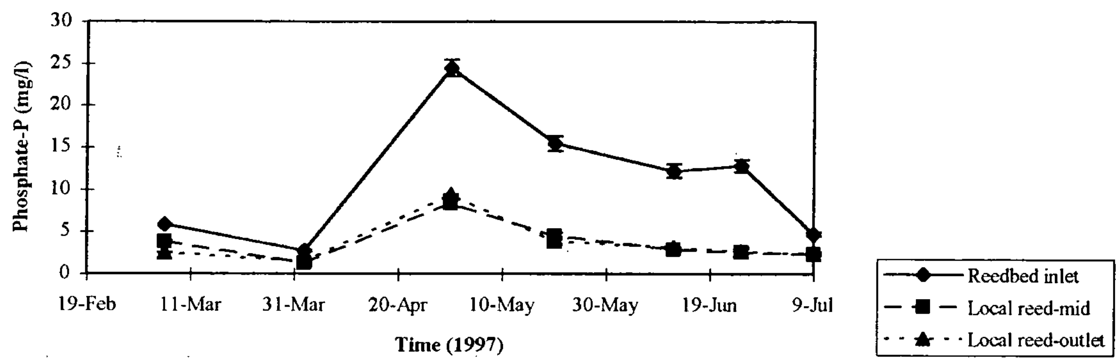
There was a significant reduction in the PO_4^{3-}-P of water between the inlet and outlet areas of the reedbed ($F_{2,24}$ = 433.59, p <0.001). Water leaving the reedbed ranged from 1.5 to 9.4 mg l^{-1} PO_4^{3-}-P, with an average of 3.6 mg l^{-1} PO_4^{3-}-P. 2-way ANOVA

Figure 20. Graphs to show the phosphate-P (mg/l) content of water samples from the CATS Terminal reedbed between 6/3/97- 9/7/97 (data represent the mean +/- SE of 3 samples)

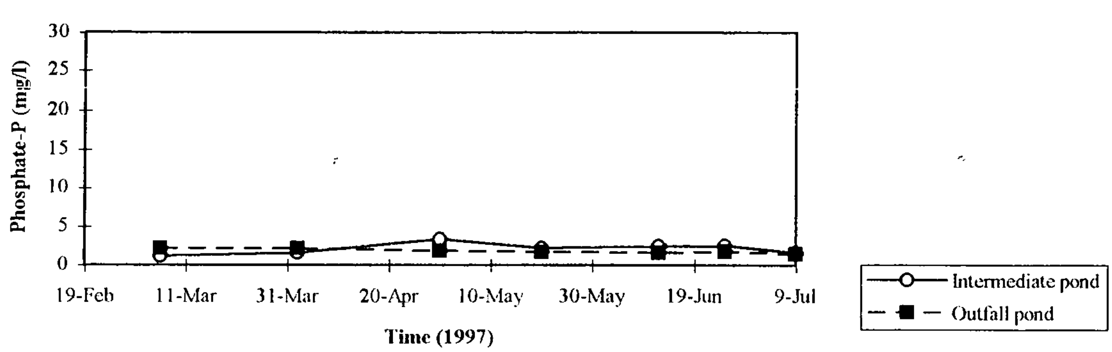
20a. POT-GROWN REEDS



20b. LOCAL REEDS



20c. INTERMEDIATE & OUTFALL POND



indicated that there was a significant difference in PO_4^{3-}-P between different sampling periods both at the inlet and outlet of the reedbed ($F_{3,24} = 55.81$, $p < 0.001$), reflecting the variable nature of the influent content, as shown in Figure 20b. There was also a significant difference in the reduction between areas in PO_4^{3-}-P during different sampling periods ($F_{6,24} = 26.01$, $p < 0.001$), with the highest reduction of 79 % on 25/6/97.

Comparison between pot-grown and local reed sections of the reedbed

There was a significant difference in the PO_4^{3-}-P of outlet water between the pot-grown and local reed sections of the reedbed ($F_{1,16} = 30.80$, $p < 0.001$), with the pot-grown section discharging lower values. 2-way ANOVA indicated that there was a significant difference in the reduction in PO_4^{3-}-P between the two types of reed areas during different sampling periods ($F_{3,16} = 13.68$, $p < 0.001$) as shown in Figures 20a and b. The average reduction in PO_4^{3-}-P between the inlet and outlet areas of the reedbed over the monitoring period was 81 % in the pot-grown section, and 73 % in the local reed section.

The Intermediate and Outfall Ponds and ICI

PO_4^{3-}-P in the Intermediate Pond ranged from 1.2 to 3.3 mg l^{-1} PO_4^{3-}-P, with an average of 2.1 mg l^{-1} PO_4^{3-}-P. The Intermediate Pond reduced the PO_4^{3-}-P concentration of the reedbed water further as shown in Figure 20c. The PO_4^{3-}-P of Outfall Pond water samples ranged from 1.4 to 2.2 mg $^{-l}$ PO_4^{3-}-P. It can be seen from the graph that the raised PO_4^{3-}-P concentration in the reedbed during the period around 30/4/97 affected concentrations in the Intermediate Pond but were diluted to background concentrations within the Outfall Pond. Concentrations of PO_4^{3-}-P in water samples from the ICI No.6 brinefield reedbed were below the level able to be detected by the SKALAR analyser (<0.05 mg l^{-1}).

The average reduction in the PO_4^{3-}-P content of the water between the inlet and the outlet of the reedbed system (the Intermediate Pond), was 80 %.

3.2.14. Calcium Magnesium/Sodium/Potassium.

The major cations of natural waters, calcium, magnesium, sodium and potassium, are not routinely analysed for performance of wastewater treatment systems, since very little removal would be expected. However, concentrations were monitored throught the reedbed for comparison with reed tissue concentrations of the elements. Unfortunately, determination of sodium and magnesium in the reed tissue extract was not possible, due to the unforseeable presence of both elements in the selenium catalyst tablets used in the extraction (not listed as present). The detailed results of the calcium and potassium concentrations of water in the reedbed system and in the ICI No.6 brinefield are provided in the disc accompanying this dissertation for future reference, if required.

3.2.15. Air temperature

Figure 21 shows the mean daily air temperatures taken at the ICI Billingham site (NZ475 221) during the monitoring period. January, February and March of 1997 recorded higher than UK normal monthly average temperatures, whilst April, May and June recorded lower than average temperatures.

3.2.16. Water temperature

Figure 22 shows the water temperatures recorded at the inlet tank to the reedbed, and within the gravel of the reedbed during the monitoring period. Water entering the reedbed from the Klargester was generally 0.5 to 1.5 °C higher than the average reedbed water temperature, although during colder periods the difference was greater.

Figure 21. Mean daily air temperature taken at ICI Billingham (NZ475 221) between 15/1/97 - 9/7/97

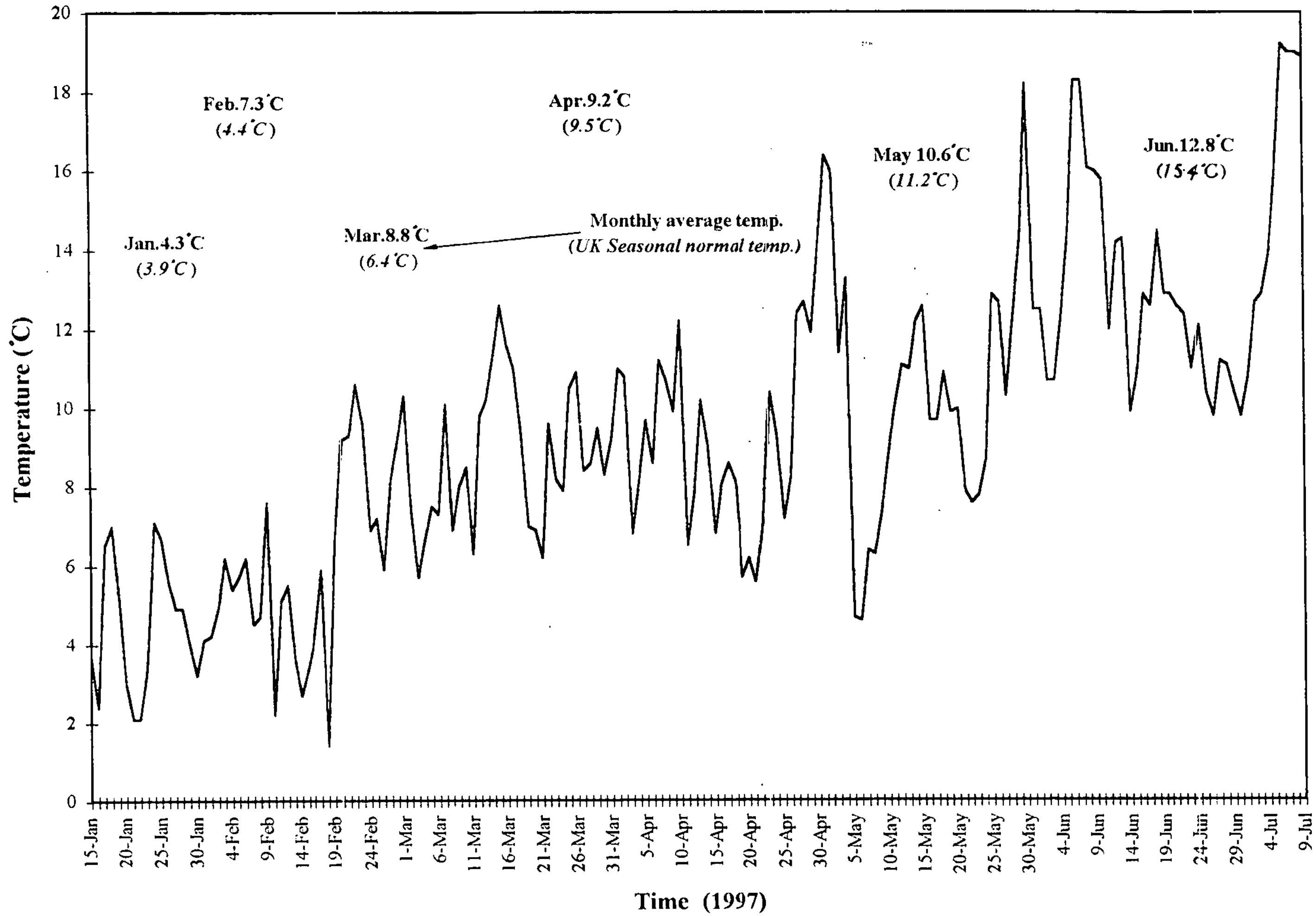
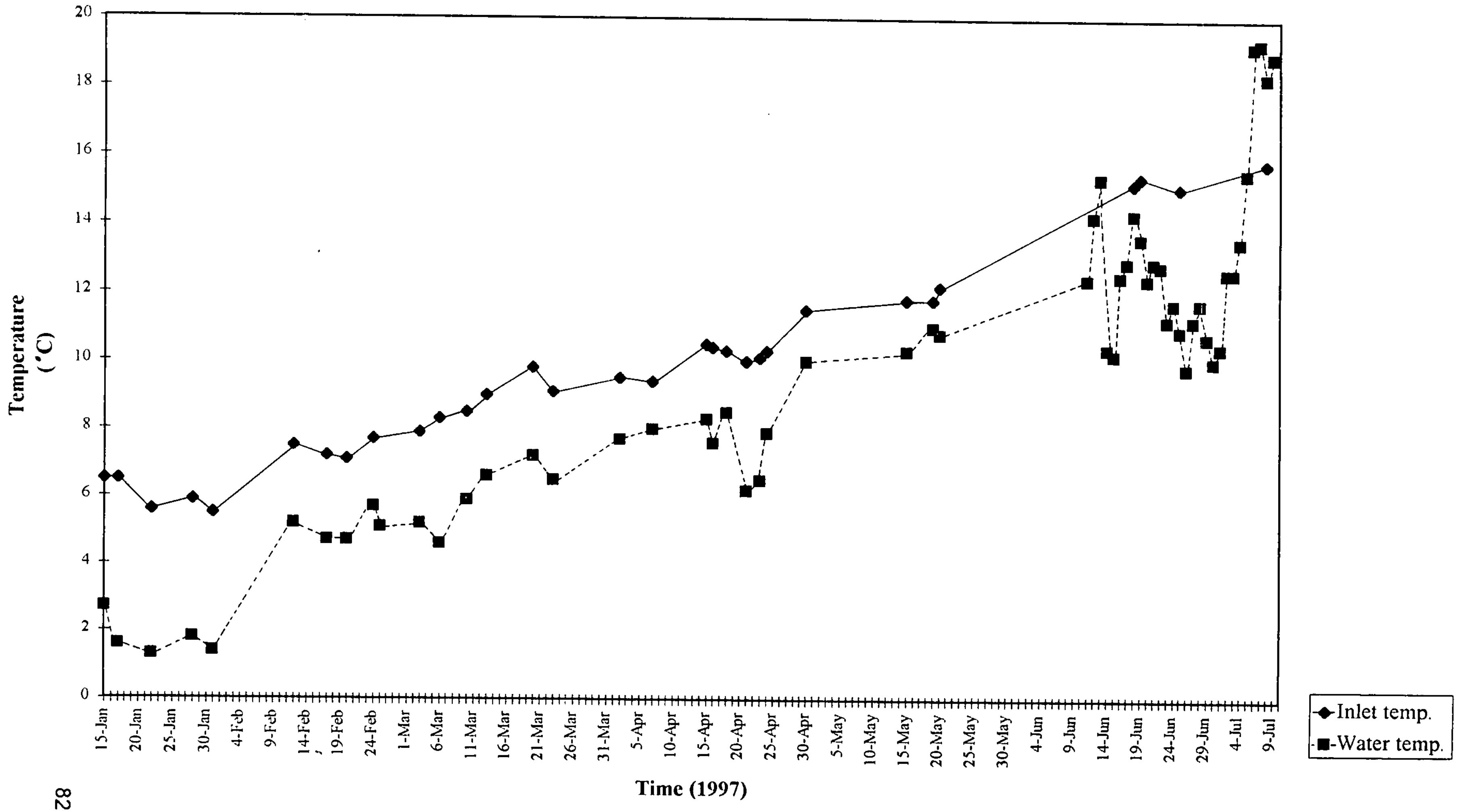


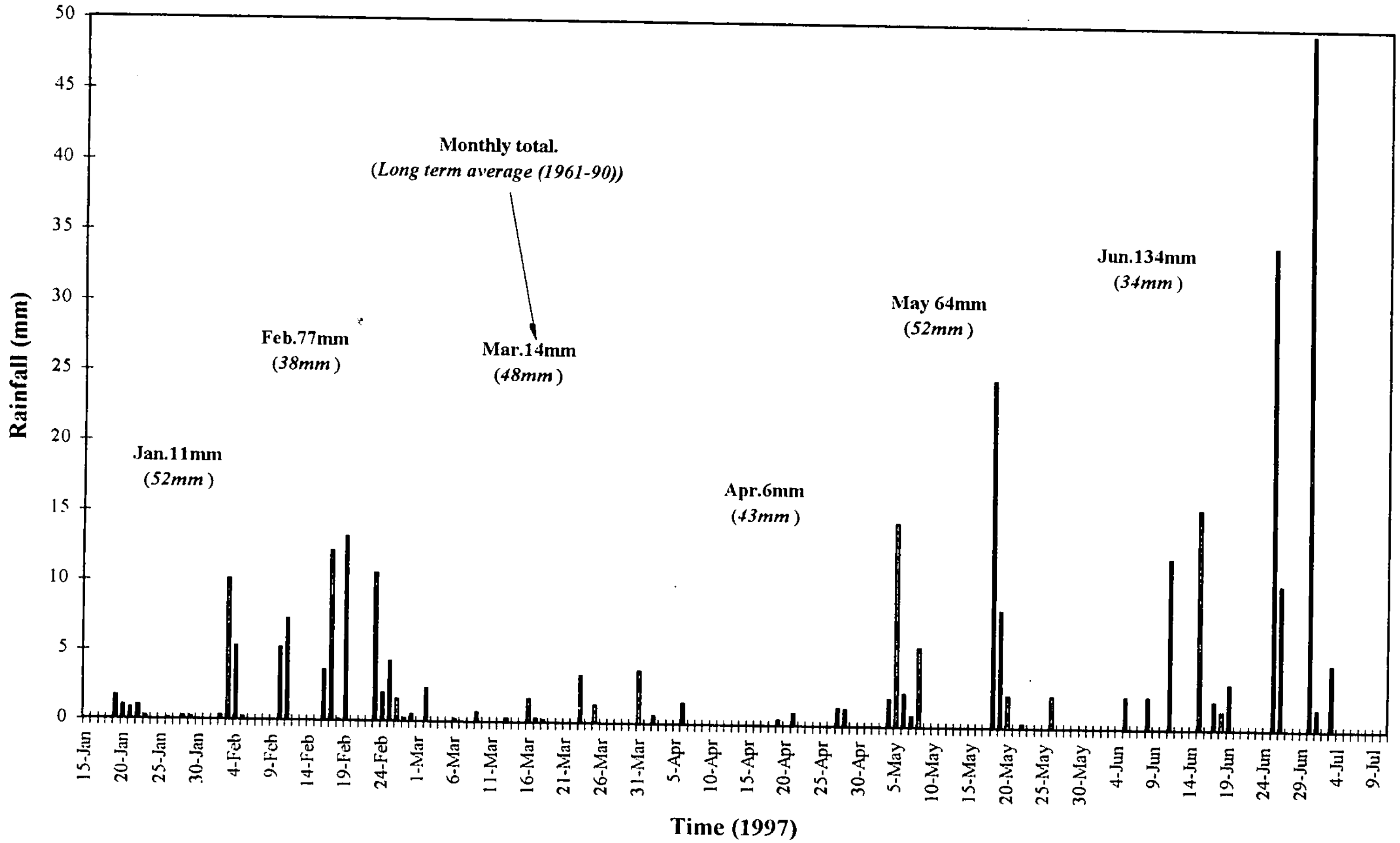
Figure 22. Water temperatures at the CATS Terminal reedbed between 15/1/97 - 9/7/97



3.2.17. Rainfall

Figure 23 shows daily rainfall recorded at the NRA West Hartlepool Station (NZ508 334) for the monitoring period. It can be seen that during February, May and June above average rainfall was recorded, and on 30/6/97, 49.6 mm was recorded. The wet conditions during May and June which culminated in high rainfall on 30/6/97, resulted in localised flooding of the site, of greatest consequence in the hollow where the Klargester was situated. The Klargester was innundated with excess groundwater with a high suspended silt content. The Klargester began to discharge into the reedbed a continuous high flow rate of groundwater and re-suspended sludge from the settlement tanks for a period of at least 6 hours (chapter two).

Figure 23. Daily rainfall (mm) from 15/1/97 - 10/9/97 taken at the Environment Agency, West Hartlepool station (NZ508 334)



3.3. Discussion

3.3.1. The performance of the reedbeds in treating site effluent

3.3.1.1. Biochemical Oxygen Demand (BOD_5)

Between 13/3/97 to 30/6/97, the Klargester was discharging effluent into the reedbed system with BOD_5 loading rate approximately 75 % higher than the maximum 20 mg O_2 l^{-1} specified (see section 1.2.4). The high concentration of BOD_5 and SS was a result of a failure within the Klargester to pump sludge back from the final settlement tank to the primary settlement zone (P. Griffin, Severn Trent Water PLC, personal communication). The increase in the inlet area BOD_5 during the monitoring period was caused by the deterioration in effluent produced by the Klargester. Once sludge had been washed out from the Klargester during flooding, the BOD_5 loading to the reedbed was reduced to 5 mg O_2 l^{-1}. The BOD_5 loading to the reedbed is likely to increase with time unless the problem is rectified. The reedbed itself was designed to reduce the expected 20 mg O_2 l^{-1} effluent to 5 mg O_2 l^{-1} BOD_5. Because of the fairly high influent suspended solids concentration, a large fraction of the influent BOD_5 was associated with settleable material. Thus a large proportion of the influent BOD_5 was removed with the suspended solids through sedimentation and filtration. The soluble fraction of the total BOD_5 was removed through the aerobic microbial degradation of organic carbon compounds (Pride *et al.*,1990).

The removal of BOD_5 could be expected to decline during the colder months due to a decrease in microbial activity as bed temperatures drop (Surface *et al.*,1993). Any such seasonal effect was masked during the study due to the deteriorating quality of the inlet wastewater. Despite the high BOD_5 concentration at the inlet, there was a significant reduction of BOD_5 between the inlet and outlet areas of the reedbed, with no significant difference in performance between the pot-grown and local reed sections. A study by Thut (1993), found that whilst some 10 % of the reduction in BOD_5 could be attributed to plants, the rest was due to the action of the gravel and its associated bacteria. This was probably the situation during the early part of the season in the CATS Terminal reedbed as significant plant growth was not apparent until May, and the BOD_5 removal was almost as effective before May as after. Although not achieving BOD_5 in outlet samples of 5 mg O_2 l^{-1}, the average outlet of 7.7 mg O_2 l^{-1} from the pot-grown reeds and 8.1 mg O_2 l^{-1} in the local reed section was impressive considering the high loading rate. During the Klargester flooding incident on 1/7/97, an inlet spot sample recorded a BOD_5 of 114 mg O_2 l^{-1}. The retention time of the wastewater was minimal, yet a spot sample taken from the Intermediate Pond outlet recorded a reduced BOD_5 of 6.3 mg O_2 l^{-1}. The reedbed proved to be an effective buffer to accidentally high discharges.

That the BOD_5 increased occasionally in the Intermediate Pond was not of concern, as all wetlands, natural and constructed, possess a carbon cycle which produces low levels of BOD_5 (1-3 mg O_2 l^{-1}), defining the lower limit of BOD_5 that can be achieved in an effluent (Brix,1994). In a study by Kuehn & Moore (1995), some BOD_5 additions were seen during the summer. Despite the high loading rate and Klargester malfunction incident, the Environment Agency authorisation of BOD_5 100 mg O_2 l^{-1} maximum discharge consent was achieved 100 % of the time.

3.3.1.2. Chemical Oxygen Demand (COD)

The COD of water entering the reedbed fluctuated with the variable nature of the wastewater, but increased with time in line with the decreasing quality of effluent from the Klargester. The chemical oxygen demand was always higher than the biological demand in the wastewater as it measured all of the organic and other compounds that could be oxidised by a strong chemical oxidant. Such reactions were unlikely to occur in the reedbed, but unlike the BOD_5 test, which took five days to indicate the oxygen demand of the wastewater, the COD test could identify high organic wastewater concentrations within a couple of hours. The wastewater from the Klargester comprised a large proportion of organic matter in suspension, much of which was deposited between the inlet and the middle section of the reedbed. This sedimentation significantly reduced the COD of the water. The material susceptible to microbial degradation was further reduced in both sides of the reedbed. That there was a significant difference in the COD of the outlet water between the local and pot-grown reeds was as a result of filtration of insoluble material by the greater density of reeds present in the latter section.

The reedbed final effluent from the Severn Trent PLC Wetwood, gravel based, tertiary treatment reedbed monitored during 1996, averaged a COD value of 48.2 mgO_2 l^{-1} (inlet average 171 mg O_2 l^{-1}), but with a minimum value of <20 mg O_2 l^{-1} and a maximum value of 345 mg O_2 l^{-1} (inlet minimum 23 mg O_2 l^{-1}, maximum 791mg O_2 l^{-1}), the variation in the 156 sample periods can be appreciated.

Although it was not a regulated determinand, compared with the average COD reduction of 72 % achieved by the Wetwood reedbed, the 60 % average reduction of COD achieved by the CATS Terminal reedbed was impressive, considering both the higher than desired influent from the Klargester (a temporary problem), and also the immaturity of the reedbed.

3.3.1.3. Suspended Solids (SS)

Approximately 60% of the organic load of domestic sewage is in suspension (Grant *et al.*,1996). A high proportion of this matter was removed in the Klargester pre-treatment system. The Klargester was designed to discharge effluent with less than 30 mg l^{-1} SS, yet the wastewater discharged into the reedbed between 21/1/97 to 30/6/97 exceeded this amount on each sampling occasion, due to the malfunction of the Klargester RBC. The SS removal was however, excellent in both sections of the reedbed and was due to sedimentation and filtration, predominantly between the inlet and middle areas. According to Auclair (1979), low water velocities, coupled with the presence of a gravel substrate and vegetation, promote fallout and filtration of solid materials. The pot-grown reed section removed significantly more SS due to the greater density of reeds which enhanced the entrapment of detrius and particulate inorganics suspended in the water both by physical obstruction and by the reduction of water velocity. Horan (1989), reports that SS can contribute up to 60 % of the BOD_5 of wastewater. This relationship was shown in the monitoring results and explains the reduction in both BOD_5 and COD in the inlet area of the reedbed.

The inlet area of the gravel bed may eventually become clogged with organic and inorganic sediments.The volatile fraction should decompose to gas and soluble matter, but the mineral portion can accumulate.This may lead to pore blockage and a reduction in the hydraulic conductivity, and decreased retention times of the bed (Kadlec & Knight,1996). A study by Tanner & Sukias (1989, cited in Kadlec & Knight,1996), measured the organic depositions in the inlet areas of gravel beds with the use of tracers. The tracer detention time was half the nominal detention time, suggesting that about 50 % of the voids were blocked.

Two problems were highlighted during the present study. Firstly, the visible, but accidental discarge of high concentrations of organic material on 1/7/97, which rapidly settled in the first area of the reedbed. Secondly, the higher than designed-for loadings of SS which entered the reedbed from the malfunctioning Klargester. The insidious build-up of organic material in the reedbed was identified only during the period of wide and repeated monitoring.

The Intermediate Pond did not reduce the SS of the reedbed water further. Algal productivity was a major generator of SS in the Intermediate Pond, especially before the pond cleared during May. This phenomenon has previously been ascribed by Brix (1994) to planktonic production in open water areas of reedbed systems. According to (Kadlec & Knight, 1996), freshwater invertebrates, fungi, and bacteria also contribute to a background level of SS in open water areas of treatment systems.

The results showed that during only one sampling period (21/4/97), when the Intermediate Pond discharged water with a SS content of 72 mg l^{-1}, the Environment

Agency standard of 50 mg $^{-1}$ SS was exceeded. The system achieved the required standard 86 % of the time. Since the Klargester fault has been identified, there is no reason to expect standards to be breached in the future.

3.3.1.4. Dissolved Oxygen (DO)

Sub-surface flow wetlands with continuous flow discharge, frequently have water with low DO, often less than 1.0 mg l^{-1} O_2 (Cooper & Green,1995). In the present study, the dissolved oxygen content of inlet waters decreased significantly within the reedbed due to a number of factors. Firstly, biological and chemical transformations within the bed required O_2; secondly, diffusion of oxygen into the water from the atmosphere was limited due to the water level being 50 mm below the surface of the gravel, also, the slow flow of water through the reedbed would not introduce more O_2 into the water.

The dissolved oxygen concentrations that were measured during the monitoring period represent the general levels present in the reedbed areas. However, levels of DO were likely to be higher around the root and rhizome area of each reed (Armstrong & Armstrong, 1990a). This variation in concentration would result in both aerobic and anaerobic areas within the reedbed, allowing for both nitrification and dentrification processes to occur.

There were significantly lower DO concentrations in the pot-grown outlet area than the local reed outlet area of the reedbed during the study, resulting in relatively higher levels of ammonium, and also lower levels of nitrate due to increased rates of dentrification.

The DO of the water within the reedbed appears to have been greatly affected by chemical and biological processes, masking any decrease due to the decline in solubility associated with increasing temperatures. The samples measured in open water areas, (Intermediate Pond, Outfall Pond and the brinefield reedbed), actually increased their dissolved oxygen concentration during summer monitoring periods. This anomaly may have been due to taking daytime samples when photosynthetic activity by the macrophytes and periphyton was occurring.

Low levels of DO within the reedbed, especially when accompanied by reduced BOD_5, COD and nitrogen species, served to indicate that the reedbed was performing efficiently.

3.3.1.5. pH

There was no significant difference between the pH of the pot-grown and local reed sections of the reedbed in either the middle or the outlet areas. The pH of water entering the reedbed had pH values which had been reduced during the nitrification process within the Klargester (the normal pH of sewage being between 6-8, Davies & Hart, 1990a). Once in the reedbed system, dentrification processes raised the pH of the water. There was no significant difference between the pH of the pot-grown and local reed sections of the reedbed in either the middle or the outlet areas. Treatment wetland effluent pH concentrations are typically neutral to slightly acidic, and sub-surface wetlands buffer the variations of incoming waters (Bavor *et al.*, 1989). The pH of the reedbed water was buffered at a level both suitable for microbial wastewater treatment activity, and also reedbed wildlife.

3.3.1.6. Conductivity

The variation in the conductivity of inlet waters was due to natural variation within the effluent received and discharged from the Klargester, examplified when conductivity increased in all areas of the reedbed on the final sample period, but not in the Outfall Pond or ICI. The increase in conductivity through the reedbed between March and April was due to spot-sampling of water released at different times, rather than indicating evapotranspiration. Sub-surface beds are less affected by evaporation, and the reeds were only beginning to grow. The fact that from the end of April, the conductivity of water samples declined through the reedbed is less easily explained. Despite the high rainfall over the site during April and May, the dates when conductivites were taken do not suggest that dilution could be a factor. Chloride levels would be expected to pass through the reedbed relatively unchanged, therefore any differences within the reedbed were likely to be as a result of different concentrations passing through the system.

3.3.1.7. Phosphate removal

Claims have been made for phosphate removal in reedbed treatment systems, but only with consistency when the substrate used has been high in iron, aluminium or calcium (Cooper & Green, 1995). It has not been determined wether adsorption via ligand exchange or precipitation reactions is the main phosphate removal mechanism (Cooper *et al.*, 1996). The continuous flow reedbed at the CATS Terminal could be manipulated to induce precipitation enhanced by alternating oxidising states, by stopping the flow through alternating sides of the reedbed. However, this method would be time consuming and if phosphate removal had been a major requirement, an iron-rich substrate would have been incorporated into the design. Also, long-term phosphate removal could be achieved by harvesting the above-ground reed biomass. Water treatment systems using floating aquatic plants have been designed to allow for the harvesting of vegetation without disrupting plant growth and water treatment (Kadlec & Knight, 1996).

Discounting the seasonal temporary uptake of phosphate by the reeds, the phosphate removal that occured was largely a physical or chemical process, and was therefore, less sensitive to temperature (Wittgren & Maehlum, 1997). The phosphate levels present in the wastewater from the construction site were not high, and originated mainly from the sewage, unlike for example, the high loadings of phosphate present in the Larchfield Farm reedbed which originated from washing powders and detergents (J. Jenkins, personal communication).

Variations in inlet water phosphate concentrations were removed significantly within the first half of both sections of the reedbed, due to adsorption sites within the gravel. However, most gravel matrices would be expected to become quickly saturated (Cooper *et al.*, 1996).

The performance of the CATS Terminal reedbed in terms of phosphate removal capacity was better than expected (80 % reduction). This could be attributed to the gravel containing calcium, and phosphate being removed by precipitation as calcium phosphate (House *et al.*, 1994). Trial beds at Brinklow (Severn Trent Water PLC), have been set up to assess the phosphate removal potential of different mediums, such as ironstone chippings, expanded firestone grog, and pea-gravel. Although the bed of ironstone chippings removed higher amounts, the pea-gravel bed removed far more phosphate than expected and it was found that the gravel contained calcium which acted to adsorb phosphate (P. Griffin, personal communication). This could be happening in the CATS reedbed. The adsorption sites will eventually become saturated. This was the experience in newly-filled beds at Middleton and Leek Wooton (Severn Trent Water), suggesting that the removal effect is only efficient during the first months of operation (Green & Upton, 1994).

Temporary plant uptake could account for the higher phosphate removal achieved in the pot-grown section. Similarly, the Intermediate Pond reduced the PO_4^{3-}-P of the reedbed water further due to uptake by plants and organisms and also further adsorption by the Intermediate Pond gravel. The length of time that the reedbed will continue to effectively reduce phosphate concentrations in the wastewater should be determined through long-term monitoring.

3.3.1.8. Nitrogen transformations

An analysis of the molecular transformation processes of ammonification, nitrification and dentrification within the reedbed help indicate whether the organic components of the wastewater have been degraded, resulting in the final discharge of less oxygen-demanding waters. Ammonification and a degree of nitrification within the Klargester released nitrogen in the form of nitrate into the reedbed. However, increases in ammonium through the reedbed indicated further ammonification occurring from the degradation of organic nitrogen.

The presence of organic nitrogen in the reedbed was a consequence of the deterioration in effluent discharged to the reedbed with high BOD_5 and particulates. The ammonium generated in the reedbed could not effectively be removed in the reedbed by nitrification due to a shortage of oxygen (<1mg O_2 l^{-1}), yet this process occurred in the Intermediate Pond where higher levels of oxygen were available.

Most UK sub-surface systems remove little ammonia because they are oxygen-limited (Cooper & Green, 1995; Kadlec & Knight, 1996). Nitrification would have been limited to the aerobic root zone areas within the reedbed. Nitrification of organic matter in the Klargester and reedbed can be expected to slow down during the winter, due to the minimum temperature for growth of *Nitrosomonas* and *Nitrobactor* being 5 °C and 4 °C (Cooper *et al.*, 1996), resulting in a decline in the removal of ammonium. However, a study by Platzer & Netter (1994), on factors affecting nitrogen removal in horizontal flow reedbeds, found that the influence of temperature on nitrification rates was less than often suggested. They found that nitrogen removal rates varied only 20-30 % over a temperature range from 1-18 °C. A seasonal reduction (not cessation) in ammonification and dentrification could also be expected, resulting in a lesser overall efficiency of nitrogen removal by the reedbed (Pride *et al.*, 1989; Davies & Hart, 1990b; Sikora et al., 1995; Kadlec & Knight, 1996; May *et al.*, 1990; Cooper *et al.*, 1996; Reddy & D'Angelo, 1997). However, sub-surface wetlands can provide greater thermal protection than surface-flow systems due to the insulating effect of the unsaturated surface layer (Wittgren & Maehlum, 1977). Biological assimilation of ammonium and nitrate by plants and microbes increased during warmer periods but the compounds were only removed from the wastewater in the short-term, being released back into the system during the winter via rhizome leaching and decomposition of organic matter, both plant and microbial.

Nitrogen transformations within the reedbed were predominantly by the process of dentrification, and an unusually high removal of nitrates was achieved during the monitoring period (92 % nitrate reduction). The reduction in inorganic-N from the inlet to the Intermediate Pond during the monitoring period was 85 %. Nitrogen removal in subsurface flow wetlands is generally about 30-40 % according to Brix (1994). The water in the outlet area of local reeds contained significantly more inorganic-N than the middle area of the reedbed, indicating that the pot-grown reeds were either taking it up or providing better conditions for dentrification, or both. Dentrifying bacteria are more abundant than nitrifiers in sub-surface wetlands, most being associated with roots rather than gravel (May *et al.*, 1990), accounting for the more efficient removal of nitrate in the higher density, pot-grown section of the reedbed. Dentrification was mediated by heterotrophic microorganisms whose rate could be limited by available organic carbon (Reddy & D'Angelo, 1997). However, the unexpectedly high levels of organic nitrogen discharge onto the reedbed provided a sufficient carbon source to continue dentrification. Although high nitrogen removal has been achieved, the higher than desirable levels of suspended matter would shorten the effective life of the reedbed and should be rectified.

During the monitoring period, dentrification appears to be the main nitrogen transformation process occuring within the reedbed, and nitrification within the Klargester and the Intermediate Pond. All have contributed to a net loss of nitrogen from the wastewater, as desired.

The use of the constructed reedbed to treat site effluent following pre-treatment in the Klargester offers a high degree of protection for the site. Constructed wetlands have been shown to perform very reliably, even under shock loads (Kuehn & Moore, 1995, and this study).

The reedbed has proved itself capable of dealing with wide variations in influent loading throughout the season. Results from the monitoring period provide a convincing demonstration of the effectiveness of the reedbed system in achieving high quality effluent to acceptable wastewater treatment standards for BOD_5 and SS, during the first 7 months of operation. The performance of the reedbed should improve with succeeding growing seasons as plant densities increase.

CHAPTER FOUR

4. THE INFLUENCE OF INPUTS OF PHOSPHORUS AND NITROGEN ON REED GROWTH AND DEVELOPMENT

Primary productivity of wetland plants is increased by the availability of water, light, and nutrients. Adding wastewater to wetlands increases the availability of nutrient and results in the stimulation of plant growth. Plant growth increases as more nitrogen and phosphorus is added, until the full growth potential is realised. However, at higher nutrient levels, plant growth slows down, while luxury nutrient uptake continues (Marschner, 1986; Reddy & Debusk, 1987; Kadlec & Knight, 1996). A comparative analysis has been undertaken of the growth and nutrient relations of pot-grown reeds and local reeds to elevated nutrients at the CATS Terminal reedbed. Inputs of atmospheric nitrogen have also been assessed. Concentrations of nutrients in plants growing in the ICI No.6 brinefield natural stand has provided a base-line estimate of nutrient assimilation.

4.1. Methods

4.1.1. Collection of reed tissue samples

Reed tissue was analysed in an attempt to determine whether the nutrient content differed between the local and the pot-grown reeds and also between different areas of the reedbed. Due to the recent establishment of the reedbed, plants were not removed for whole plant analysis. The top 10 cm was cut from the second youngest leaf from five, randomly selected, reeds in each area. Plants were sampled from the inlet, middle and outlet areas of both pot-grown and local reeds. A further 10 reeds were sampled from randomly selected ICI No.6 brinefield reeds. The tissue from different reeds was sampled on four occasions between 20/5/97 and 9/7/97.

4.1.2. Reed tissue nutrient extraction

Once cut from the plant, reed sections from each area were placed in paper envelopes, and placed within two hours into the laboratory oven for 24 hours at 80 °C. Once dried to a constant weight (24-48 h), the envelopes were stored in a desiccator prior to weighing, followed by nutrient extraction using a modified micro-Kjeldahl method (Allen *et al.*, 1974).

Each sample was weighed, chopped finely and added to a micro-Kjeldahl flask with 3 cm^3 H_2SO_4 and 1/4 of a selenium catalyst tablet. The flask was heated gently (c.150°C) for 30 minutes and then at a higher temperature (c.400 °C) for 90 minutes. After cooling, the extract was filtered with Whatman GF/C glass microfibre filters, and made up to 25 cm^3 with distilled water in a labelled bottle. For each batch of samples, a control flask was also heated containing only the acid and catalyst tablet.

4.1.3. Total Kjeldahl nitrogen content of reed tissue

The digestion process oxidised organic matter in the reed tissue to release the nitrogen it contained as ammonia. A determination of the total ammonia in the sample by the SKALAR flow analyser gave the total Kjeldahl nitrogen content of the reed shoot tissue. All extract samples were diluted by a factor of 20 before analysis. The control samples were incorporated into the flow analyser in place of a distilled water / sulphuric acid matrix during the run. The automated procedure for the detection of NH_4^+ was based on the modified Berthelot reaction: NH_4^+ was chlorinated to monochloramine which reacted with salicylate to 5-aminosalicylate. After oxidation and oxidative coupling, a green coloured complex was formed. The absorption of the complex was measured at a wavelength of 660 nm.

4.1.4. Phosphorus content of reed tissue

The reed tissue extract was diluted by a factor of 20 before determination of total phosphorus as phosphate by the SKALAR flow-analyser. The procedure within the analyser being the same as for the determination of phosphate in the water samples.

4.1.5. Atmospheric nitrogen

Dry deposition levels of atmospheric nitrogen dioxide (NO_2) were measured using passive diffusion tube samplers, which collect by molecular diffusion of the gas through an acrylic tube to triethanolamine absorbant. Six passive diffusion tubes were positioned at eye height on the northern perimeter fence close to the reed bed on 6/2/97, as shown in Plate 6, and were replaced and analysed fortnightly, until 9/7/97. Six tubes were also positioned in the No.6 brinefield control site for comparison (Plate 5). The acrylic tubes of 7.1 cm length and 1.01 cm internal diameter were prepared and analysed as detailed by Ashenden and Bell (1988). Standard solutions were prepared from sodium nitrate and were used to plot a calibration curve, from which the concentrations of NO_2 collected could be obtained. The standards were as follows:-

1) 0.25 $\mu g\ NO_2$-N mg l^{-1} 2) 0.75 $\mu g\ NO_2$-N mg l^{-1} 3) 1.25 $\mu g\ NO_2$-N mg l^{-1} 4) 2.0 $\mu g\ NO_2$-N mg l^{-1}

Stockton Borough Council provided NO_2 data for their monitoring sites at other locations around the Tees Estuary. These sites were on BASF owned land, recorded as Stockton BASF2 and Stockton BASF3, on a monthly basis as an additional source of information. Figure 1 shows the location of the monitoring sites refered to in this study. Prevailing wind directions and daily air quality data for the Teesside area during the study period were also provided by Stockton Borough Council, and Middlesbrough Borough Council.

4.2. Results.

4.2.1. Reed tissue phosphorus content

Pot-grown reeds

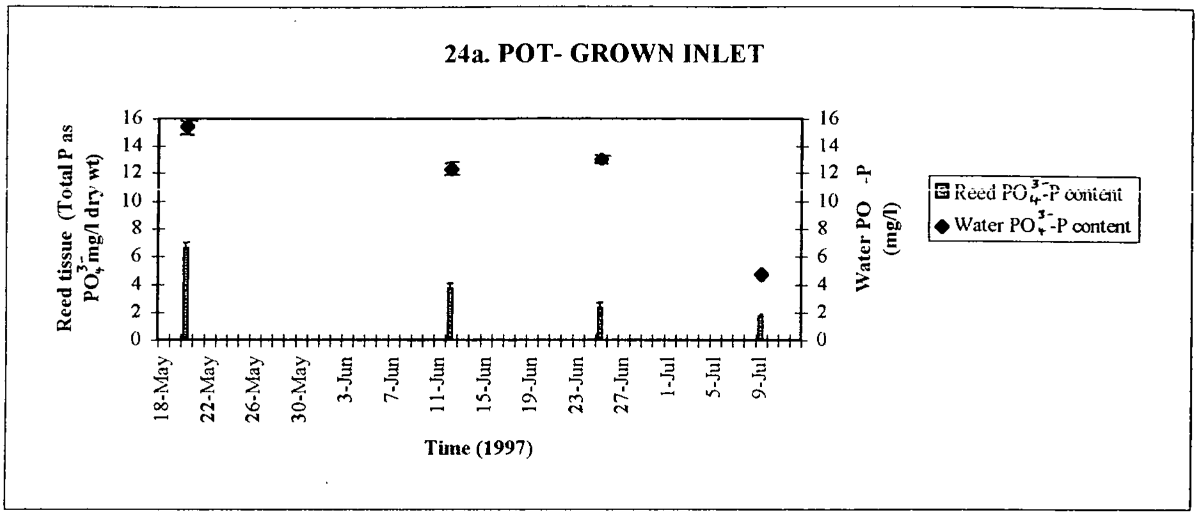
Phosphorus content in pot-grown reed leaf tissue ranged from 1.1 to 6.6 mg PO_4^{3-}-P g^{-1} dry wt. during the monitoring period. Statistical analysis using 2-way ANOVA indicated a significant difference ($F_{2,48}$ = 14.47, p <0.001) in the phosphorus content of reed leaf tissue in different areas of the reedbed. Highest tissue concentrations were found in inlet area reeds and ranged between 1.7 to 6.6 mg PO_4^{3-}-P g^{-1} dry wt, as shown in Figure 24. It can also be seen from the same figure that tissue concentrations in pot-grown reeds decreased significantly with time, the highest concentration being found in all areas of the reedbed on 20/5/97 ($F_{3,48}$ = 36.78, p <0.001).

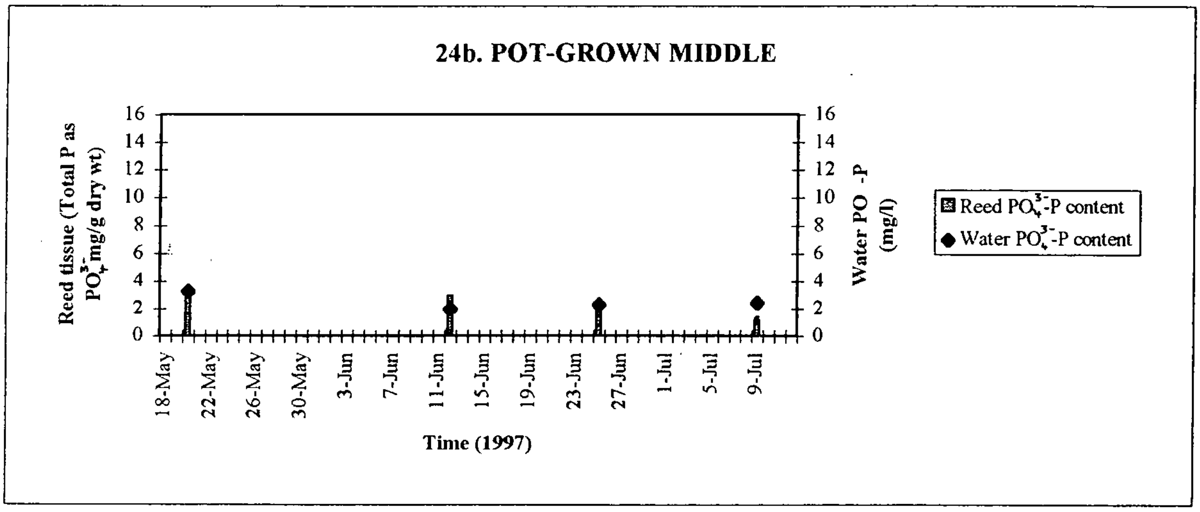
Figure 24 a, b and c show a positive relationship between the phosphorus content in the water and reed tissue content. Water phosphate-P concentrations which ranged from 0.84 to 24.45 mg l^{-1} PO_4^{3-}-P, were higher earlier in the growing season when tissue concentrations were highest. Water phosphate-P concentrations declined significantly between the inlet area and the middle area of the reedbed ($F_{1,16}$ = 581.23, p <0.001).

Local reeds

Phosphorus content in local reed leaf tissue ranged from 1.1 to 3.8 mg PO_4^{3-}-P g^{-1} dry wt. during the monitoring period. 2-way ANOVA did not indicate a difference in the phosphorus content of reed tissue in different areas of the local area reedbed. Figure 25 shows that reeds growing in the outlet area contained similar (20/5/97), or even higher amounts of phosphorus in reed leaf tissues (12/6/97). Statistical analysis (ANOVA) did show a significant decrease in reed leaf tissue phosphorus with time ($F_{3,48}$ = 36.46, p <0.001). Figure 25a, b and c show that concentrations declined from

Figure 24. Graphs showing the phosphate-P content in water and reed leaf tissue in the pot-grown section of the CATS Terminal reedbed between 20/5/97-9/7/97. (data represent the mean +/- SE of 3 samples)





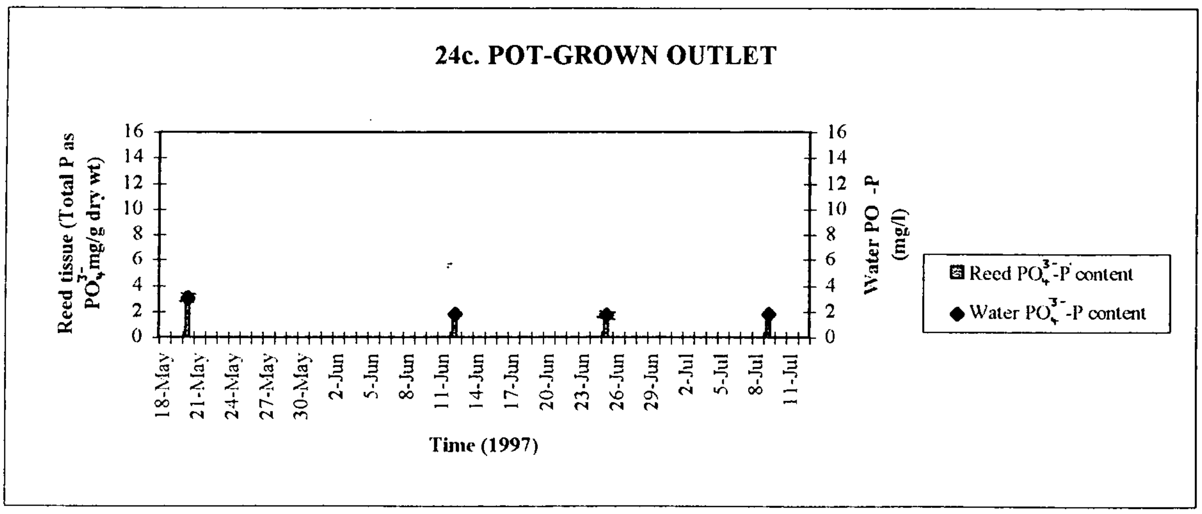
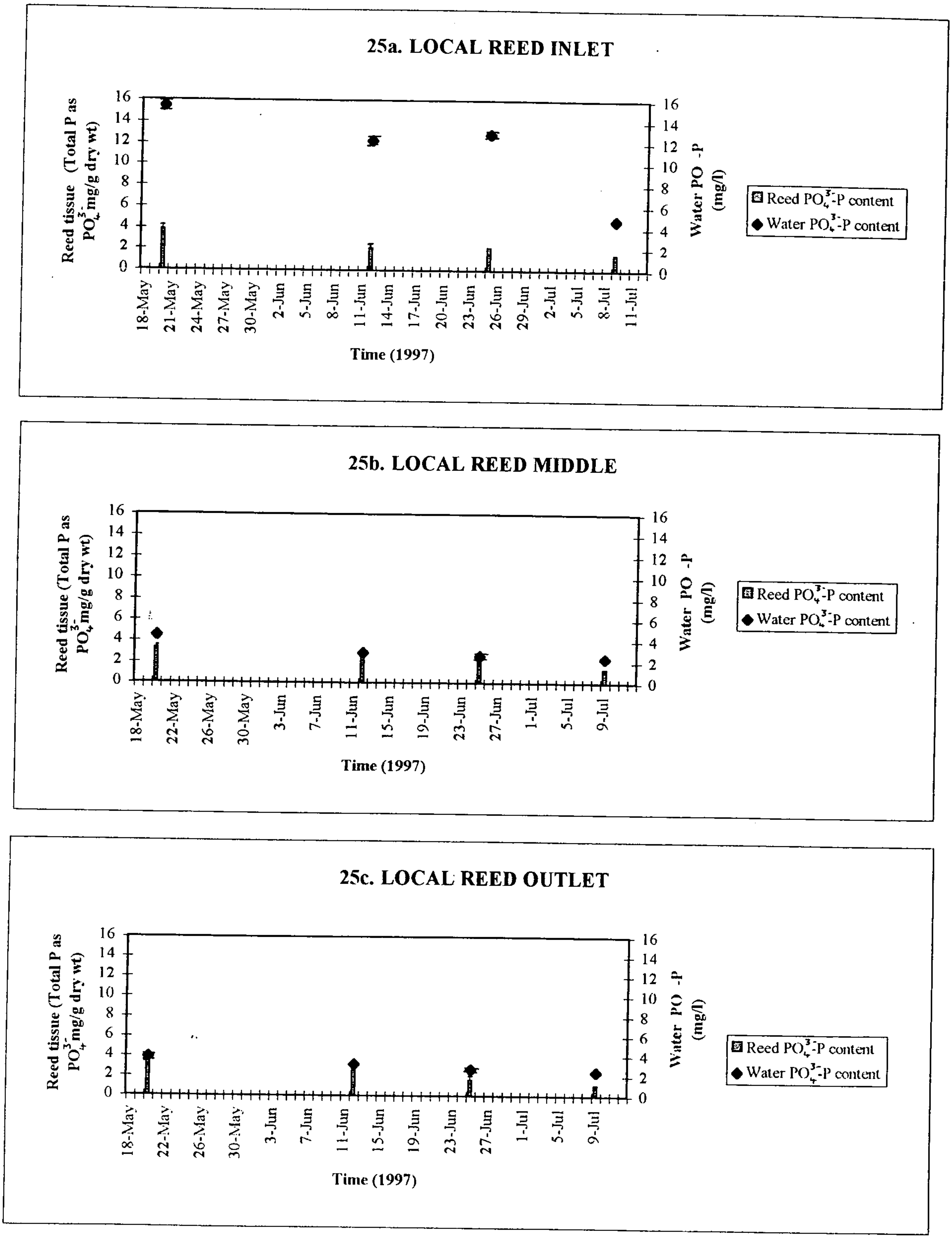


Figure 25. Graphs showing the phosphate-P content in water and reed leaf tissue in the local-reed section of the CATS Terminal reedbed between 20/5/97-9/7/97. (data represent the mean +/- SE of 3 samples)



3.8 mg PO_4^{3-}-P g^{-1} dry wt. in both the inlet and outlet sections of the reedbed on 20/5/97, to <1.5 mg PO_4^{3-}-P g^{-1} dry wt. on 9/7/97.

Water phosphate-P concentrations declined at each monitoring period between the inlet area and the middle area of the reedbed ($F_{1,16} = 491.1$, $p < 0.001$).

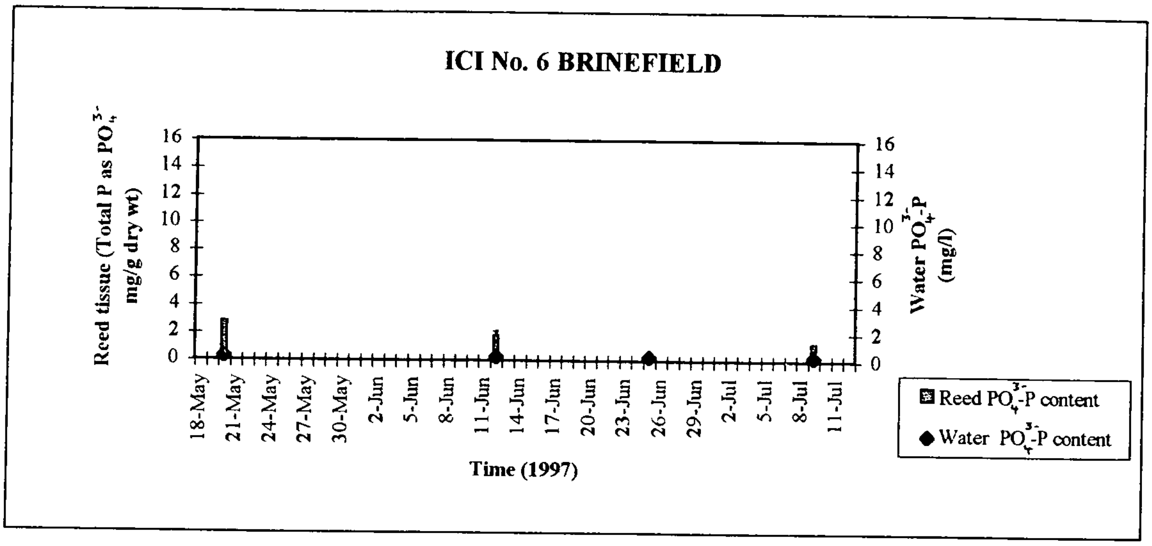
Comparison between pot-grown and local reed sections of the reedbed

2-way ANOVA indicated a significant difference in the phosphorus concentration of reed leaf tissues between the pot-grown inlet and local reed inlet areas of the reedbed ($F_{1,32} = 16.81$, $p < 0.001$), the pot-grown reeds having a higher average concentration of phosphorus in reed leaf tissues at each monitoring period. There was no significant difference in reed leaf tissue phosphorus concentrations between the outlet areas of pot-grown and local reeds. Figures 24 and 25 show the tissue concentrations at each time period. The differences with time proved to be significant at both the inlet area ($F_{3,32} = 31.72$, $p < 0.001$) and the outlet area ($F_{3,32} = 23.23$, $p < 0.001$).

Comparison between the CATS Terminal reedbed and ICI No.6 Brinefield reeds.

Phosphorus content in ICI No.6 brinefield reed leaf tissue ranged from 0.2 to 2.8 mg PO_4^{3-}-P g^{-1} dry wt. during the monitoring period. Although there was no significant difference in the phosphorus content in reed leaf tissue between the two outlet areas of the CATS Terminal reedbed, each area when compared with ICI reeds, contained significantly higher amounts of phosphorus, (pot-grown outlet / ICI, $F_{1,32} = 19.98$, $p < 0.001$; local reed outlet/ICI, $F_{1,32} = 17.94$, $p < 0.001$). Pot-grown reeds in the outlet area contained significantly higher average concentrations of phosphorus at each time period ($F_{3,32} = 8.50$, $p < 0.001$). Figures 24, 25 and 26 shows the differences in reed leaf tissue phosphorus concentration between areas and with time. All areas showed a significant decrease in tissue phosphorus content with time. ICI reeds sampled on 25/6/97 contained four samples with levels below the limit of detection of the Skalar flow-analyser. Only trace amounts of phosphate-P were detected by the Skalar flow-analyser in all of the ICI water samples. This may reflect low amounts of phosphorus in the tissues and water. Nevertheless, the trend of decreasing phosphorus with time remains apparent.

Figure 26. Graph showing the phosphate-P content in water and reed leaf tissue in the ICI No.6 brinefield reedbed between 20/5/97-9/7/97 (data represent the mean +/- SE of 3 samples)



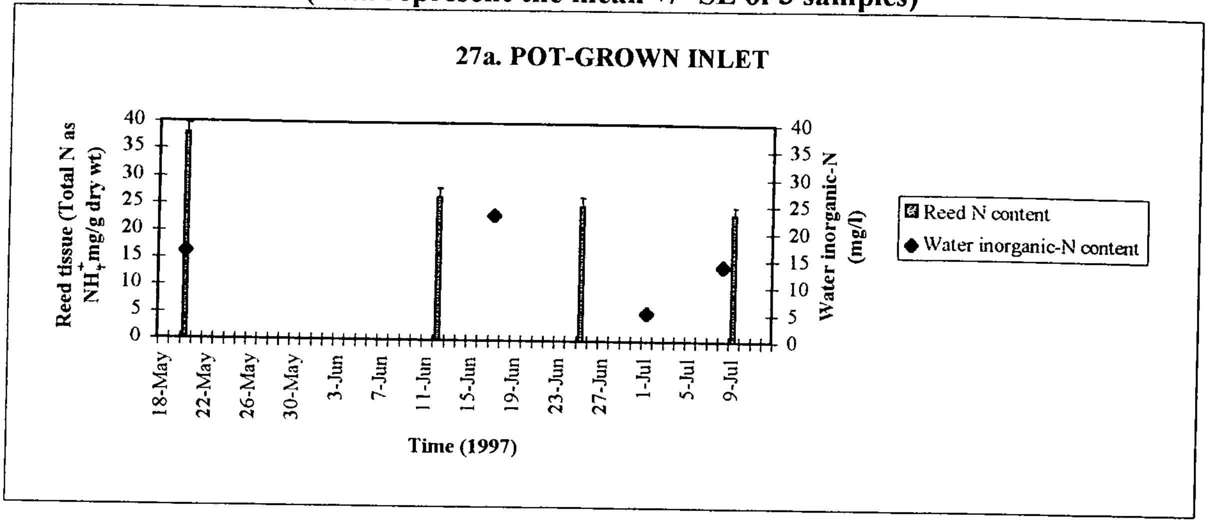
4.2.2. Reed tissue nitrogen content

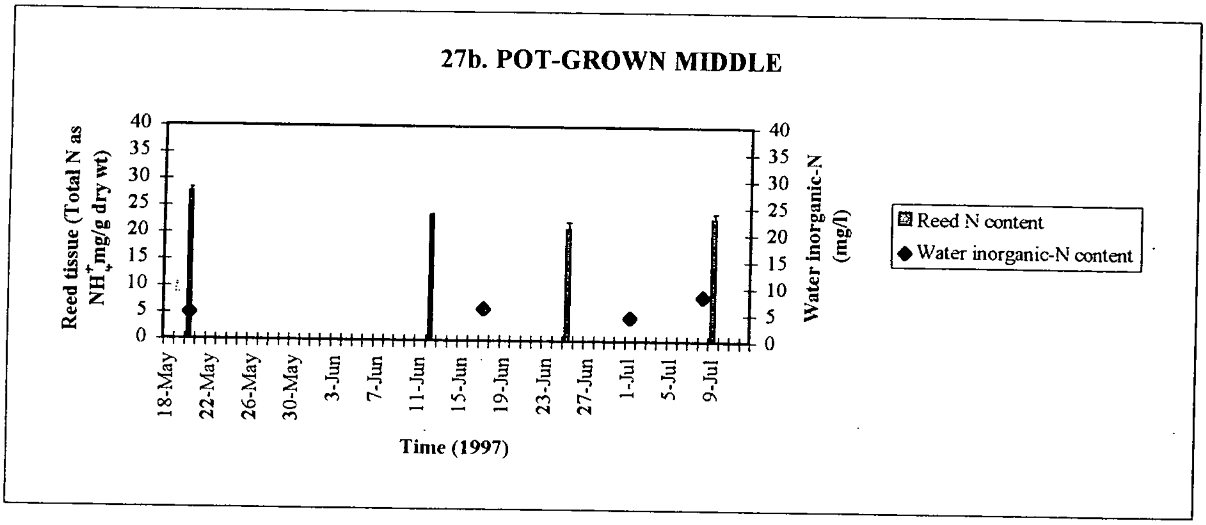
Kjeldahl digestion provided the total nitrogen content of the reed leaf tissue. As the water samples were not analysed for organic nitrogen (chapter three), the sum of the inorganic nitrogen components of the water (ammonium, nitrate and nitrite), have been considered in analysis.

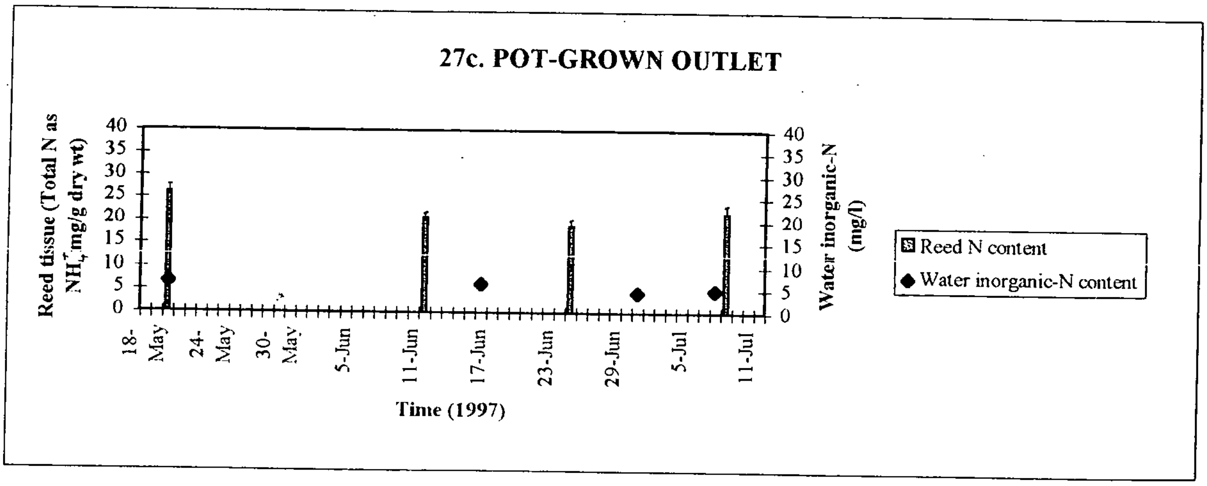
<u>Pot-grown reeds</u>

Nitrogen content in pot-grown reed leaf tissue ranged from 18.8 - 37.8 mg N g^{-1} dry wt. during the monitoring period. 2-way ANOVA indicated a significant difference ($F_{2,48}$ = 16.46, p <0.001) in the nitrogen content of reed leaf tissue in different areas of the reedbed. Highest tissue concentrations were found in inlet area reeds which ranged from 23.4 - 37.8 mg N g^{-1} dry wt., as shown in Figure 27a, whilst the difference in nitrogen

Figure 27. Nitrogen content in water and reed leaf tissue in the pot-grown section of the CATS Terminal reedbed between 20/5/97-9/7/97 (data represent the mean +/- SE of 3 samples)







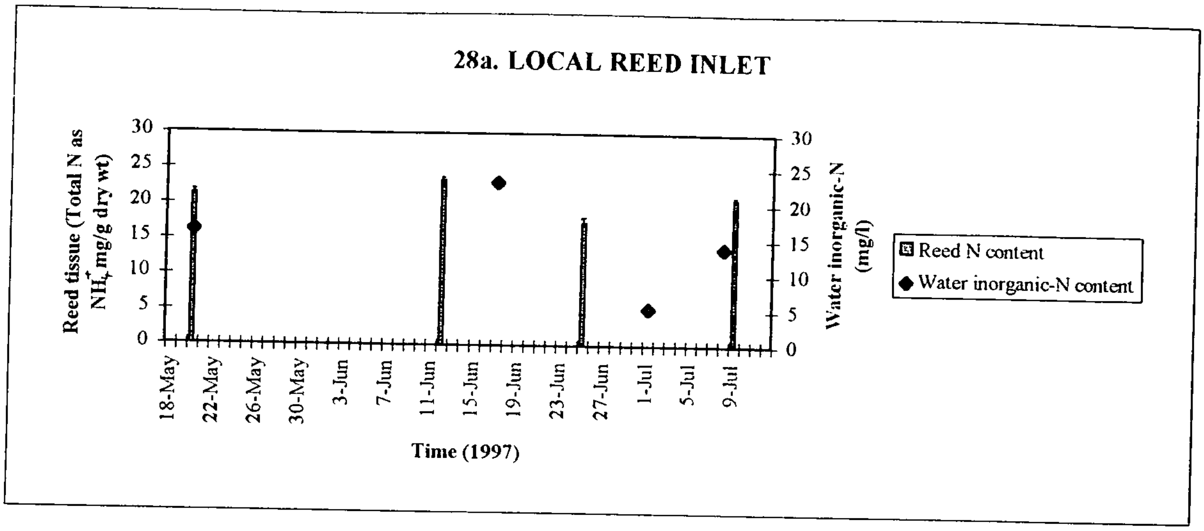
content between reeds in the middle section and the outlet section did not prove to be significant. Figure 27a also shows that tissue nitrogen concentrations in pot-grown reeds decreased significantly with time in all areas of the reedbed ($F_{3,48}$ = 20.26, p <0.001). Figure 27b and c show an increase in leaf tissue nitrogen content on 9/7/97 in the middle and outlet sections of the reedbed. The increase was due to the influx of organic material throughout the reedbed on 1/7/97 by the disfunctioning Klargester (chapter two). 2-way ANOVA of inorganic-N content of water samples did not include results from 1/7/97 as the retention time of effluent passing through the reedbed provided anomalous results.

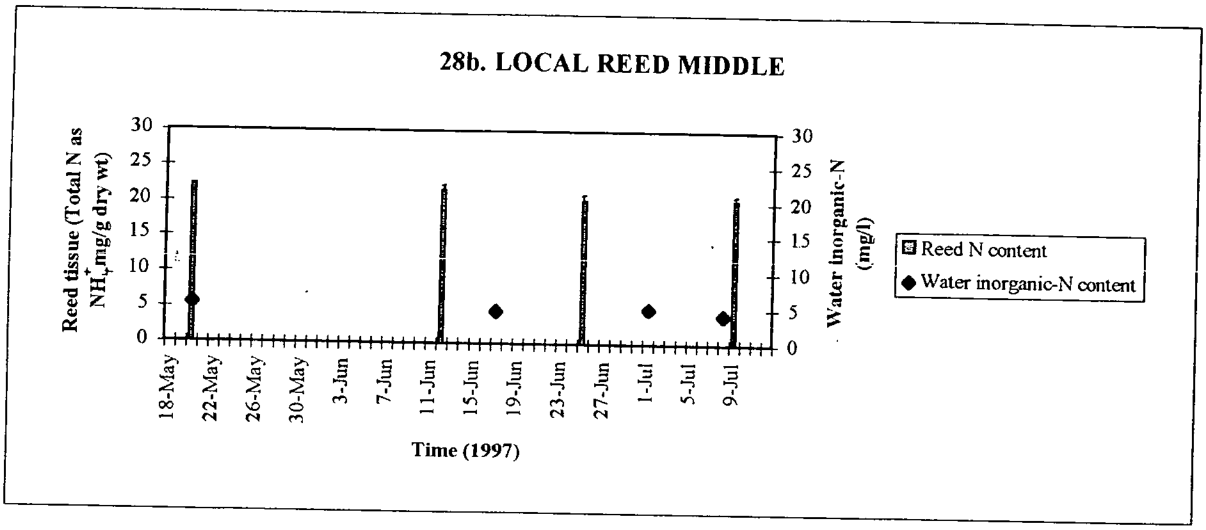
Figure 27a, b and c show the positive relationship between the nitrogen content of the reed leaf tissue and the inorganic-N content of the water. Water inorganic-N content which ranged from 4.4 - 23.0 mg l^{-1}, was significantly higher in the inlet area than other areas of the reedbed ($F_{2,18}$ = 785.99, p <0.001), whilst the difference in inorganic-N content of water in the middle and outlet areas was not significant. The increase for the 9/7/97 may also be attributed to the Klargester malfunction on the 1/7/97. Figure 27a, b and c show a positive relationship between the increase in inorganic-N content of the water and the increase in leaf tissue nitrogen content after 1/7/97.

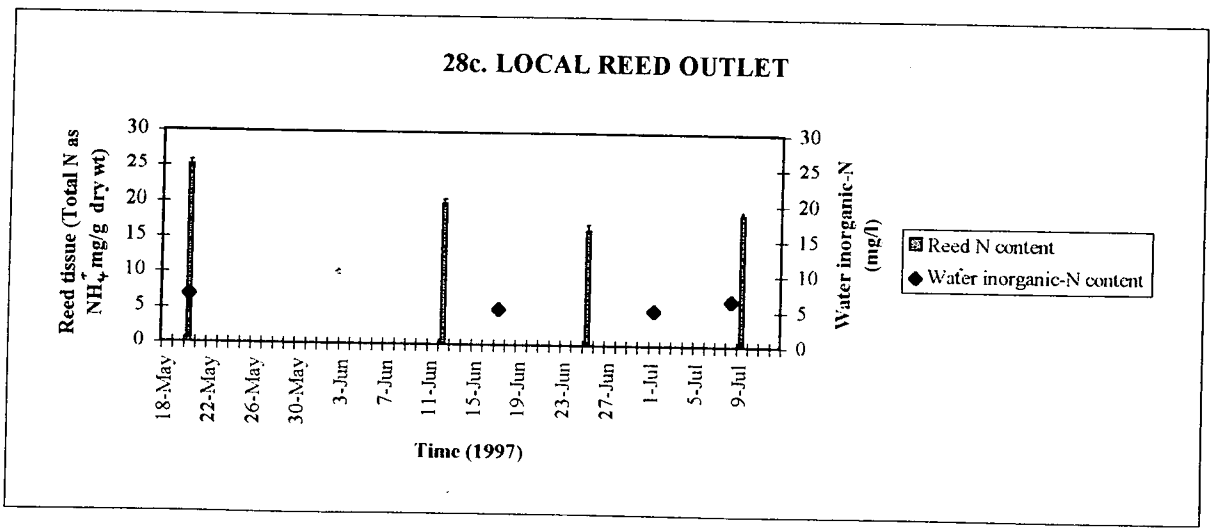
Local reeds

Nitrogen content in local reed leaf tissue ranged from 16.3 - 25.1 mg N g^{-1} dry wt. during the monitoring period. 2-way ANOVA did not indicate a significant difference in the nitrogen content of reed leaf tissue in different areas of the local area reedbed as shown in Figure 28. A general decrease with time in nitrogen leaf tissue content was significant ($F_{3,48}$ = 9.52, p <0.001). Figure 28 shows that concentrations declined between 20/5/97 to 25/6/97 and increased at the inlet and outlet areas of the reedbed on 9/7/97 following the Klargester malfunction. Water inorganic-N content which ranged from 4.1 - 23.0 mg l^{-1}, was significantly higher in the inlet area than other areas of the reedbed ($F_{2,48}$ = 2102.36, p <0.001).

Figure 28. Nitrogen content in water and reed leaf tissue in the local reed section of the CATS Terminal reedbed between 20/1/97-9/7/97 (data represent the mean +/- SE of 3 samples)







Comparison between pot-grown and local reed sections of the reedbed

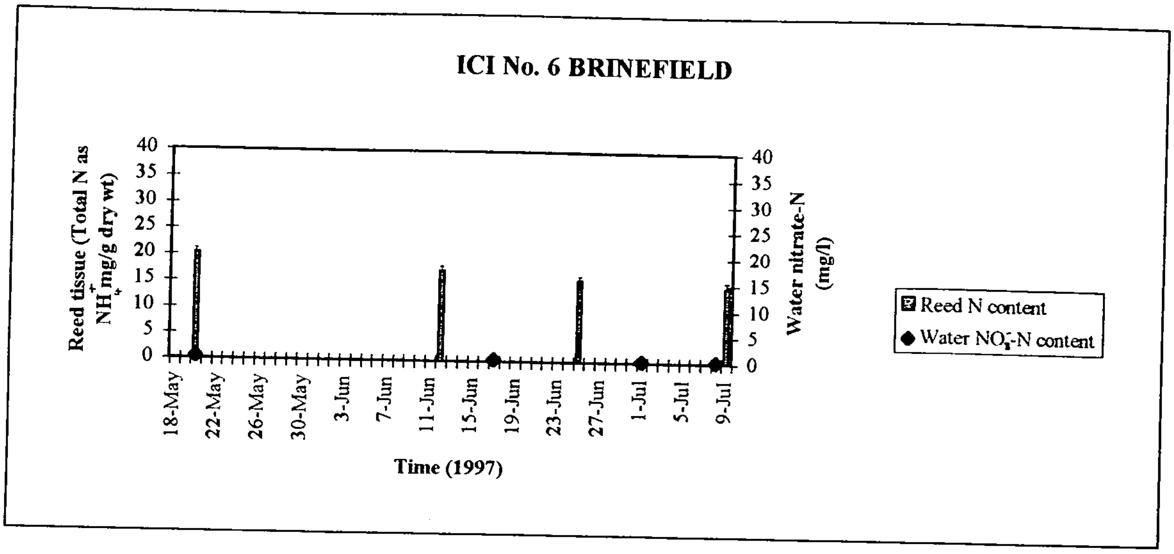
2-way ANOVA indicated a significant difference in nitrogen content of reed leaf tissues between the pot-grown inlet and local reed inlet areas of the reedbed ($F_{1,32}$ = 44.35, p<0.001), the pot-grown reeds having a higher average concentration at each monitoring period. There was, however, no significant difference in reed leaf nitrogen concentrations between the outlet areas of pot-grown and local reeds (2-way ANOVA). Figures 27 and 28 show the tissue concentrations in each area and for each time period. The differences with time proved to be significant at both the inlet area ($F_{3,48}$= 11.63, p <0.001), and the outlet area ($F_{3,48}$= 9.08, p <0.001).

In comparison with the pot-grown section of the reedbed where there was little difference in inorganic content of the water between the middle and outlet areas, the water in the outlet area of local reeds contained significantly more inorganic-N than the middle area of the reedbed ($F_{1,32}$= 62.76, p <0.001).

Comparison between the CATS Terminal reedbed and the ICI No.6 Brinefield reeds.

Nitrogen content in ICI No.6 brinefield reed leaf tissue ranged from 14.3 - 20.2 mg N g^{-1} dry wt. during the monitoring period. 2-way ANOVA indicated a significant difference in nitrogen content of reed leaf tissues between the two outlet areas of the CATS Terminal reedbed and the ICI brinefield reeds ($F_{2,48}$= 13.26, p <0.001). The brinefield reeds contained significantly lower amounts of nitrogen, a trend which was repeated significantly over time ($F_{3,48}$= 13.57, p <0.001). Figures 27, 28 and 29 show the decrease in nitrogen content with time. Unlike the CATS Terminal reeds, the ICI reeds were not subject to an added increase in nitrogen in the water, when the Klargester discharged sludge into the reedbed on 1/7/97, and do not, therefore show an increase in tissue nitrogen content on 9/7/97. The comparison between the CATS Terminal reeds and the ICI reeds suggests that the increase in nitrogen content in the pot-grown and local reed tissues on 9/7/97 was due to the increased nitrogen content of the water from 1/7/97.

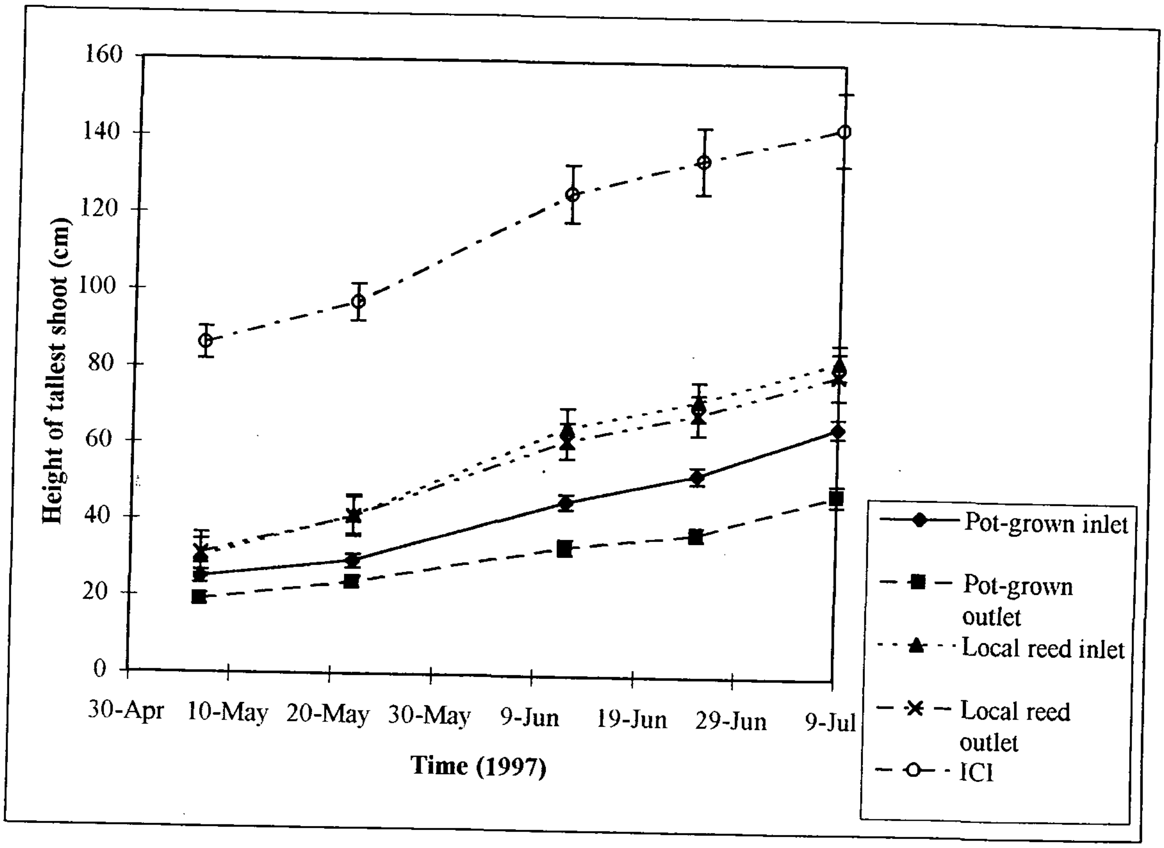
Figure 29. Graph showing nitrogen content in water and reed leaf tissue in the ICI No.6 brinefield reedbed between 20/5/97-9/7/97 (data represent the mean +/- SE of 3 samples)



4.2.3. Reed growth

Figure 30 shows the height of the tallest shoot at the CATS Terminal reedbed and No.6 brinefield site between 7/5/97 to 9/7/97, points representing the mean ± SE of 10 reeds in each area.

Figure 30. Graph to show the height of the tallest shoot at the CATS Terminal reedbed and the ICI No.6 brinefield site between 7/5/97-9/7/97 (data represent the mean +/- SE of 10 samples)



4.2.3.1. ICI reeds

ICI reeds were taller than the CATS Terminal reedbed plants when measurements began on 7/5/97, with the average height of the tallest shoot being 86.1 ± 4.1 cm. The most rapid period of growth occurred between 22/5/97 to 12/6/97. Reeds continued to grow taller at a reduced rate and measurements ceased on 9/7/97 before a growth 'plateau' had been reached. The average height of the tallest shoot was 143.3 ± 9.5 cm. There was a variation in the growth rate with time of the 10 ICI reeds that were measured, this can be seen with reference to the standard error bars plotted on Figure 30. When measurements ceased on 9/7/97, the reeds had not produced flower heads, and reeds no. 1 and 6 were turning brown.

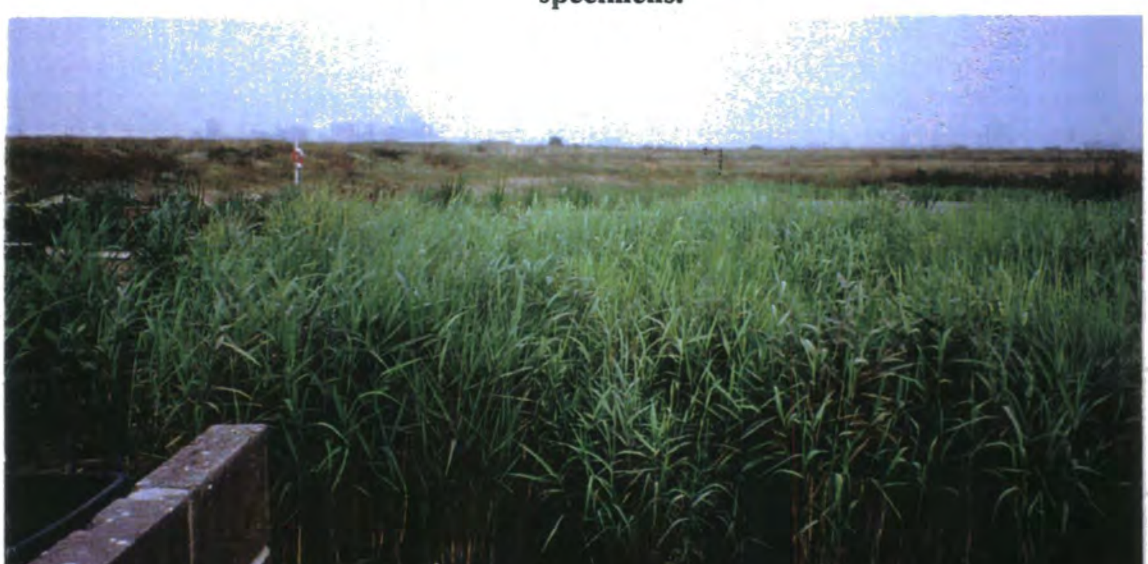
4.2.3.2. Pot-grown reeds

When the pot-grown reeds were planted in the reedbed gravel in December, 1996, all 1000 reeds were approximately 20 cm in height. When height measurements commenced in early May, the 10 pot-grown inlet reeds averaged 24.9 ± 1.6 cm in height, whilst the pot-grown outlet reeds had an average height of 19.1± 1.4 cm. Reeds in the outlet and inlet areas increased height at a greater rate between 22/5/97 to 12/6/97, and continued to grow at a reduced rate in line with ICI reeds. However, between 25/6/97 to 9/7/97, the growth rate of the pot-grown reeds increased. This may have been due to the extra organic material which entered the reedbed on 1/7/97. When measurements stopped on 9/7/97, the pot-grown inlet reeds had reached an average height of 65.3 ± 2.5 cm, whilst the outlet reeds averaged 47.6 ± 2.8 cm.

When reed growth in terms of reed shoot height commenced in May, the shoots of the individual pot-grown reeds were counted in the outlet section, the 10 plants sprouting an average of 7 shoots. It was decided not to continue counting shoots at measuring periods as the ICI reed shoots could not easily be assigned to individual plants. With hindsight however, an accurate account of individual plant shoot density would have been a valuable additional measure of reed growth. On 12/8/97, a random count of three reeds in the outlet area averaged 21 shoots per plant (Plate 15), whilst reeds in the inlet area averaged 259 shoots per plant (Plate 16). Clearly, rhizome and shoot density developed considerably during the first years' growing season at the reedbed. By 12/8/97, no plants in the pot-grown section had produced flower shoots.

Plate 15. Pot-grown *Phragmites australis* outlet section of the CATS Terminal reedbed, August 1997, showing shoot-density of individually planted specimens.

Plate 16. Pot-grown *Phragmites australis* inlet section of the CATS Terminal reedbed, August 1997, showing shoot-density of individually planted specimens.



4.2.3.3. Local reeds

The local reeds that were transplanted from Wilton ICI were split into smaller clumps and rhizome sections and planted into the second half of reedbed gravel in December 1996. On 7/5/97, the average height of inlet area reeds was 29.9 ± 4.7 cm, whilst outlet reeds averaged 19.1 ± 1.4 cm in height. Reeds in the outlet and inlet areas increased height at a greater rate between 22/5/97 to 12/6/97, and continued to grow at a reduced rate in line with ICI reeds. However, between 25/6/97 to 9/7/97, the growth rate of the local reeds increased. This may have been due to the extra organic material which entered the reedbed on 1/7/97 due to the Klargester incident. When measurements ceased on 9/7/97, the local inlet reeds had reached an average height of 82.8 ± 4.5 cm, whilst the outlet reeds averaged 79.0 ± 6.1 cm. Shoot density could not be used as a measure of growth to compare outlet and inlet areas of the reedbed as the clumps were unequal when planted. On 12/8/97, all of the local reeds were flowering but none had produced seed heads.

Regression was employed to establish a relationship between reed growth (height) and time. As the growth pattern was not linear, both time and height data were ln transformed prior to regression analysis. Figure 31 shows the ln transformed regression lines for the pot-grown reeds, local reeds and ICI No.6 brinefield reeds. In order to determine if there was a significant difference between areas in terms of reed height growth, *t*-tests were undertaken on the regression lines (Table 5).

Figure 31. The height of the tallest shoots of 10 *Phragmites australis* in the CATS Terminal reedbed and ICI No.6 brinefield between 7/5/97-9/7/97

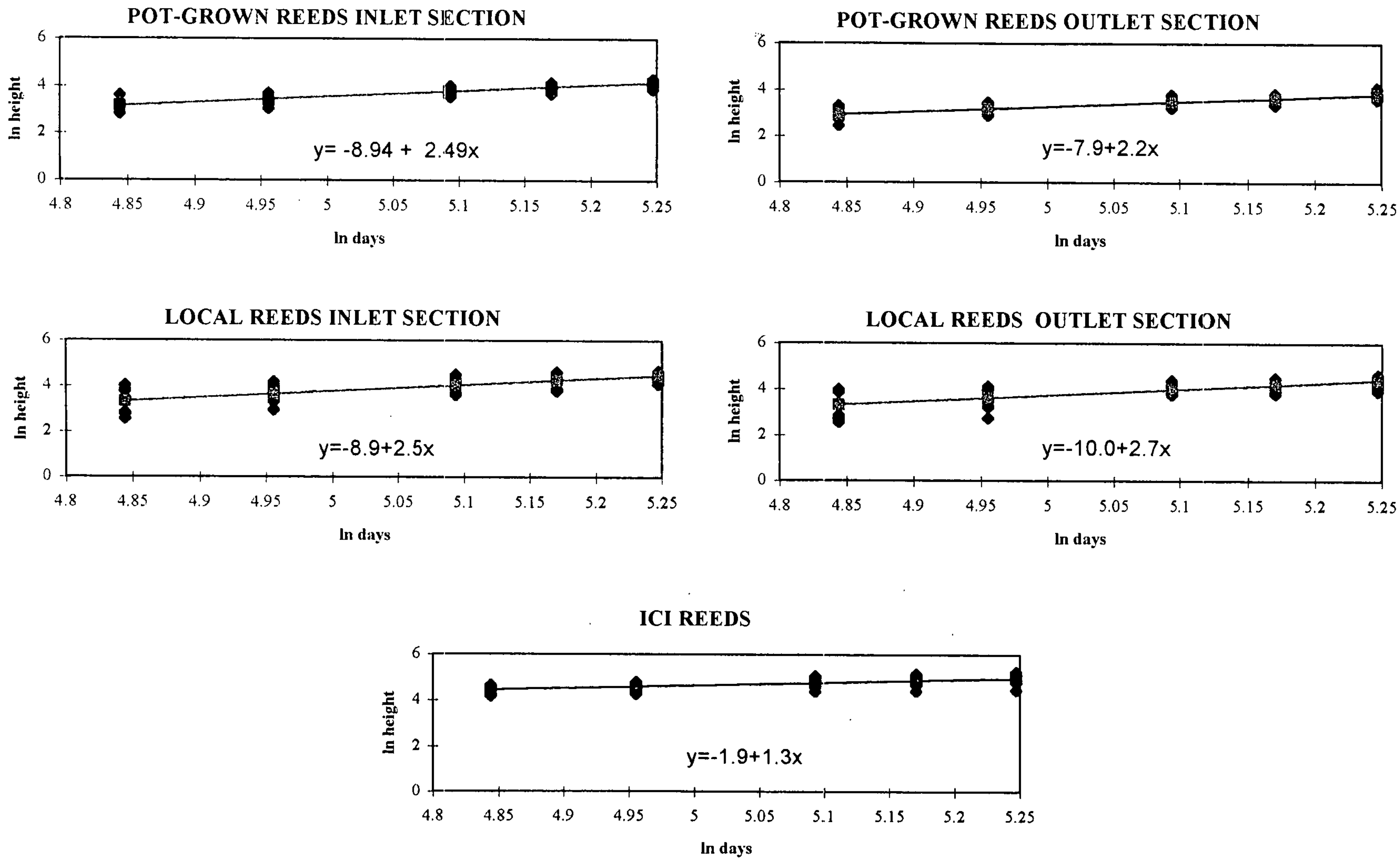


Table 5. *t*-test results to show the difference between growth (height) regression lines of reeds measured at the CATS Terminal reedbed and ICI No.6 brinefield, between 7/5/97 and 9/7/97.

Areas of reed growth (height) comparison	***t*-test result**
Pot-grown inlet / Pot-grown outlet	(t= 1.023, df= 96, p >0.05)
Local reed inlet / Local reed outlet	(t= 0.176, df= 96, p >0.05)
Pot-grown inlet / Local reed inlet	(t= 0.945, df= 96, p >0.05)
Pot-grown outlet / Local reed outlet	(t= 1.219, df= 96, p>0.05)
Pot-grown inlet / ICI	**(t= 4.902, df= 96, p <0.001)**
Pot-grown outlet / ICI	**(t= 3.603, df= 96, p <0.001)**
Local reed inlet / ICI	**(t= 4.073, df= 96, p<0.001)**
Local reed outlet / ICI	**(t= 3.482, df= 96, p <0.001)**

(results in bold indicate significant differences)

Regression analysis indicated that all areas of pot-grown and local reeds made significantly more growth, in terms of height when compared with the growth of ICI brinefield reeds. Differences in growth (height), between the inlet and outlet sections of the pot-grown reedbed were not significant. Shoot density measurements, had they been taken between the areas, may have proved significant. Differences in growth, in terms of height, between the inlet and outlet areas of local reeds were also not significant, nor were differences between local reed and pot-grown reeds.

4.2.4. Atmospheric nitrogen

Results of atmospheric nitrogen dry deposition at both the reedbed and the ICI No.6 brinefield reedbed sites during the monitoring period are summarised in Table 6 below.

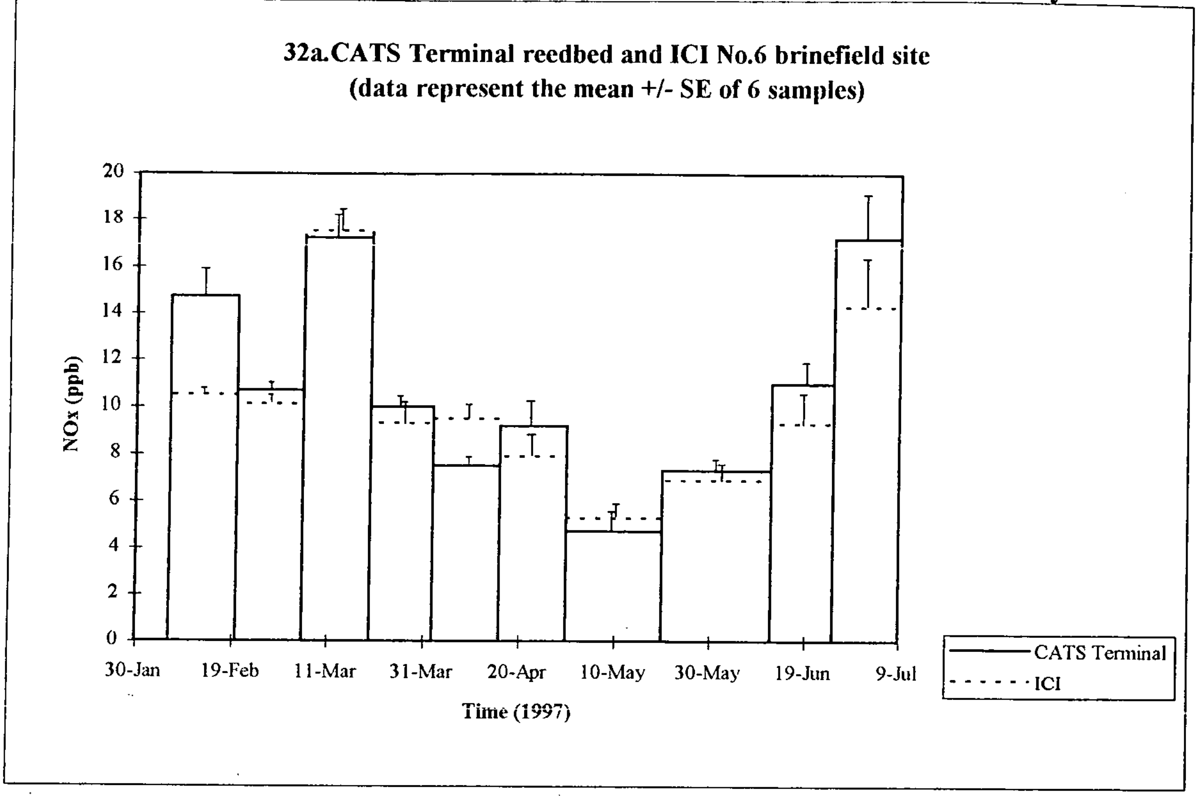
Table 6. Atmospheric nitrogen dry deposition at the CATS Terminal reedbed site and ICI No.6 brinefield site between 6/2/97 to 9/7/97. Figures represent the mean (± SE) of 6 samples.

Dates (1997)	CATS Terminal reedbed site NO_2 ppb	ICI No.6 brinefield site NO_2 ppb
6 Feb - 20 Feb	14.7 (3.1)	10.5 (1.4)
20 Feb - 6 Mar	10.7 (0.5)	10.1 (0.7)
6 Mar - 20 Mar	17.2 (2.1)	17.5 (1.8)
20 Mar - 2 Apr	10.0 (0.9)	9.3 (0.9)
2 Apr - 16 Apr	7.5 (0.4)	9.5 (0.9)
16 Apr -30 Apr	9.2 (1.2)	7.9 (0.9)
30 Apr - 20 May	4.7 (0.5)	5.3 (0.3)
20 May - 12 Jun	7.3 (0.6)	6.9 (0.4)
12 Jun - 25 Jun	11.0 (1.1)	9.3 (1.7)
25 Jun - 9 Jul	17.2 (2.2)	14.3 (2.0)

NO_2 concentrations measured at the CATS Terminal reedbed site were generally higher than concentrations measured at the ICI reedbed site. NO_2 concentrations measured over the same period from the BASF2 and BASF3 sites are shown graphically in Figure 32 and can be compared with the monitoring results from the site.

Routine and non-routine releases of NO_2 from stacks at the CATS Terminal site were expected to increase the annual average ground level concentration over ambient levels by 3.2 %, 500 m from the emission (Anon, 1990). Figure 33 shows the predicted NO_2 isopleths for the Seal Sands area contributed by the site.

Figure 32. Graphs to show atmospheric dry nitrogen deposition (ppb) at the CATS Terminal reedbed, ICI No.6 brinefield site and Stockton Borough Council BASF2 and BASF3 sites from Feb. to July 1997



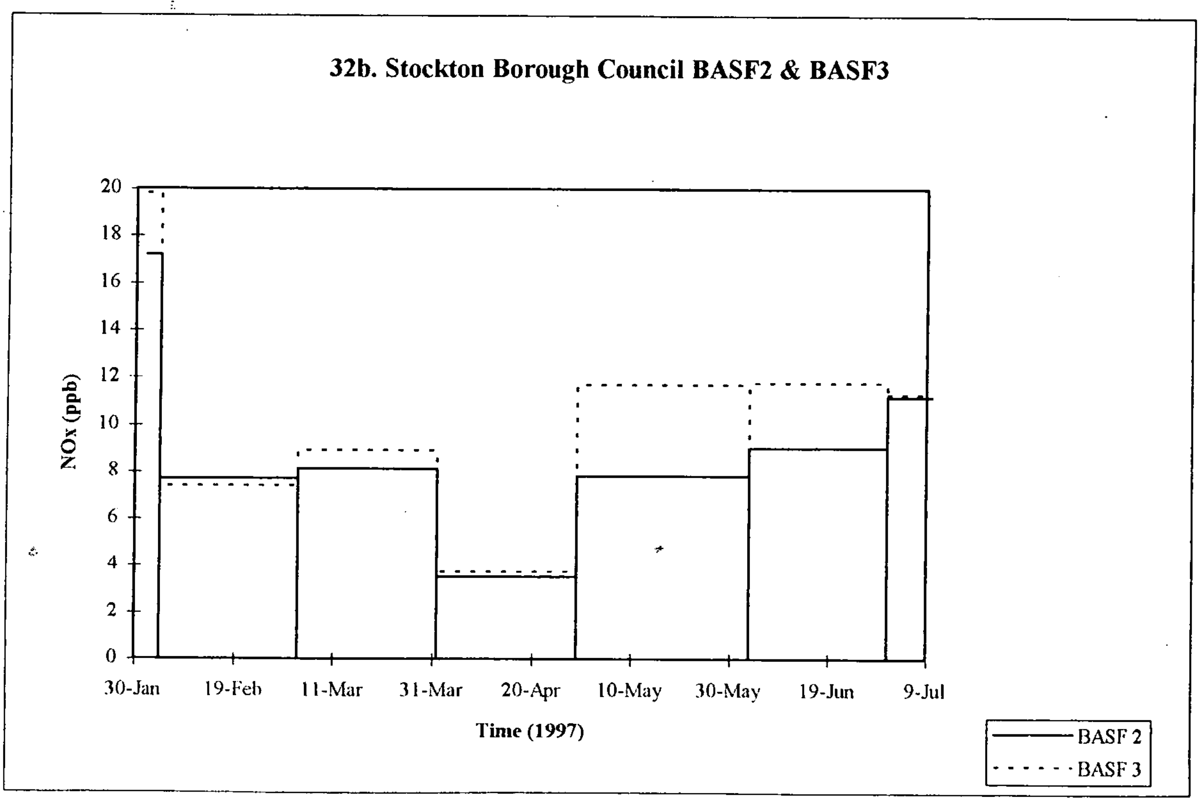
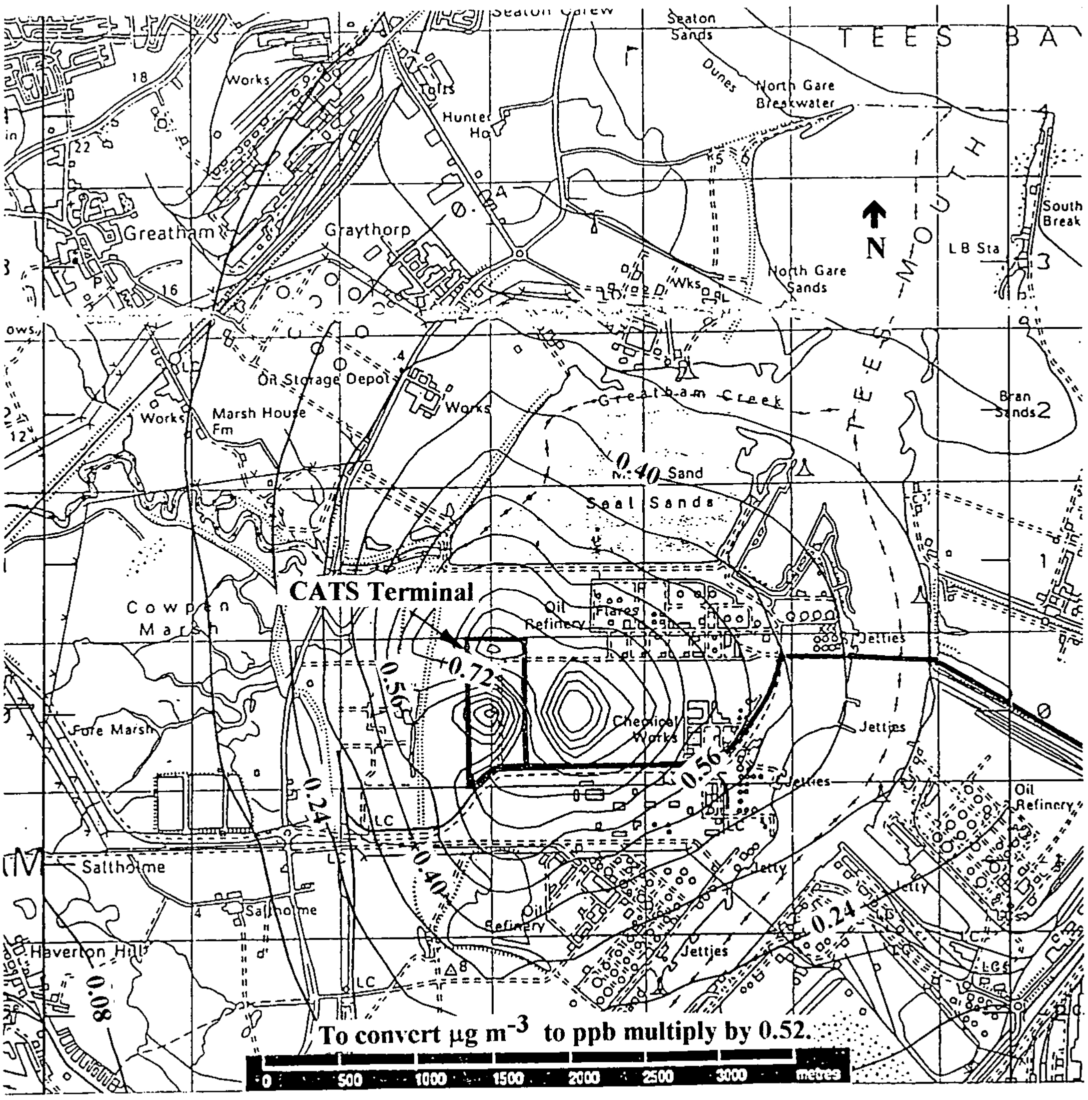


Figure 33. Predicted isopleths showing the contribution of the gas processing plant to the NOx annual average ground level concentration (µg m^{-3}). (Amoco CATS Environmental Statement, Anon, 1990)

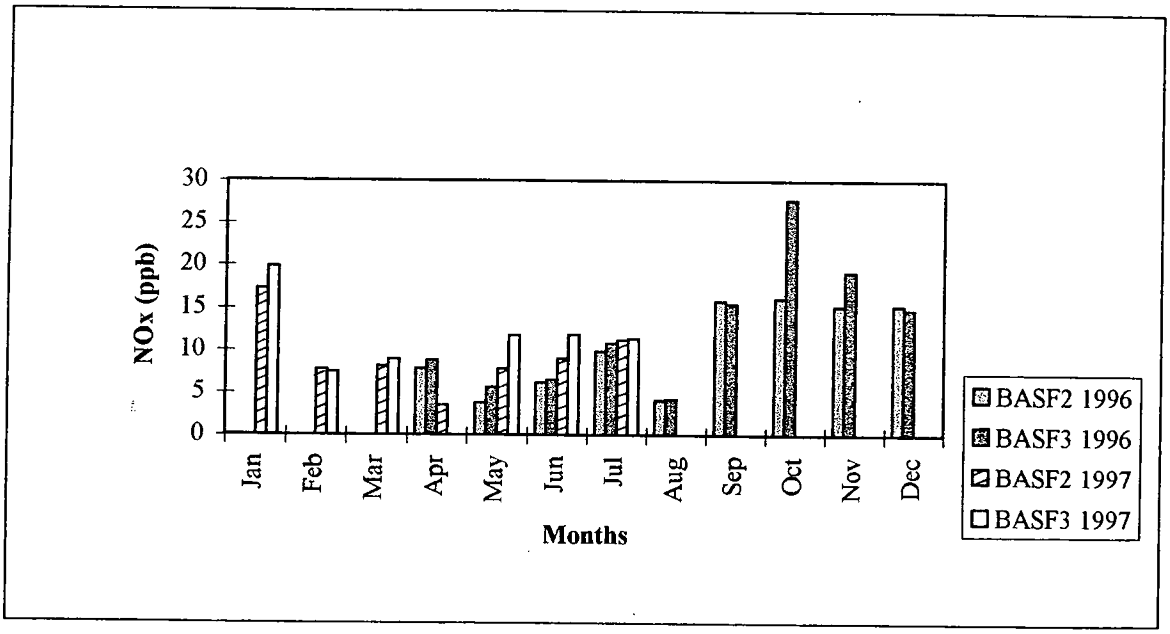


Average NO_2 concentrations measured at the site were higher than concentrations measured at the ICI reedbed site, the BASF2 and BASF3 site, reflecting the contribution made by site emissions.

At both of the reedbed sites, overall NO_2 levels declined between early February and 20 May when levels of 7.3 ppb were measured at the CATS Terminal site. Levels of NO_2 proceeded to rise from 20 May until 9 July at both sites when concentrations of 17.2 ppb were measured at the CATS site.

Measurements from the Stockton BASF2 and BASF3 monitoring sites vary between sites. However, they also show a decline in NO_2 concentration from January until late April followed by a rise in concentration during May. Figure 34 shows the Stockton BASF2 and BASF3 concentrations for nine months in 1996 plus the 1997 results until July.

Figure 34. Atmospheric dry nitrogen deposition at Stockton Borough Council BASF2 and BASF3 monitoring stations from April 1996 to July 1997.



During the winter months, NO_2 concentrations were higher than during the summer months for both 1996 and 1997 in the area. The seasonal pattern of elevated NO_2 concentrations during winter months and lower concentrations during summer months has been observed in studies by Goldsmith (1986), Stockton Borough Council (1996), and Robson (1996). The seasonal cycle reflects the increased use of fossil fuels during the winter. Also shallower boundary layer depths and lower windspeeds during winter give generally poorer dispersion conditions (Dufield & Luke, 1995). Raised concentrations occurred during the summer months when NO_2 became trapped in occasional temperature inversions (C. Speed, Project manager, 'Air quality today', Middlesbrough Borough Council, personal communication). Although motor vehicles made the largest contribution to ground-level concentrations in the area, atmospheric conditions increased the influence of point sources such as the CATS Terminal gas processing plant, the Enron power station and the Dupont nylon plant, on ground level pollution (C. Speed, personal communication).

A NO_2 survey was carried out by Stockton Borough Council between 1995/96, with passive diffusion tubes to monitor NO_2 concentrations at both town centre and industrial (non traffic) sites. The survey concluded that levels of NO_2 were highest at urban road-side sites, and sites 20-30 meters from busy roads, but also that background urban sites (>50 meters from a busy road) recorded NO_2 concentrations that were much higher than an equivalent industrial background location, such as Seal Sands Road. The April 1997 NO_2 level of 3.1 ppb measured at the BASF2 site was compared with a concentration of 11.8 ppb measured during the same period at the Yarm High Street monitoring station.

As part of a national monitoring programme, the Department of The Environment (DoE) have a network of stations throughout Britain, where a typical rural DoE monitoring site at Lullington Heath had an annual mean in 1995 of 8 ppb (Duffield & Luke, 1995). The DoE Billingham station recorded the highest annual average concentration (19 ppb in 1996), within the Tees valley area, although this annual mean has declined yearly from the 23 ppb annual mean recorded in 1987 (Duffield & Luke, 1995). The UK governments Environmental Expert Panel on Air Quality Standard (EPAQS) for NO_2 of 150 ppb (expressed as a one hour average), has been accepted by the draft National Air Quality Strategy. The strategy also proposes a limit for NO_2 of 20 ppb expressed as an annual mean (Anon, 1997b).

A 1997 review on air quality in the Tees Valley area (Anon, 1997b) reported that the area consistently experiences good air quality for NO_2 (below 50 ppb) and has among the lowest concentrations of those measured in the UK with the exception of remote and rural areas. However, for Sulphur oxides, peak concentrations are among the highest of those measured in the UK. Concentrations of other atmospheric pollutants should also be considered when interpreting monitoring results as interactions between pollutants may occur.

4.3. Discussion

4.3.1. The influence of inputs of phosphorus and nitrogen on reed growth and development.

4.3.1.1. Inputs of phosphorus and nitrogen from the constructed reedbed

The technique of removing 10 cm from the second youngest leaf from each shoot (for tissue analysis) may not have been ideal in determining the nutrient status of the ICI reeds. Nitrogen, phosphorus and potassium are mobile in the phloem and are translocated from old to young leaves in response to nutrient stress, in order to maintain fairly constant levels in younger leaves (Pearcy *et al.*, 1989). Therefore, in future studies, if young and old leaves of the same plant were analysed, additional information could be obtained about the nutrients which are readily translocated. This would identify if the ICI reeds were nutrient deficient, and higher levels of nitrogen in the mature leaves of effluent supplied reeds could indicate luxury consumption (Marschner, 1986).

The timing of reed samples can affect the calculations of nutrient storage in different plant parts, reflecting the seasonal growth cycle and nutrient partitioning of the plant (Kuhl & Kohl, 1993). Due to the immaturity of the CATS Terminal reedbed, the destructive analysis of root and rhizomes was inadvisable, hence the seasonal effect of nutrient translocation could not be studied. However, Boar (1992) found that reed shoot tissue sampled in May, had an average content of 2.9 % nitrogen and 0.63 % phosphorus, whilst samples in September had an average content of 1.0 % nitrogen and 0.25 % phosphorus. In Boar's 1992 study, root and rhizome nitrogen and phosphorus concentrations decreased in spring to support young shoots, and increased in autumn. By September, 1997, the CATS Terminal reeds had become well established, and future studies should include include destructive methods of analysis to determine rhizome, shoot and leaf tissue nutrient concentrations over different seasons.

A further consideration in comparative analysis over time, is the decline with age of most mineral nutrient concentration in plant tissue. This decline, or dilution effect, is caused by a relative increase in the proportion of structural material and of storage compounds in the dry matter (Marschner,1986). This supporting, non-metabolic tissue also has lower nutrient requirements. Therefore, the concentration of both nitrogen and phosphorus in the reed tissues could be expected to decline with the growing season.

4.3.1.2. The relationship between increased nutrient availability and the nutrient content in the reeds

Results show that the pot-grown reeds increased both their phosphorus and nitrogen leaf tissue concentrations in reeds growing in the inlet section of the reedbed. The concentrations of both nitrogen and phosphorus in the water and in the reed tissue were significantly higher than in other areas of the reedbed. The increased nutrient concentrations in the reed leaf tissue persisted in the inlet area throughout the growing season, although concentrations declined with time due to a dilution effect. An increase in tissue nitrogen and phosphorus concentration of the reeds can act as an indicator of nutrient avilability, especially when a decreasing gradient occurs with distance from the wastewater inlet (Hammer, 1989; and Kadlec & Knight, 1996). A study by Ulrich and Burton (1985), on the effects of nitrate, phosphate and potassium fertilization on the growth and nutrient uptake patterns of *Phragmites australis,* found that potassium fertilization was found to have no significant effect, but nitrate and phosphate strongly and interactively affected nutrient uptake and plant dry weight. The positive relationship between nitrogen availability and reed tissue content was also shown when the pot-grown reeds in the middle and outlet area of the reedbed quickly responded to the influx of organic material into the reedbed during the Klargester malfunction on 1/7/97.

The locally transplanted reeds also received high concentration of nitrogen and phosphorus in the inlet area, but the reed leaf tissue concentrations were not significantly higher in the inlet area than elsewhere in the reedbed, where much lower concentrations of nutrients were available in the water. Spring growth in *Phragmites australis* is supported by the nutrient reserves of the rhizome, so it is influenced by the conditions of the previous growing season (Boar *et al.*, 1991). Rhizomes can therefore provide a record of growing conditions over a longer period than can annual shoot and leaf tissues.

During the first season of growth, the pot-grown reeds showed the greatest response to the nutrients available in the reedbed as the rhizomes were immature and they had little previous reserves. That the local reeds did not increase their tissue nitrogen and phosphorus content in line with the concentration gradient of available nutrients, does not mean that luxury uptake did not occur. A direct comparison with the tissue content of other reeds at the Wilton site where the reeds originated, was not made, but it is highly likely that the effluent supplied reeds have taken up extra nutrients. This is illustrated by the increase in tissue nitrogen concentration in plants from all areas of the reedbed following the increased in nitrogen available to the system from 1/7/97.

Although there was no significant difference in the nitrogen and phosphorus content in reed leaf tissue between the two outlet areas of the CATS Terminal reedbed. Each area, when compared with ICI reeds, contained significantly higher amounts of phosphorus and nitrogen. Although a decreasing nutrient gradient through the reedbed reduced the availability of nutrient uptake to the reeds, the nitrogen and phosphorus present remained significantly higher than concentrations present in the brinefield water. Only trace amounts of phosphate and nitrate were detected in the brinefield water yet the reeds were healthy and the tissue nitrogen & phosphorus content decreased with the growing season in line with the CATS Terminal reeds. Future studies could indicate whether the nutrients available at ICI were sufficient (translocation of nutrients from older to younger leaves). The ICI reeds would obtain nitrogen from internal nutrient cycling, detrius decomposition and atmospheric inputs. And according to Kadlec & Knight (1996), phosphorus cycling can be extensive in wetlands despite its scarcity in freshwater systems. A positive relationship was shown to exist between elevated concentrations of nitrogen and phosphorus in reed shoot tissue and water nutrient concentration, during the early part of the growing season. Whether increased nitrogen and phosphorus in leaf tissue contributes to increased growth is discussed below.

4.3.1.3. The relationship between increased nutrient availability and the growth of *Phragmites australis.*

A study by Graneli (1985), on the biomass response after nutrient addition to natural stands of *Phragmites australis* in Sweden, found that although increases in potassium and phosphorus accumulated in the tissues, it did not lead to an increase in biomass production. Such findings contradict the accepted view that an increase in available phosphorus stimulates growth and causes increases in biomass (Kadlec & Knight, 1996). It could be that other, undetermined factors were limiting in the Swedish reed stands studied by Graneli.

During this study, growth was determined by changes in reed height with time. Although the rate of reeds growing in the nutrient enriched inlet sections were higher than in other areas of the reedbed, the difference was not significant. However, the growth of the reeds in the ICI No.6 brinefield, was significantly less than for the nutrient enriched brinefield reeds. Had growth been determined by shoot production and plant density, differences, especially within the pot-grown section of the reedbed, may have proved significant. The gradient in shoot density (associated with nutrient concentration) between the inlet and outlet of the pot-grown section became more apparent as the season progressed (Plates 16, 17 & 18). Edwards *et al.*(1993), found that a similar growth

Plate 17. Pot-grown *Phragmites australis* section of the CATS Terminal reedbed, July 1997, showing a decrease in shoot-density away from the inlet section. (Local reed inlet section in the foreground showing less successful establishment of planted reeds)

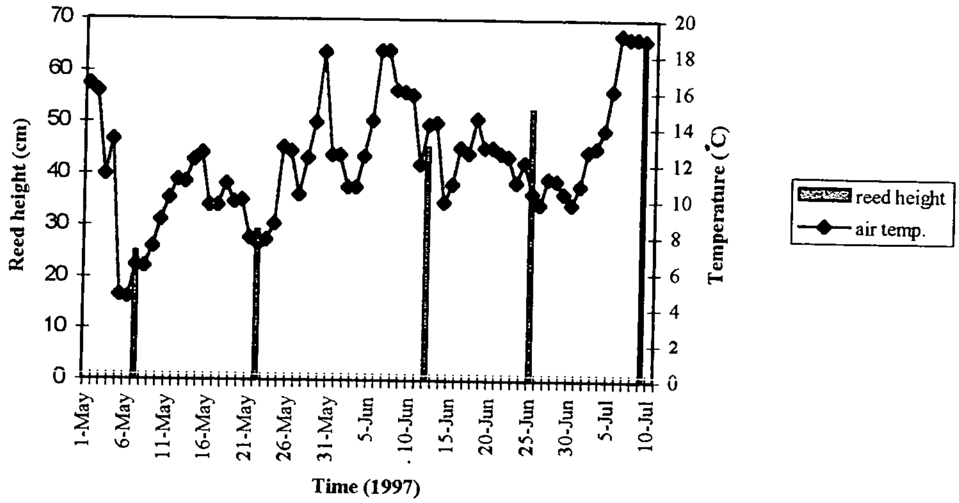
Plate 18. Pot-grown *Phragmites australis* outlet section of the CATS Terminal reedbed, August 1997, showing shoot-density and height of reeds.

gradient in a constructed wetland in Kentucky, was caused by a gradient of decreasing nutrients. A nutrient gradient in reed biomass was also identified by Parr (1990).

The maximum growth (determined by shoot height) for all of the sections monitored, occurred between 22/5/97 and 12/6/97. This maximum period of growth shows a positive relationship with higher nutrient availability and higher leaf tissue nutrient concentrations during the same period. Although only trace levels of phosphate were available in the ICI No.6 brinefield water, nitrate levels and also leaf tissue nutrient concentrations were higher between the period of highest growth. The reduction in the nitrogen and phosphorus content of the leaf tissue during this period could be due to the dilution affect during this period of rapid growth. The positive relationship between nutrient availability and increased growth was also shown between 26/5/97 and 9/7/97, when growth increased for reeds in all sections of the CATS Terminal reedbed following increased nitrogen availability and increased tissue concentration. The ICI reeds did not receive an influx of water nutrients, and neither tissue content nor growth increased during this period.

The period of maximum growth (22/5/97 to 12/6/97) was related to a period of high nutrient availability and elevated leaf tissue concentration. However, the air temperature also increased during this period, as shown in Figure 35. An increase in air temperature will generally result in an increase in the rate of net photosynthesis of plants. *Phragmites australis* clearly responded quickly to high nutrient concentrations and temperatures. The increased temperature of the inlet water did not have a significant effect on growth rate as the water would cool to the ambient temperature as it passed through the gabions and into the reedbed gravel. The increased growth (in terms of height) of the CATS Terminal reeds between 25/6/97 and 9/7/97 was unlikely to be due to temperature (which was not high during the period), as ICI reeds did not show a similar response. Growth was increased due to the higher nutrient supply, with the inlet areas showing the biggest response. Rapid growth during the spring, associated with elevated nutrient concentrations, confered an advantage to the CATS Terminal reeds in the form of increased substrate available for photosynthesis and growth.

Figure 35. Graph to show the relationship between the growth of the tallest shoots in the pot-grown section (mean of 10 reeds) and daily air temperature at the CATS Terminal reedbed between 7/5/97-9/7/97



4.3.1.4. The relationship between increased nutrient availability and the development of *Phragmites australis.*

The study by Edwards *et al.* (1993), also reported that, although the reduction in aerial reed growth away from the inlet of the reedbed appeared to be associated with a gradient of decreasing nutrients, a corresponding reduction in rhizome growth could not be determined. Ulrich and Burton (1985), found that elevated nitrogen concentrations increased above-ground growth of *Phragmites australis* and decreased the root/ shoot ratio. This increase in aerial growth at the expense of rhizome development was also supported by Kuhl and Kohl (1993), Boar *et al.*(1991), and Wellburn (1994). A decreased root:shoot ratio is unfavourable for nutrient aquisition (Marschner, 1986), although not a problem in the nutrient-enriched reedbed system, a reduction in the rhizome biomass would also result in reduced substrate for microbial water purification. Ulrich and Burton (1985), also found that although increases in phosphate increased reed biomass, the nutrient did not significantly affect the root:shoot ratio.

In the UK, work by Boar *et al.*(1991), on the quality of reed for thatching, found that increased nitrogen in reed shoots produced softer growth and weaker thatch. When nitrogen is in plentiful supply, the activities of key enzymes of phenol metabolism are supressed, and so the production of phenolics, the precursors of lignin synthesis, is reduced, according to Matsuyama and Diamond (1973, cited in Boar *et al.*,1991). Lush but weaker reed stems, produced as a result of elevated nitrogen concentrations, were thought to be a problem at the CATS Terminal reedbed during early spring growth, when emerging stems were damaged by strong winds. However, the increased density of the reeds provided adequate protection.

Elevated nutrient concentrations in the reedbed may alter the timing of the translocation of nutrients to the rhizomes. In a study by Kuhl and Kohl (1993), on the seasonal nitrogen dynamics of reed beds, it was found that increased and sustained nitrogen availability delayed reed senescence and the onset of translocation to the rhizome. They also found that in the main growth period between May and June, nitrogen content was highest in the upper, younger internodes, decreasing to the shoot base. This gradient was absent in August, but in nitrogen enriched reeds, the gradient remained until October. In naturally growing reed stands, there was an earlier termination of the developmental cycle. If an extension of the growing season caused by delay in senescence occurs at the CATS Terminal reedbed, the nutrient assimilation capacity of the reeds may be extended.

4.3.1.5. Inputs of atmospheric nitrogen dioxide

Although plants have developed a range of diverse mechanisms to obtain nitrogen, considerably less is known about how plants adapted to low nitrogen inputs react to additional nitrogen deposition (Kuhl and Kohl, 1993). The 1997 Tees valley report on air quality found that the area experienced good air quality for NO_2. during the first nine months of 1997 (S. Smith, Environmental Services Department, Stockton-on-Tees Borough Council, personal communication). The locally transplanted reeds and the ICI No.6 brinefield reeds were acclimatised to the levels of atmospheric NO_2 in the area, but recent addition of the Enron Power Station and the CATS Terminal gas processing plant have become additional sources of oxides of nitrogen.

Even for plants that have heavy additions of artificial fertilizers, an additional input of nitrogen from the atmosphere is not negligable. Atmospheric inputs in excess of 40 kg ha^{-1} a^{-1} have been recorded 50 km from London, much of which arrived in the winter (Wellburn, 1994). *Phragmites australis* have been growing in the CATS Terminal reedbed with high levels of nitrogen, and although their growth rate has increased with increasing concentrations of the nutrient, the contribution made by additional inputs of atmospheric nitrogen would be negligable as increased concentrations during the winter would not benefit the reed which is dormant during this period. However, the presence of atmospheric NO_2 during the growing season may affect the sensitivity of the reeds to other pollutants such as SO_2. A greater than additive effect was observed in studies of four grass species by Ashenden & Mansfield (1978), during the growing season. Also, when ozone combines with nitrogenous gases, enhanced leaching of organic solutes and mineral nutrients from leaves could occur (Marschner, 1986), this effect would be counterproductive in the wastewater treatment reedbed.

At low levels of available nitrogen, plants exposed to low concentrations of nitrogen oxides often show stimulated growth, whereas plants grown with an adequate supply of nitrogen may have decreased biomass and may show signs of visible damage (Wellburn, 1994). Although some plants show evidence of being able to detoxify and utilize the additional nitrogen from the atmospheric NO_2, the net costs to the plant of general repair and maintenance of detoxification processes are often reflected in poor growth (Wellburn, 1994). Also, the reeds grown in elevated nitrogen concentrations are likely to have decreased root:shoot ratios, resulting in an increase in the amount of leaf area available for pollutant uptake (Wellburn, 1994).

The levels of atmospheric NO_2 monitored during the study are well below the levels designated as being harmful to vegetation. Similarly, any slight reduction in the growth rate of the reeds, if it occurred, would not affect the water purification performance of the reedbed.

Although the levels of Atmospheric NO_2 monitored at the site were below the level harmful to vegetation, the increased ground concentrations in the immediate area due to the CATS Terminal gas processing plant may have a nutrient enrichment affect on the area. The grassland vegetation and the No.6 brinefield wetland habitat have developed gradually since reclamation of the area in the mid-1970's. The nutrient poor status of both habitats has been determined during this study, reflecting that atmospheric NO_2 levels in the area have not resulted in significant nutrient enrichment of the area up to now. As the gas processing plant has only been operational since 1993, increased ground level concentrations of atmospheric NO_2 may begin to increase the nutrient status of the grassland and possibly the brinefield reedbed site. A study of May Moss, a nutrient poor blanket bog in the North York Moors, was undertaken to see whether community composition would be altered by nutrient enrichment, by inputs of atmospheric nitrogen deposition (Robson, 1996). Following nutrient enrichment experiments on *Sphagnum* spp., he found that a two fold increase in the average (4.6 ppb) levels of NO_2 could be absorbed without any noticable change in the nature of the community species composition over the timescale of the study (four months).

In the Netherlands, experiments have provided strong evidence of a link between atmospheric nitrogen deposition and long-term vegetative changes in calcareous grasslands (DoE, 1994), resulting in a loss of species richness. However, communities are dynamic and successional changes in grassland and wetland communities will occur with time with or without additional atmospheric nitrogen inputs.

It will be important, however, to continue monitoring atmospheric NO_2 deposition at the site in order to determine whether ground levels remain higher than other nearby monitoring sites. Long-term monitoring of reed growth and tissue levels, both at the site and the brinefield reedbed may indicate beneficial or toxic effects of the gas. Similarly, the nutritional status of the grassland soil should periodically be monitored.

CHAPTER FIVE

5. SOILS

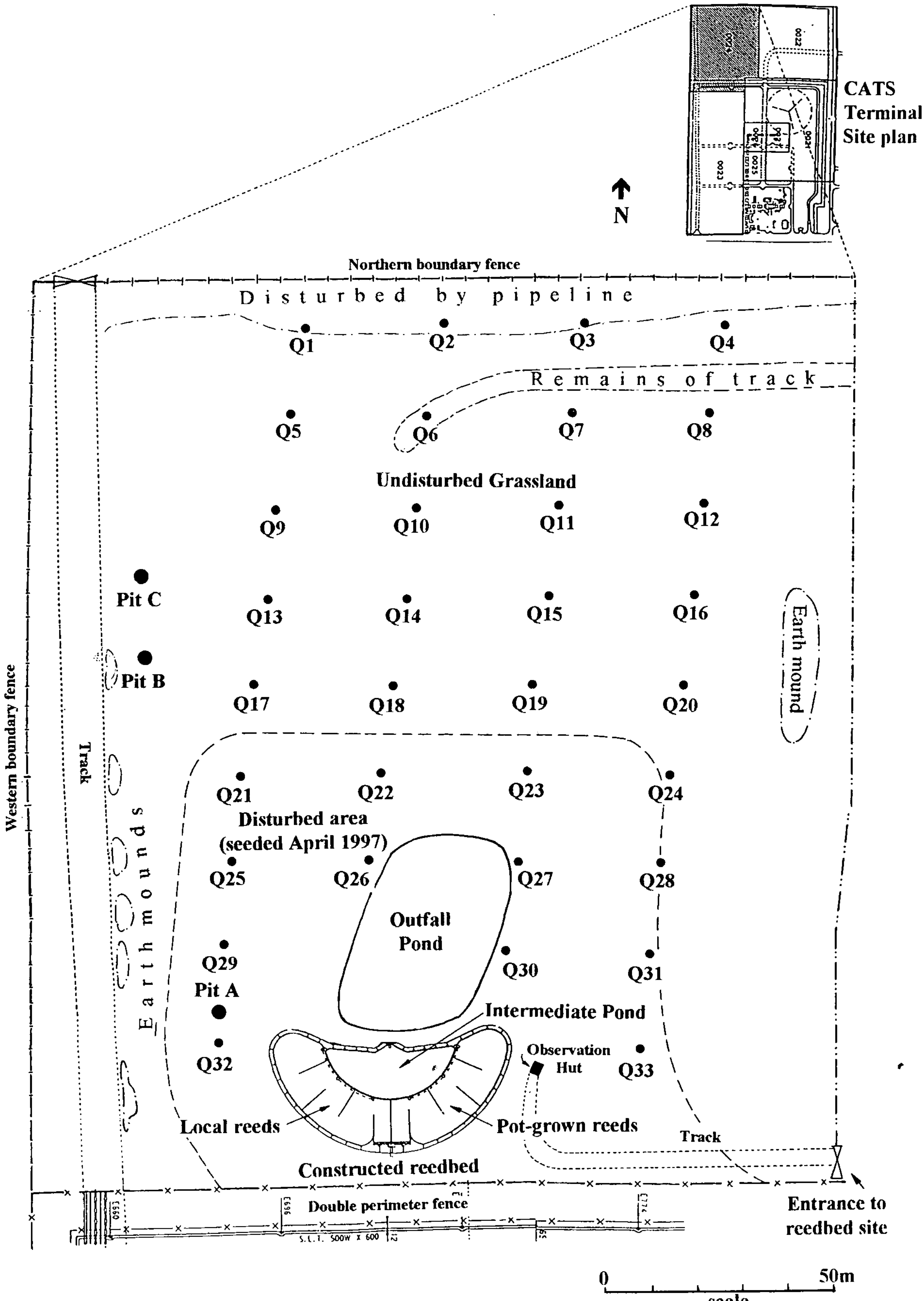
The site lies on land which was reclaimed in 1974 by using hydraulically placed sand, and some alluvial and glacial clays. The immature soils that have developed on the site support grasses with patches of short, herb-rich vegetation. During the site preparation of the reedbed in the spring of 1996, the Outfall Pond was excavated, with soils being distributed around the pond. This area, and soils disturbed during the construction of the reedbed, were regraded during October 1996. The resulting exposed area required a management plan, as the disturbed soil contained rhizomes of *Elymus repens* (L.) Gould (Couch-grass), along with seeds of ruderal species which would colonise the area and adversely influence the undisturbed grassland if allowed to regenerate naturally. It was decided, after consultation with INCA and English Nature, to seed the area with a suitable seed mix in order to ameliorate the effect of the disturbance (Figure 36) (c.f. section 6.1).

The present study aimed to provide a baseline of the soil status of the project site in order to relate vegetation communities to soil characteristics and chemical composition.

5.1. Methods

A grid system of permanent quadrat markers was positioned to cover the site as samples would need to be spatially referenced to allow for both accurate and repeatable sampling and subsequent analysis. Figure 36 shows the location of the 33 permanent quadrat markers. Quadrats were laid out in approximately N-S transects, 20 m apart and E-W transects, 30 m apart. The grassland was visually sub-divided into areas of
1) tall-grass dominated, 2) short, herb-rich, and 3) seeded (following construction work). A pit (1 m deep x 1 m square) was excavated in each of the three areas. Soil profiles were produced for each pit following guidelines by Rowell (1994). Quadrats 9, 13 and 16 were selected as areas typical of tall-grass, quadrats 7, 12 and 17 of short herb-rich, and

Figure 36. CATS Terminal constructed reedbed and grassland site showing network of permanent quadrat markers.



quadrats 21, 23 and 31 of the seeded areas. All soil analyses were undertaken on samples from the selected quadrats in triplicate, giving nine analyses for each vegetation type

On 11th March 1997, a 50 x 50 cm wire quadrat was placed on the ground with the permanent quadrat marker forming the north-west corner. Soil was removed with an auger to a depth of 10 cm , approximately 20 cm outside the remaining three corners, and bulked. Soil samples were air-dried in the laboratory and passed through a 2 mm mesh sieve, providing a 'fine earth' fraction.

5.1.1. Soil pH

Approximately 2 cm of air dried soil was placed into labelled 100 cm^3 glass beaker and sufficient distilled water was added to form a thin paste. The samples were allowed to stand for one hour and pH readings were taken with a calibrated pH meter.

5.1.2. Soil conductivity

Soil conductivity was determined on a saturation extract using a Kent EIL 5003 conductivity meter. Distilled water was added to 20 g of air dry soil to form a thin paste. The paste was transferred to a measuring cell (constant K=1) of the conductivity bridge. The multiplication switch was set to 10^3. The temperature control of the conductivity bridge was adjusted to the temperature of the extract, and the conductivity reading was taken.

5.1.3. Soil moisture content

The soil moisture content was measured as a percentage weight loss after drying. 20 g of soil was placed into a pre-weighed crucible and placed in an oven pre-heated to 105 °C for 24 hours. After cooling in a dessicator, the crucible was re-weighed and the percentage soil moisture was calculated using the formula:-

$$\% \text{ moisture} = \frac{\text{Initial weight of soil (g) - Oven dry weight of soil (g)}}{\text{Initial weight of soil (g)}} \times 100$$

5.1.4. Soil organic content

Due to the uncertain origin and possible combustible nature of a portion of the infill material used in the reclamation of the site, the organic content of the soils could not be determined with confidence.

5.1.5. Soil particle size analysis

Particle size analysis was undertaken on soil samples using the sieving and hydrometer method recommended by the Department of Geography, University of Northumbria (Anon, 1991).

5.1.6. Soil carbonate content

5 g of soil was placed in a labelled 150 cm^3 beaker, into which 100 cm^3 1M HCl was added. The solution was stirred several times over the period of one hour. The samples were covered and allowed to settle overnight. 20 cm^3 of the cleared liquid was transferred into a 100 cm^3 beaker with 15 drops of bromothymol blue indicator. The aliquot was titrated with standardised 1M sodium hydroxide until the endpoint (a colour change from yellow to blue). The titration was first undertaken without soil to standardise the sodium hydroxide. Percentage calcium and magnesium carbonate was calculated using the following formula:-

$$\% \text{ calcium + magnesium carbonate} = (\text{blank titration - sample titration}) \times 5.$$

5.1.7. Soil extraction for total nitrogen and total phosphorus determination

The soil samples were digested using a modified micro-Kjeldahl method (Allen *et al.*, 1974). 0.5 g of soil was placed in a micro-Kjeldahl flask with 3 cm^3 H_2SO_4, 2.5 cm^3 distilled water, and 1/2 a selenium catalyst tablet. The flask was heated gently for 30 minutes (c.150°C), and then at a higher temperature (c.400°C) for 2 hours 30 minutes. After cooling, the extract was filtered with Whatman GF/C glass microfibre filters, and made up to 50 cm^3 with distilled water. For each batch of samples (5), a control flask was also heated containing only the acid, water and catalyst tablet, to provide a chemical 'blank'.

5.1.8. Total Kjeldahl nitrogen content of the soil.

The digestion process oxidised organic matter in the soil to release the nitrogen it contained as ammonia. A determination of the total ammonia in the sample by the SKALAR flow analyser gave the total Kjeldahl nitrogen content of the soil.

All extract samples were diluted by a factor of 10 before analysis. The control samples were incorporated into the flow analyser in place of a distilled water/sulphuric acid matrix during the run.

5.1.9. Total phosphorus content of the soil

The soil extract was diluted by a factor of 10 before determination of total phosphorus by the SKALAR flow-analyser. The control samples were incorporated into the flow analyser in place of a distilled water/sulphuric acid matrix during the run. The procedure within the analyser being the same as for the determination of phosphate in the water samples (c.f. section 3.1.11).

5.2. Results

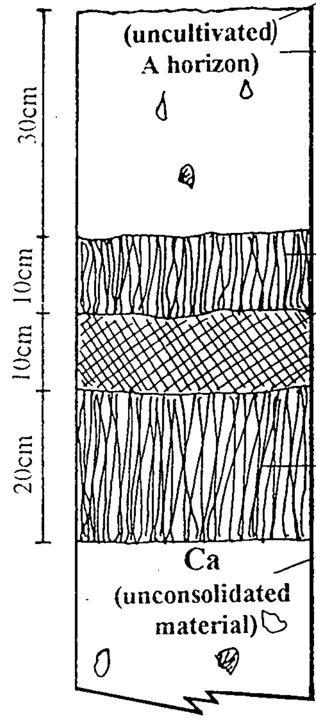
The grassland was visually sub-divided into areas of tall-grass, of short, herb-rich grassland, and the seeded area. Results of the soil analyses of the three distinct areas served to relate the different vegetation types to soil characteristics and chemical composition. The established grassland was however, a mixture of patches dominated by tall-grass, or by herbs with bare ground, but there were also large areas where neither tall-grasses nor herbs were dominant.

Soil pits A, B & C were excavated to a depth of 1 m in each of the three areas and the soil profiles produced are shown in Figures 37 to 39. Differences in stone content were noticed in the different soil profiles. Pit C, excavated in the grass area, contained few stones, whereas the soil profiles in Pits A & B contained a high percentage of stones. Stony soils may be excessively drained because of the reduced volume of soil to hold water (Rowell, 1994).

Figure 37. Soil Pit A

Area covered with material from Outfall Pond 1995. Re-graded October 1996.
Topsoil scoured March 1997 prior to seeding in mid-April 1997.
Immature soil profile
Bare earth.

Sandy loam



Bare earth

Unconsolidated material
Munsell soil colour
Dry colour- 2.5Y 6/3 (light yellowish brown)
Wet colour - 2.5Y 4/4 (olive brown)
Ped structure - angular blocky

Roots and covered vegetation

Fine dark layer - no visible structure
Munsell soil colour
Dry colour- 2.5Y 4/1 (dark grey))
Wet colour - 2.5Y 2.5/1 (black)

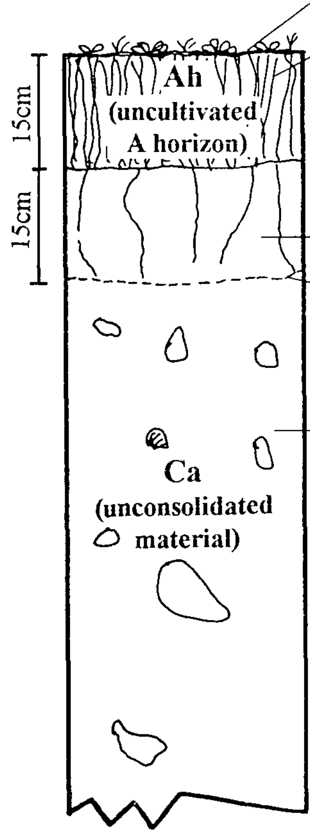
Roots and organic material

Yellow sand infill.
Abundant stones
Munsell soil colour (Anon, 1992)
Dry colour - 2.5Y 6/2 (light brownish grey).
Wet colour - 2.5Y 4/4 (olive brown)

Date of profile - 27/3/97
Location - CATS Terminal reed bed project, NZ 521 246
Land form-
a) Surrounding land form flat.
b) microtopography uneven.
c) slope angle 0-2%.
Vegetation and Agriculture-
a) Land use - unmanaged.grassland.
b) Vegetation cover -bare earth.
c) Human influence - reclaimed from estuarine mudflats and then unmanaged until 1995 when area was covered with material excavated from outfall pond. In order to prevent weed incursion the area was re-seeded with locally native species of grass and wildflowers during mid-April 1997.
Parent material
Hydraulically placed sand with some alluvial and glacial clays including some crushed slag.
Drainage
a) Depth of water table- <5m from surface.
b) Moistness of exposed profile - Water is removed from the soil profile rapidly. Generally sandy, undifferentiated, porous profile.

Figure 38. Soil Pit B

Undisturbed grassland-predominantly short, herb-rich grassland.
Immature soil profile

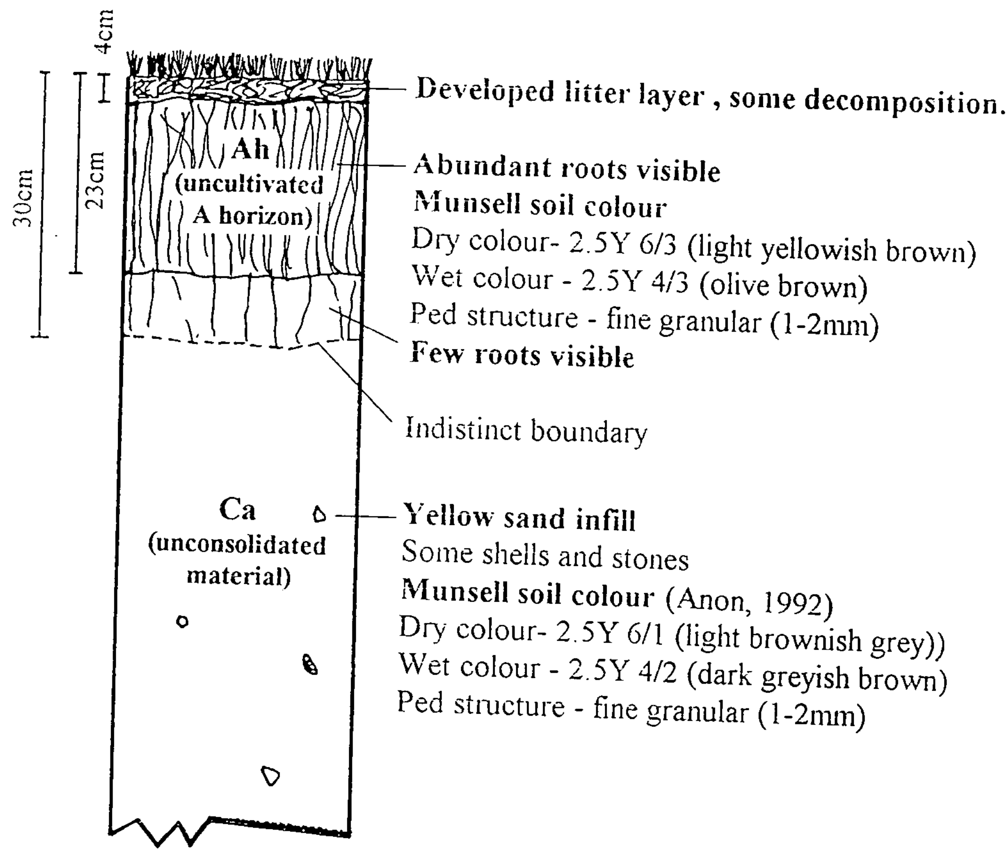


Date of profile - 27/3/97
Location - CATS Terminal reed bed project, NZ 521 246
Land form-
a) Surrounding land form flat.
b) microtopography uneven.
c) slope angle 0-2%.
Vegetation and Agriculture-
a) Land use - unmanaged grassland.
b) Vegetation cover - short herbs.
c) Human influence - reclaimed from estuarine mudflats and then unmanaged.
Parent material
Hydraulically placed sand with some alluvial and glacial clays including some crushed slag
Drainage
a) Depth of water table- <5m from surface.
b) Moistness of exposed profile - Water is removed from the soil profile rapidly. Generally sandy, undifferentiated, porous profile.

Figure 39. Soil Pit C

Grass dominated area.
Immature soil profile

Sand



Date of profile - 27/3/97
Location - CATS Terminal reed bed project, NZ 521 246
Land form-
a) Surrounding land form flat.
b) microtopography uneven.
c) slope angle 0-2%.
Vegetation and Agriculture-
a) Land use - unmanaged.grassland.
b) Vegetation cover -dense grassland >95% cover.
c) Human influence - reclaimed from estuarine mudflats and then unmanaged.
Parent material
Hydraulically placed sand with some alluvial and glacial clays including some crushed slag.
Drainage
a) Depth of water table- <5m from surface.
b) Moistness of exposed profile - Water is removed from the soil profile rapidly. Generally sandy, undifferentiated, porous profile.

5.2.1. Soil particle size.

The results of the soil particle size analyses are shown in the following table.

Table 7. United States Department of Agriculture (U.S.D.A.) textural particle sizes for soil samples from the CATS Terminal reedbed, associated grassland site, taken on 11/3/97.

	Quadrat	Sample wt.(g)	% Sand	% Silt	% Clay	U.S.D.A.Texture.
Grass	9	50.13	85	13.0	2	Loamy sand
	13	50.10	82.2	15.8	2	Loamy sand
	16	50.27	91.3	6.6	2	Sand
	C	50.38	86.2	11.8	2	Sand
Herb-rich	7	50.41	89.6	8.3	2	Sand
	12	50.03	87.3	10.7	2	Sand
	17	50.04	88.1	9.8	2	Sand
	B	50.17	92.1	5.9	2	Sand
Seeded	21	50.30	67.1	30.9	2	Sandy loam
	23	50.40	52.5	45.5	2.1	Sandy loam
	31	50.58	69.3	28.8	2	Sandy loam
	A	50.41	63.2	34.8	2	Sandy loam

The particle size was predominantly sandy. Sandy soils have a poor ability to hold water for plant use (Rowell, 1994), and any nutrients are likely to be leached through the profile. Soils sampled from the seeded area around the Outfall Pond contained a higher percentage of silt and were classified as sandy loams. The seeded area contained material deposited from the excavation of the Outfall Pond, with an immature, unconsolidated soil profile typified by soil pit A (Figure 37).

The results of further soil analyses are summarised in Table 8.

Table 8. Results of physical and chemical analyses of soil samples from the CATS Terminal reedbed, associated grassland site, taken on 11/3/97. (± 1 SE) shown in brackets. n= 3 for each quadrat tested.

Quadrat	pH of paste	Conductivity of paste ($ECdSm^{-1}$)	% Soil moisture	Carbonates (% Ca + $MgCO_3$)	Total N (mg g^{-1} dry wt)	Total P (mg g^{-1} dry wt)
Grass 9	8.2 (±.01)	0.09 (±.01)	13.8 (±.10)	11.8 (±.14)	0.8 (±.04)	2.3 (±.14)
13	8.1 (±.00)	0.08 (±.01)	13.9 (±.05)	14.3 (±.30)	0.8 (±.07)	1.8 (±.08)
16	8.1 (±.01)	0.11 (±.01)	19.5 (±.17)	12.0 (±.37)	0.8 (±.02)	2.0 (±.11)
Herbs 7	8.3 (±.00)	0.08 (±.01)	9.5 (±.17)	15.6 (±.31)	0.4 (±.02)	2.0 (±.24)
12	8.2 (±.01)	0.10 (±.01)	16.9 (±.12)	18.7 (±.07)	0.7 (±.01)	1.9 (±.06)
17	8.2 (±.01)	0.09 (±.00)	11.8 (±.05)	12.7 (±.22)	0.5 (±.01)	1.3 (±.05)
Seeded 21	8.0 (±.01)	0.29 (±.01)	14.6 (±.14)	12.2 (±.14)	0.8 (±.00)	2.1 (±.14)
23	8.1 (±.00)	0.20 (±.01)	18.4 (±.14)	2.7 (±.32)	1.0 (±.00)	2.7 (±.37)
31	8.1 (±.01)	0.22 (±.01)	14.3 (±.12)	8.8 (±.29)	0.6 (±.04)	2.4 (±.22)

5.2.2. Soil pH

Soil paste pH ranged from 8.0 to 8.3 over the site and were alkaline. The highest pH values were recorded from the soils with herb-rich vegetation. With reference to soil pit B (Figure 38), the higher pH values were probably attributable to the presence of basic slag and shells in the substrate.

5.2.3. Soil conductivity

Soil conductivity (of the saturation extract) in the grassland ranged from EC_e 0.08 to 0.11 dS m^{-1}. 2-way ANOVA indicated that there was little difference between the soil conductivity of the grass and herb-rich quadrats. The conductivity of the re-graded (seeded area) soil was signficantly higher than that of the grassland

($F_{2,18}$ = 268.25, p <0.001), and ranged from EC_e 0.20 to 0.29 dS m^{-1}. According to Rowell (1994), saline soils are those with EC_e values greater than 4 dS m^{-1}. Salts within the soil profile were redistributed in the re-graded soil, yet all of the quadrats comprised relatively non-saline soils.

5.2.4. Soil moisture content

The percentage soil moisture content of quadrats 21, 23 and 31 which ranged from 14.3 to 18.4 %, were taken from areas of recently graded, transitory bare ground and therefore provide only a baseline for future vegetation analyses, and were therefore, not included in statistical analysis.

The soil moisture of the grass quadrats ranged from 13.8 to 19.5 %. The soils supporting short herbs had the lowest soil moisture content which ranged from 9.5 to 16.9 %. There was significant variation in soil moisture within both vegetation types, but 2-way ANOVA indicated that the soil moisture content of the grass quadrats was significantly higher than the soil moisture content of the herb-rich quadrats ($F_{1,12}$ = 641.29, p <0.001).

5.2.5. Soil Carbonate content

Carbonates maintain alkaline conditions in soils. Soil samples from most quadrats contained a high percentage of calcium and magnesium carbonate ranging from 2.7 to 12.2 % in the re-graded area quadrats, from 11.8 to 14.3% in the grass quadrats, and from 12.7 to 18.7 % in the herb-rich quadrats where soils with slag, stones and marine shells were abundant. There was significant variation in carbonate content within the vegetation types, however, 2-way ANOVA indicated that the soils in the herb-rich quadrats contained significantly higher amounts of carbonates than the grass or the seeded area quadrats ($F_{2,18}$ = 436.34, p <0.001).

5.2.6. Soil total nitrogen content

Soils from the re-graded, seeded area contained from 0.6 to 1.0 mg g^{-1} dry wt of total nitrogen. Soils from the grass quadrats contained 0.8 mg g^{-1} dry wt of total nitrogen compared to the lower values found in the herb-rich quadrats,which ranged from 0.4 to 0.7 mg g^{-1} dry wt of total nitrogen. There was no significant difference between the total nitrogen content of the soils in the grass and the seeded area quadrats. However, 2-way ANOVA indicated that the soils supporting grass vegetation contained significantly higher amounts of total nitrogen than the soils supporting herb vegetation ($F_{1,16} = 69.35, p < 0.001$).

5.2.7. Soil total phosphorus content

Soils from the re-modelled, seeded area contained from 2.1 to 2.4 mg g^{-1} dry wt of total phosphorus. Soils from the long grass quadrats contained 1.8 to 2.3 mg g^{-1} dry wt of total phosphorus compared to the lower values found in the herb-rich quadrats, which ranged from 1.3 to 2.0 mg g^{-1} dry wt of total phosphorus. There was no significant difference between the total phosphorus content of the soils in the grass and herb-rich quadrats, although there were significant differences in total phosphorus content within the vegetation types. 2-way ANOVA indicated however, that the seeded area quadrats contained significantly higher amounts of total phosphorus in the soil than present in the grass and herb soils ($F_{1,16} = 20.87, p < 0.001$).

5.3. Discussion

Core samples of the site taken by Allied Exploration and Geotechnics LTD. in 1989 show complex strata of sand and silt, which vary from place to place as would be expected of hydraulically placed infill (Anon, 1990). In the upper strata, sand is predominant with slag, stones and shells, so that the surface is very freely drained. Soil pits A, B, and C (Figures 37 to 39) illustrate the local substrate variation. The immature soils that have developed on the site are sandy and stony with poor water retaining ability (Anon, 1989).

Patches of short, herb-rich vegetation have developed on the sandy, stony soils where excessive drainage has prevented the vegetation reaching high cover or biomass. The lack of a distinct litter layer has resulted in the soils underlying the herb vegetation having low organic content. Organic matter is a main source of nitrogen and phosphorus for plants and it also enables the soil to retain more moisture. A lack of organic matter can also lead to the soil surface drying out. According to Bannister (1976), herbaceous plants which are grown permanently exposed to dry conditions and wind (a frequent factor in the exposed site), have a better control of water loss, although the consequence of this control is poorer growth. The soil moisture content of the short, herb-rich vegetation quadrats was significantly lower than that available in the grass dominated quadrats. Many of the herbs present were characteristic of low-moisture conditions and had long tap-roots to obtain sub-surface moisture, or reproduced vegetatively by producing stolons, allowing offspring to obtain moisture from the parent plant until they become established on a suitable substrate (chapter six).

Grasses have become established on the less stony substrate (Figure 39), which has allowed deeper root penetration. The most abundant grass, *Festuca rubra* L., is not a drought tolerant species but it possesses a long tap root (Grime *et al.*, 1988). The denser vegetation and developing litter layer both serve to retain some moisture and nutrients.

A further reduction in the availability of soil moisture to vegetation occurs when saline soils lower osmotic potential, causing physiological drought (Rowell, 1994). However, conductivity indicates that the site soils were not saline. Any salts originating from the infill material may have been leached away by rain water during the process of soil development.

The soils that have developed on the site are alkaline. Carbonates maintain alkaline conditions in soils and the soils in the herb quadrats contained significantly higher amounts of carbonates than the grass and seeded areas, due to the relatively higher amounts of slag and stones in the substrate. The high pH is reflected in the presence of calcicole (calcium-loving) plants such as *Hieracium pilosella* L. and *Blackstonia perfoliata* (L.) (chapter six). *Pastinaca sativa* L. according to Knees (1989), has a specific requirement for chalk and serves as an indicator species for chalk substrates. Similarly, some invertebrate groups such as Gastropods, Diplopods and Isopods have high calcium requirements and may be restricted to alkaline soils (Curry, 1994). Isopods were particularly abundant on the site and molluscs were locally frequent (chapter seven).

Nitrogen can be a growth-limiting factor for species growing in alkaline soils, as the mobilisation of nitrogen is reduced above pH 8 (Allen, 1974). According to Marschner (1986), a high percentage of the soil nitrogen is organically bound in humus, which becomes available to plants after mineralization by soil microorganisms into inorganic nitrogen. The small amount of litter and organic material in the short, herb-rich areas resulted in reduced amounts of available mineralized inorganic nitrogen. Also, rates of mineralization can be very slow in dry soils (Lewis, 1986). The concentration of nitrate, the inorganic form of nitrogen available in solution to plants, is generally low compared to the total nitrogen content of the soil (Bannister, 1976). The soils supporting predominantly grass vegetation contained significantly higher amounts of total nitrogen than those supporting the herb-rich vegetation. The higher biomass and productivity of vegetation in the grass areas produced a relatively deeper organic litter layer (Figure 39), resulting in a greater moisture retaining ability of the soil, and although not measured in the analysis, a presumably higher mineralized nitrogen content.

The greater part of the site comprised sandy soils with poor water retaining ability. Any soluble nitrate available was likely to be leached through the soil profile resulting in mineral nutrient stress. Mineral nutrient stress limits the root growth of many species making them susceptible to drought (Grime & Curtis, 1976; Marschner, 1986). According to Bannister (1976), the hydraulic conductivity of dry soil is very low and the depletion of water in the vicinity of plant roots can result in the inability of the roots to extract sufficient available phosphate. Phosphorus may also be deficient in calcareous soils because of its precipitation as insoluble phosphates which are unavailable to plants (Bannister, 1976). Rowell (1994) suggests that precipitation as insoluble Calcium phosphates is the dominant phosphorus transformation when pH values are above 7.0. The total phosphorus content of the herb and grass soils were not significantly different. Available phosphate was not determined in the soil analysis but may be deficient in the grassland soils as many of the grassland plants exhibited reddish stems, a deficiency symptom noted by Bannister (1976) and Marschner (1986).

The nutrient-poor dry soils support a herb-rich grassland community. The herb-rich vegetation contains legumes typical of unproductive grasslands such as *Lotus corniculatus* L. and *Trifolium pratense* L. which produce local enrichment of soil nitrogen (Grime *et al.*, 1988). However, edaphic factors have prevented the vigorous growth of competitive species, and a slow progression of vegetation succession.

Soils of the re-modelled area contained significantly higher concentrations of total phosphorus and total nitrogen compared with the soils in the herb-rich quadrats. The recently disturbed soils appear to have released nutrients which have been exploited by the ruderal species present during the first season's growth. Future soil monitoring will determine whether the colonising species have depleted the released resources, and the effect of the damp soils around the Outfall Pond on the diversity of grassland vegetation.

CHAPTER SIX

6. BOTANICAL COMPOSITION OF THE GRASSLANDS

The site, created in 1974 has been left to recolonise naturally, unmanaged. Although species diversity has been affected by occasional rubbish tipping and vehicular disturbance. By the mid-1990's, the site supported a herb-rich grassland with very few scattered shrubs. A botanical survey of the whole of the CATS Terminal site was carried out by Environmental Resources Ltd in 1989, and formed part of the Environmental Impact Assessment of the site prior to development of the Terminal (Anon, 1990). A further botanical survey of the whole site was carried out by Cleveland Environmental Consultants Ltd. in 1995, prior to an expansion of the developed site (Garside, 1995). In order to determine the impact of the constructed reedbed system, a botanical survey of the grassland associated with the reedbed was carried out during the present study as a baseline against which to monitor future succession.

6.1. Methods

During October of 1996, an initial botanical survey of the undisturbed grassland was carried out in order to identify species present on the site. The timing of the survey was not within the optimum season for botanical fieldwork, but was undertaken for the purpose of ordering a similar grass and wildflower mixture to be planted on the area disturbed and re-modelled during construction.

The disturbed area (area 0.6 ha) was sown on 17th April, 1997 with approximately 60 Kg of wildflower (24 %) and grass (76 %) seed. The wildflower and grass seeds, varying in size and weight, were mixed thoroughly with sawdust to ensure a uniform distribution and visability of sowing. Once sown, the ground was lightly raked. Some seed was retained and bare-patches of earth were re-seeded in June.

Between 1-12th July, 1997, a botanical survey of the site was carried out using the framework of 33 permanent quadrat markers which covered the undisturbed grassland and the disturbed areas of the project site (Figure 36). A 50x50 cm wire quadrat was placed on the ground with the permanent quadrat marker forming the north-west corner. Species were identified wherever possible using Rose (1981), (1989), and Hubbard (1992). Nomenclature of flora follows that of Clapham, Tutin & Moore (1989). Within each quadrat, a quantative measure of the abundance of every taxon was recorded using the Domin scale as shown in Table 9. Cover was assessed by eye as the total vertical shade cast by the aerial parts of all its members within the quadrat (Graham, 1988).

Table 9. The Domin scale for visual estimate of cover.

Domin value	% cover
10	91-100 %
9	76-90 %
8	51-75 %
7	34-50 %
6	26-33 %
5	11-25 %
4	4-10 %
3	< 4 % with many individuals
2	< 4 % with several individuals
1	<4 % with few individuals

Species not found within quadrats, but present on the site were also recorded using a modified DAFOR scale:-A= Abundant, F = Frequent, O = Occasional, and R = Rare. Aquatic and marginal plants were identified but not monitored systematically.

A visit to the site by Ian Lawrence and Vincent Jones, both of the Cleveland Naturalists' Field Club confirmed the identification of certain 'difficult' and locally rare species.

6.2. Results

The botanical species recorded in the 33 permanent quadrats within the grassland associated with the reedbed system, between 1 and 12/7/97 are given in Appendix 1 along with an estimate of their abundance. Byophytes were not identified.

Species which occurred in the grassland but not within the quadrats are listed in Appendix 2. The lists should not be regarded as exhaustive as, although early July is a good time of the year for botanical recording, a few spring and late-summer flowering species may not have been in evidence during July.

6.2.1. Undisturbed grassland area

The largest area of undisturbed grassland was situated to the north of the reedbed wetland system, and included permanent quadrats 5 to 20 (Plate 20). Three communities were apparent on preliminary visual observation:-

GRASS-DOMINATED (Plate 20)	Less species-rich communities with a high overall vegetation cover (>90 %), in which the grasses *Festuca rubra* L. and *Agrostis stolonifera* L. were dominant. *Lotus corniculatus* L. was also abundant and frequent. *Hieracium pilosella* L. was also frequent but less abundant.

Plate 19. Permanent quadrat marker in area of mixed herbs and grass, July 1997. (Pitfall trap in the foreground)

Plate 20. Grass dominated vegetation within the undisturbed grassland, adjacent to the CATS Terminal reedbed, July 1997.

HERB-RICH (Plate 21)
: Species-rich communities with a low overall vegetation cover (25-50 %), in which low-growing herbs such as *Anthyllis vulneraria* L., *Taraxacum* spp., and *Hieracium pilosella* were abundant. *Blackstonia perfoliata* (L.) Hudson and *Lotus corniculatus* were frequent but less abundant, as were the grasses *Agrostis stolonifera* and *Festuca rubra.*

MIXED HERBS & GRASS (Plate 19 & 22)
: A mixed community with a more even proportion of grass and herbs, with a vegetation cover of between 25-90 %. The grasses *Festuca rubra* and *Agrostis stolonifera* were frequent and abundant, as were the herbs *Hypochoeris radicata* L., *Lotus corniculatus, Hieracium pilosella* and *Trifolium repens* L.

Distribution of the three different vegetation communities within the site are shown on Figure 40, where it can be seen that the majority of the site was mixed herb and grass community.

Contours shown in Figure 4 show that the relatively flat grassland site lay between 0.5 to 2.0 m above the water table (the Outfall Pond was not lined and the water level indicated the level of the water table). Although 60 % of grass dominated quadrats (9, 13 & 16) lay closer to the water table, so were 66 % of the herb-rich quadrats. The relatively greater water-retaining ability of the soils supporting predominantly grass vegetation was probably associated with the moisture retaining ability of the litter layer (chapter five), rather than proximity to the water table.

The northern boundary of the site was elevated (>1.5 m above the water table), and had been disturbed prior to the study due to the installation of a pipeline. Permanent quadrats 1 to 4 contained species characteristic of disturbed sites such as *Cirsium arvense* (L.) Scop. and *Tussilago farfara* L.. Locally frequent in the area between

Plate 21. Herb-rich vegetation within the undisturbed grassland, adjacent to the CATS Terminal reedbed, July 1997.

Plate 22. Mixed herbs and grass vegetation within the undisturbed grassland, adjacent to the CATS Terminal reedbed, July 1997.

quadrats 1 to 2 was *Crepis biennis* L. (Rough Hawk's-beard), a species which had not previously been recorded in the Tees Estuary area (I.Lawrence, personal communication).

Quadrat 6 was situated within a disused track and contained a few poorly developed patches of *Agrostis stolonifera, Lotus corniculatus, Taraxacum* spp., *Tripleurospermum maritimum* (L.) Koch and *Tussilago farfara*. North of quadrat 8, within the track area, *Melilotus alba* Medicus, was growing well, although not commonly found within the county (I.Lawrence, personal communication).

The western boundary of the grassland contained a series of small mounds (Figure 40), which had been left on the site following the construction of a post and wire fence. The mounds supported grasses such as *Agrostis stolonifera* and *Festuca rubra,* but mainly herbs such as *Achillea millefolium* L., and *Diplotaxis tenuifolia* (L.) DC.

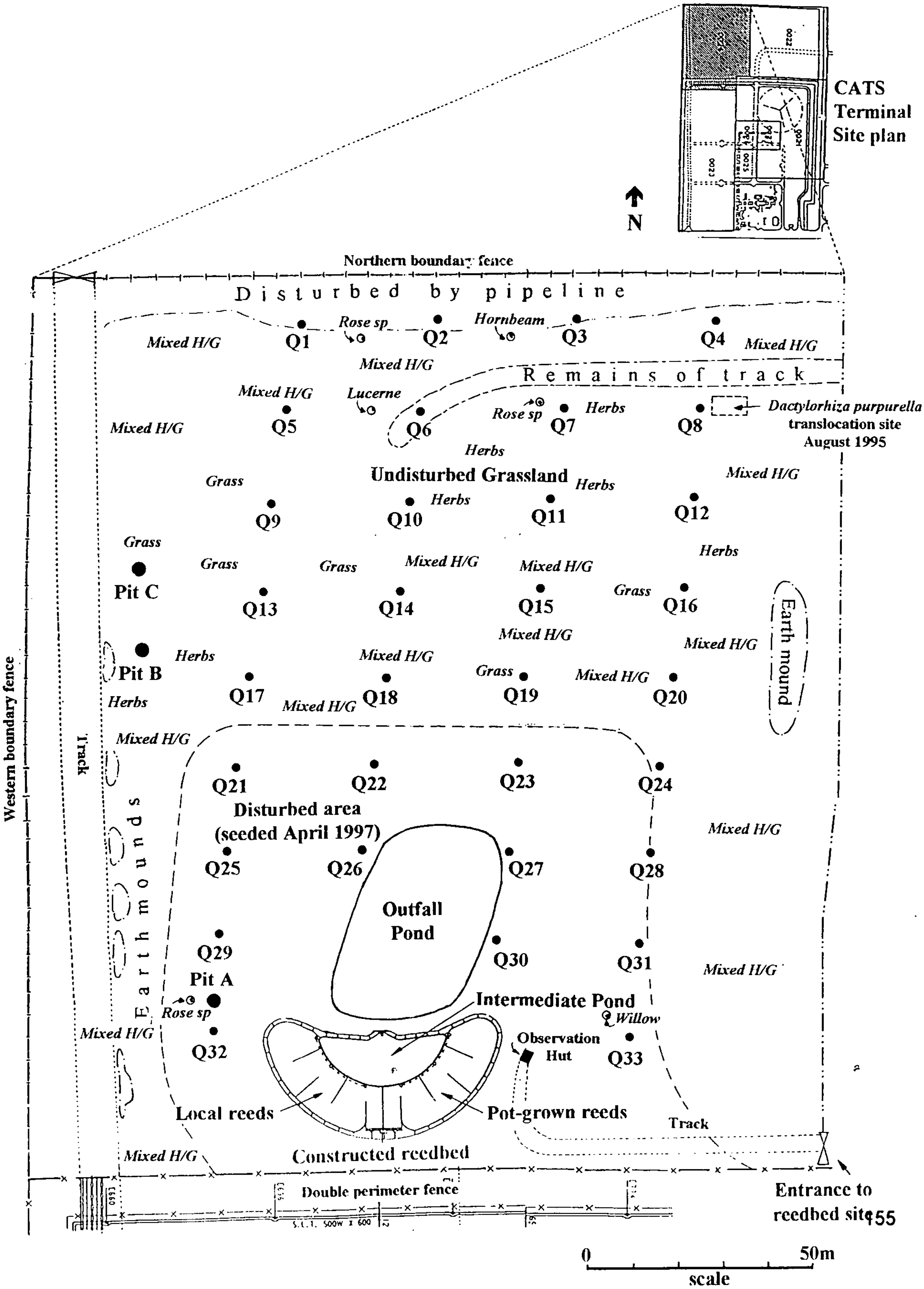
Another mound of earth was also present on the site between quadrats 16 and 20 and the eastern boundary fence. The area between this mound and the fence was less well-drained and contained a more dense sward of *Festuca rubra* and herbs including *Linaria purpurea* (L.) Miller.

To the west of the mound, in an area of predominantly low-growing herbs, to the east of quadrats 12 and 16, naturally regenerating specimens of *Pilosella praelta* subsp. *praelta* * * were identified. The Yellow 'Fox-and Cubs' being a nationally uncommon species of Hawkweed, had not previously been recorded in Cleveland (V.Jones, personal communication).

The botanical survey of the whole of the CATS Terminal site undertaken in 1995 by Cleveland Environmental Consultants Ltd. recommended the translocation of *Dactylorhiza purpurella* (T. & T.A.Stephenson) D. (Northern Marsh Orchid), from areas to be developed at the terminal, to a receptor site. During August 1995, a JCB translocated groups of orchids, taking as much of the surrounding soils and vegetation as

* Species identified by V. Jones, Cleveland Naturalists' Field Club.

Figure 40. CATS Terminal constructed reedbed and grassland site showing distribution of vegetation communities.



possible in order to transfer soil mycorrhizal fungus, to a site to the east of quadrat 8 (Figure 40, Plate 23). Between September 1996 to September 1997, no spikes of the orchid were identified either in the translocation area or the Terminal site. An abundance of Northern Marsh Orchids have been recorded growing in the ICI No.4 brinefields in past years, yet few were recorded flowering in 1997 (D.Muir, INCA, personal communication). However, frequent spikes of *Gymnadenia conopsea* subsp. *densiflora* (Wahlenb.) (Fragrant Orchid), were present within the grassland site during the early summer of 1997 (Plate 22).

Ruderals were an important component of the vegetation, even within the relatively undisturbed grassland areas, especially *Cirsium arvense*, *Senecio jacobaea* L. and *S.squalidus* L.

The site has not been managed by cutting or grazing since it was created in 1974. A few, poorly developed shrubs have become established including, a single specimen of *Salix* spp. (Willow), *Medicago sativa* L. (Lucerne), two species of Rose (*Rosa* agg.), and one young *Carpinus betulus* L. (Hornbeam).

6.2.2. Seeded area

The botanical species recorded in permanent quadrats 21 to 33 (Figure 40) in the area seeded during April 1997, between 1-12/7/97 are given in Appendix 1 along with an estimate of their abundance. Species which occurred in the seeded area but not within the quadrats are listed in Appendix 2

Species included in the seed mix which were positively identified during the botanical survey are shown in the following table.

Plate 23. Northern Marsh Orchid (*Dactylorhiza purpurella*) translocation area within the undisturbed grassland, adjacent to the CATS Terminal reedbed, July 1997.

Plate 24. Seeded area, adjacent to the CATS Terminal reedbed, August 1997

Table 10. Composition of the seed mixture as supplied by *Herbiseed*, Wokingham, sown on 17/4/97, in the area disturbed by the construction of the CATS Terminal reedbed, indicating species which had been positively identified in the seeded area by 30/7/97. (The seed mix contained 1 Kg of each species, with the remaining 40 Kg being equal weights of *Agrostis stolonifera, Festuca rubra* cv. *Condessa* and *Festuca rubra* cv. *Merlin*)

Botanical name	**Common name**	**Positively identified**
Achillea millefolium	Yarrow	✓
Agrostis stolonifera	Creeping Bent	✓
Anthoxanthum odoratum	Sweet Vernal-grass	-
Anthyllis vulneraria	Kidney Vetch	-
Arrhenatherum elatius	False Oat-grass	✓
Aster tripolium	Sea Aster	-
Cackile maritima	Sea Rocket	-
Cynosurus cristatus	Crested Dog's-tail	-
Dactylis glomerata	Cock's-foot	✓
Daucus carota	Wild Carrot	✓
Deschampsia cespitosa	Tufted Hair-grass	-
Diplotaxis tenuifolia	Perennial Wall-rocket	✓
Erigeron acer	Blue Fleabane	-
Festuca rubra cv.*Condessa* & cv.*Merlin*	Red Fescue	✓
Holcus lanatus	Yorkshire Fog	✓
Linaria vulgaris	Common Toadflax	✓
Lolium perenne	Perennial Ryegrass	✓
Lotus corniculatus	Bird's-foot-trefoil	-
Pastinaca sativa	Wild Parsnip	✓
Trifolium arvense	Hare's-foot Clover	✓
Trifolium pratense	Red Clover	✓
Tripleurospermum maritimum	Sea Mayweed	✓
Vicia sativa (agricultural)	Common vetch	✓
Vicia sativa (wild)	Common vetch	✓

Of the plants and seedlings that were identified from the seed mix, it is not known whether certain species such as *Agrostis stolonifera* and *Diplotaxis tenuifolia* germinated from the seed mix or from the soil seed bank. Similarly, unsown wildflowers which were identified such as *Centaurea cyanus* L., *Chrysanthemum segetum* L., and *Papaver rhoeas* L., may have originated from the soil seed-bank or seed-mixture contaminants. Unfortunately, many grass and herb seedlings were too small to be positively identified during the survey period. Future monitoring may confirm the establishment of seed-mix species.

The seeded area became dominated by the fast-germinating ruderal species *Sinapis arvensis* L. and *Conium maculatum* L.. However, once such species died-back, light was available for other germinating seedlings. In July, three months after seeding, the area surrounding the outfall pond, the area bordering the reedbed, the work-hut and the access track were becoming vegetated with species from Table 10. Ruderals and persistent weeds were also identified within the re-vegetating areas such as *Capsella bursa-pastoris* (L.) (Shepherd's-purse), *Chenopodium album* L. (Fat-hen), *Polygonum aviculare* L. (Knotgrass), *Senecio vulgaris* L. (Groundsel), *Tussilago farfara* (Coltsfoot), *Elymus repens* (Couch), and *Cirsium arvense* (Creeping Thistle). However, the establishment of the seed mix during the summer of 1997 reduced the bare-ground available for further weed invasion (Plate 24). *Festuca rubra* (Red Fescue), *Arrhenatherum elatius* (L.) Beauv. ex J. & C. Presl (False Oat-grass), *Trifolium pratense* (Red Clover), *Tripleurospermum maritimum* (Sea Mayweed), and *Vicia sativa* L. (Common Vetch) germinated particularly well.

The sloping margins along the west and east of the Outfall Pond were less successfully vegetated. During early June, the bare ground areas were re-seeded, but heavy rain during June, although aiding germination, removed many seedlings along the sloping margins.

6.2.3. Aquatic and marginal plants

Any marginal and emergent vegetation which had developed around the Outfall Pond were removed when the pond margins were re-graded during the spring of 1997, prior to seeding. The seed mix contained only grassland species, therefore aquatic and marginal vegetation which appeared during the summer of 1997 were from the soil seed bank, or natural colonisers. Marginal species included *Atriplex littoralis* L. (Grass-leaved Orache, *Reseda luteola* L. (Weld), *Epilobium hirsutum* L. (Great Willowherb), and *Catabrosa aquatica* (L.) Beauv. (Water Whorl-grass). Within the Outfall Pond, large areas of *Potamogeton crispus* L. (Curled Pondweed) were present during the summer.

6.2.4. National Vegetation Classification (NVC) of the undisturbed grassland

Within the grassland quadrats, 1 to 20, quadrats 1 to 4 were situated on raised ground which had been disturbed during 1995 by the installation of a pipeline, and these were omitted from subsequent analysis. Data from quadrats 5 to 20 were considered most suitable for National Vegetation Classification (NVC) of the grassland using the computer programme TABLEFIT, with the Domin values of species abundance. The programme used the species data and assigned the site to a vegetation type or plant community identified and described in British Plant Communities (Rodwell, 1991). The programme defined a measure of goodness of fit between samples of vegetation and the expected species composition of each vegetation type.

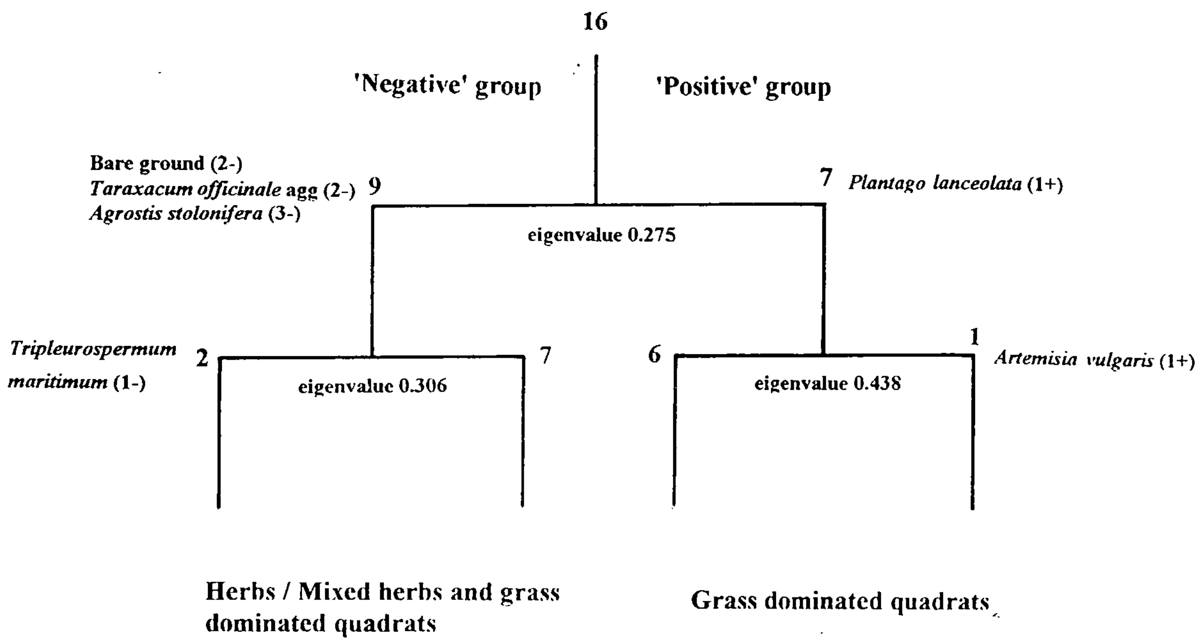
The programme assigned the CATS Terminal grassland as NVC type **MG5a** *Cynosurus cristatus - Centaurea nigra* sub-community *Lathyrus pratensis*, with goodness of fit 49 % (very poor).

6.2.5. Multivariate analysis

Multivariate analysis was undertaken on the 33 species identified in quadrats 5 to 20, to investigate the existence of distinct species assemblages. The species list quantified by their Domin values was classified by Two-Way Indicator Species Analysis (TWINSPAN) (Hill, 1979a) and ordinated by Detrended Correspondence Analysis (DECORANA) (Hill, 1979b). All species were considered equally and downweighting of rare species was not used.

The TWINSPAN computer programme produced a hierarchical classification of the 16 quadrats, grouping those with similar floras and identifying 'indicator' species that differentiated the groups (Hill, 1979a). The classification separated the grassland quadrats into habitat groups which were illustrated in the form of a dendrogram (Figure 41).

Figure 41. Dendrogram showing the first two TWINSPAN divisions of 33 species found in 16 quadrats at the CATS Terminal reedbed associated undisturbed grassland, with the indicator species for each division. (Pseudospecies cut levels in brackets)



Division one produced a positive group which included all of the quadrats which were dominated by grass. The positive species used as an indicator for the division was *Plantago lanceolata* L.. The negative group included the remaining quadrats that contained both herb-rich and mixed vegetation. The negative indicator 'species' used for the division were bare ground, *Taraxacum officinale* agg, and *Agrostis stolonifera*. It is important to note that the indicator species used in each division in TWINSPAN were only the best indicators of each particular division, and were not necessarily typical species of only one group or habitat (Luff *et al.*, 1989). *Plantago lanceolata,* the positive indicator, was also present in the mixed vegetation and herb-rich quadrats, whereas bare ground (negative indicator), although present to some extent in all of the quadrats, was very characteristic of the mixed vegetation and herb dominated quadrats. Further divisions two and three, did not produce ecologically distinct groups.

The species list of grassland flora were ordinated by Detrended Correspondence Analysis (DECORANA). All species were considered equally and downweighting of rare species was not used. Eigenvalues and variance explained by axes 1 to 4 are given in the table below.

Table 11. Eigenvalues for DECORANA axes generated by analysis of CATS Terminal grassland flora from quadrats 5 to 20, identified between 1-12/7/97.

DECORANA axis	Eigenvalue	Variance explained
Axis 1	0.3452	45 %
Axis 2	0.2598	34 %
Axis 3	0.1195	15 %
Axis 4	0.0448	6 %

*The variance explained was calculated by dividing the eigenvalue of each axis by the sum of the eigenvalues of all four (Jeffries, 1989).

Axes one and two explained 79 % of the variation and Figure 42 gives the resulting DECORANA ordination of the grassland quadrats using the first two axes. Polygons based on the TWINSPAN classification illustrate the different vegetation groups. The ordination with respect to axis one divided the quadrats into two broad groups, corresponding to the grass and the mixed/herb-rich vegetation groups which were distinguished visually. The quadrats dominated by grass were situated towards the higher end of the first principal axis, whilst the quadrats with herb-rich and mixed cover were situated towards the lower end. The first principle axis described a gradient which may have been related to increasing vegetation cover towards the higher end of the axis, and decreasing cover towards the lower end. Quadrat 6, was situated on an earth track scored zero on the first axis and was predominantly bare ground with little vegetation. Quadrat 13, however, had a relatively closed cover of grass. Axis 1 may also be related to substrate porosity and nutrient content. At the higher end of the axis, the grass quadrats contained relatively higher levels of nutrients and a deeper litter layer,whilst the herb dominated quadrats were excessively drained with a negligable litter layer to retain moisture or provide nutrients (chapter five). The variation between the quadrats along axis two was less distinct and could not be explained by any of the environmental parameters measured during the study.

Figure 43 shows the DECORANA ordination of species from the grassland quadrats. Species plotted towards the higher end of the first axis were those classified as the positive group by TWINSPAN, and include the grasses *Festuca rubra* and *Elymus repens,* and the herbs *Hypochoeris radicata* and *Lotus corniculatus.* Species plotted towards the negative end of the first axis included *Taraxacum* species, *Tussilago farfara,* and *Tripleurospermum maritimum.* The latter are ruderal species associated with the early stages of succession and are common on disturbed areas with a high proportion of bare ground. Such species are able to become established in the absence of the more competitive grass species.The first axis may therefore be related to variation in cover, with

Figure 42. DECORANA ordination plot (axis 1 by axis 2) of the CATS Terminal reedbed associated undisturbed grassland quadrats. Polygons based on TWINSPAN classification

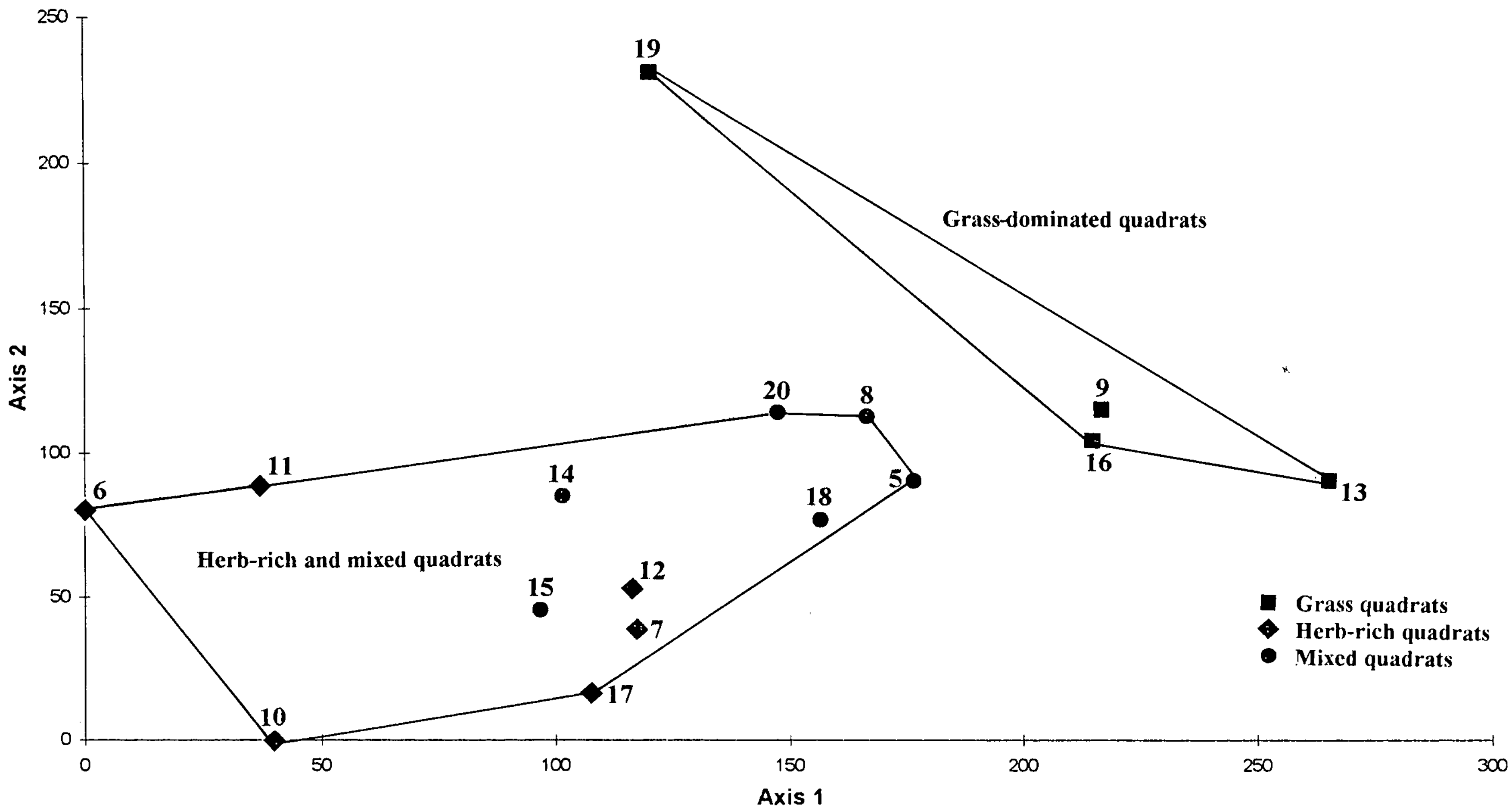
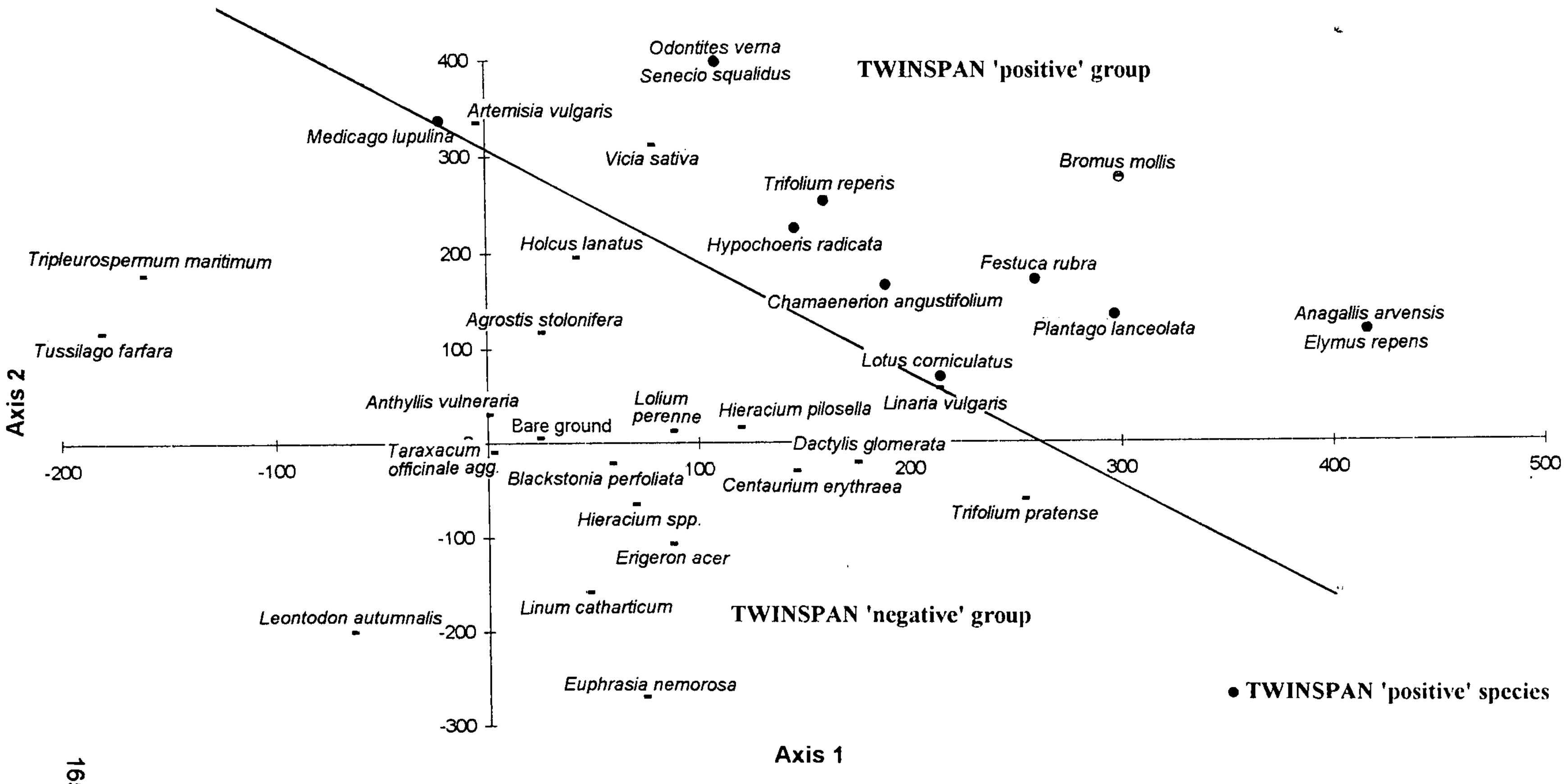


Figure 43. DECORANA ordination plot (axis 1 by axis 2) of the CATS Terminal reedbed associated undisturbed grassland species.



the more competitive species providing a more closed grass sward towards the higher end of the axis, with the less competitive and ruderal species plotted towards the negative end of the axis.

6.3. Discussion

As mentioned above, the TABLEFIT programme defined the undisturbed grassland as a Mesotrophic NVC type **MG5a** *Cynosurus cristatus - Centaurea nigra* sub-community *Lathyrus pratensis,* with goodness of fit 49 % (very poor). In this sub-community, legumes are prominent including *Lotus corniculatus* and *Trifolium* species, and grasses may have a substantial cover but often with poor growth (Rodwell, 1992). However, type MG5 communities are generally found on drought-free, mesotrophic to nutrient-rich soils with a pH of between 4.5 to 6.5. The soils of the undisturbed grassland were alkaline (pH 8.0 to 8.3), were low in available nutrients, and had a poor water-retaining ability (chapter five). The poor fit of the classification is further examplified by the presence of calcicoles - species which are characteristic of alkaline soils (Lane,1992), such as *Medicago lupulina* L., *Hypochoeris radicata, Linum catharticum* L. and *Hieracium pilosella.*

The TWINSPAN classification divided the grassland quadrats into two habitat groups, separating the grass areas from the mixed and predominantly herb-rich vegetated quadrats. The ordination indicated that substrate porosity, nutrient content, and occasional human disturbance may have been the main factors determining the establishment of plant communities. Species that have become established in the 'grass' areas include *Trifolium repens, Festuca rubra* and *Hypochoeris radicata,* and are species categorised by Grime (1979) as being C-S-R strategists - typical of habitats where competition, stress, and/or disturbance are constant features (Grime,1979).

Water stress affects plant physiological processes and may indirectly lead to reduced growth (Bannister, 1976). Reduced growth is also a consequence of nutrient deficiency. Plants may have become adapted to the particular conditions of the site by having a lower nutrient requirement; by being able to absorb nutrients more efficiently under conditions of low supply (Bannister,1976), and/or by being intrinsically slow-growing (Grime and Hunt, 1975). *Festuca rubra* and *Agrostis stolonifera* were the dominant grasses within the grassland, but neither has achieved a high biomass. According to Grime *et al.* (1988), dominance in stressed environments is associated with "conservative patterns of resource utilization". Other species present may not have been suffering from nutrient deficiency, as plants differ both in their requirements and in their capacities to absorb various nutrients (Bannister, 1976). The symbiotic fixation of atmospheric nitrogen by leguminous plants such as *Lotus corniculatus, Medicago sativa, Trifolium pratense* and *T.repens*, means that they can exist on nutrient-poor soils. Most grasslands in Britain are arrested communities in that grazing, cutting or burning prevents their progression, yet environmental conditions can also prevent rapid sucession (Lane, 1992). The stresses imposed by a shortage of water and available nutrients, coupled with the exposed situation, has lead to a species-rich community in which no single species has become dominant. The differences in the moisture-retaining ability of the soil (chapter five) has resulted in the slow succession of vegetation stages developing at different rates. Although the oldest successional stage was predominantly grass with occasional shrubs, the site was dominated by the species-rich mixed herb and grass community. The open herb community was a younger successional stage with bare ground patches largely of legumes (*Lotus corniculatus* and *Medicago lupulina*), and rosette herbs (*Hieracium pilosella* and *Taraxacum officinale* agg). The species were able to tolerate drought conditions because they had long tap-roots or were stoloniferous; they could tolerate low nutrient levels, or were nitrogen 'fixers'. The youngest successional stages were found on the disturbed mound areas and comprised ruderals such as *Cirsium vulgare* (Savi) Ten. and *Tussilago farfara.*

Although no major development appears to have existed on the grassland site, the area has been reportedly used for tipping garden waste (D.Muir, INCA, personal communication). Such past periods of occasional disturbance before the area was acquisitioned for the CATS Terminal could also account for the mosaic of successional stages present in the grassland.

According to Kirby (1992), a gradual transition between different habitats provides a greater number of ecological niches than a sudden transition. The vegetation of the grassland was predominantly mixed herb and grass cover, with no 'hard' divisions as defined by the TWINSPAN classification. The grassland contains a range of habitats with structural diversity increased by the absence of grazing or cutting. Grasses and herbs have been left to flower and set seed, and the different growth forms of the vegetation provide different microclimates suitable for the shelter and hibernation of invertebrates (chapter seven).

6.3.1. The influence of the reedbed on the composition of the herb-rich grassland.

The vegetation that has developed naturally on the site since the area was reclaimed includes stress-tolerant species of herbs and grass which are characteristic of dry, sandy, unproductive grasslands. The construction of the treatment reedbed and the associated intermediate and outfall ponds resulted in areas of disturbed ground which required seeding. The immediate effect of the reedbed on the site has been in the introduction of a disturbed habitat and also aquatic and marginal habitats.

The areas disturbed and re-graded in early 1997 were not treated with herbicides. Therefore, ruderal species from the existing soil seed bank could not be prevented from germinating. Small seeds, such as those of ruderals are typical of open, potentially dry situations where there numbers aid rapid colonization and their small size may ensure adequate contact with the supply of soil moisture (Bannister, 1976). The bare ground was rapidly invaded by species associated with frequent soil disturbance such as *Papaver rhoeas, Capsella bursa-pastoris, Senecio vulgaris* and *Polygonum aviculare,* although *Sinapis arvensis* and *Sisymbrium altissimum* L. were the most abundant species. *Conium maculatum,* once only a casual in northern-England, has increased in the industrial areas in Teesside since the 1960's along with *Diplotaxis tenuifolia* (Lawrence, 1994), and both were present in the seeded area. *Lactuca virosa* L. has spread rapidly since it was first recorded in Cleveland on industrial slag (Lawrence, 1994) and was noticably present on the disturbed site. Following the early flowering of *Sinapis arvensis* and *Sisymbrium altissimum*, species from the seed mix became established, and the amount of bare ground available for further weed invasion was reduced. However, the ruderal species present in the seeded area may invade bare-ground areas of the existing grassland in the future due to the prevailing south-westerly winds that cross the site. Previous studies comment on the limitations of dispersal of local native species (potential colonists) and that the establishment of native vegetation may be lengthy (Grey, 1982, cited in Davis, 1986). The seed mix was necessary to ameliorate the detrimental effect of germinating ruderal species on the existing grassland by influencing the composition of the vegetation.

Quadrats from the seeded area were not included in the NVC or multivariate analysis, as the fluctuations in species in newly created areas undergo considerable change, with ruderal species establishing rapidly before declining, and other species increasing from lower levels of abundance. Studies by Boyce (1995), on the establishment and composition of vegetation on land restored after open-cast coal mining, stress the importance of long-term monitoring on the change in species composition.

The species diversity of the grassland site has been increased by the youngest successional stage found in the seeded area. Species such as *Anagallis arvensis* L. and *Tripleurospermum maritimum* are ruderals that are likely to disappear once more permanent vegetation becomes established. The allocation of captured resources into flowers and seed is not compatible with the development of an extensive root and shoot system necessary for dominance and extended occupation (Grime *et al.*, 1988).

Introduced disturbance after a period of establishment results in a mix of ruderals and grassland species. According to Kirby (1992), the botanical (and invertebrate) interest of a site is increased if it includes an area of disturbed ground and ruderal plants. The successional management strategy of 'Introduced disturbance' has inadvertantly been achieved at the site by the introduction of the reedbed system.

Species diversity has also been increased by the introduction of *Phragmites australis* in the reedbed itself, and the marginal aquatic and submerged plants in the Intermediate Pond.

Absence of fish in the Outfall Pond has allowed the naturally colonising marginal and submerged vegetation to become established during 1997. The gently sloping northern margins of the outfall pond have unfortunately been invaded by *Elymus repens*, reducing the habitat value for wading birds. However, the grass provides a varied vegetation for damp-loving invertebrates. The marginal vegetation developing around the pools provides resting, feeding and hunting sites for adult insects emerging from the water (Kirby, 1992) (Plates 7 & 8), and for adult insects whose larvae are aquatic such as dragonflies (chapter seven).

The construction of the reedbed system has introduced both aquatic and marginal habitats to the site, increasing the botanical diversity of the site. The network of permanent quadrats will be valuable in monitoring change in the future.

CHAPTER SEVEN

7. INVERTEBRATE MONITORING

In order to determine the impact of the constructed reedbed system on the invertebrate diversity of the project site, a monitoring system was designed which could be repeated on a long-term basis. No previous invertebrate data had been produced for the site, therefore, surveys carried out during the present study formed a baseline with which to compare future data.

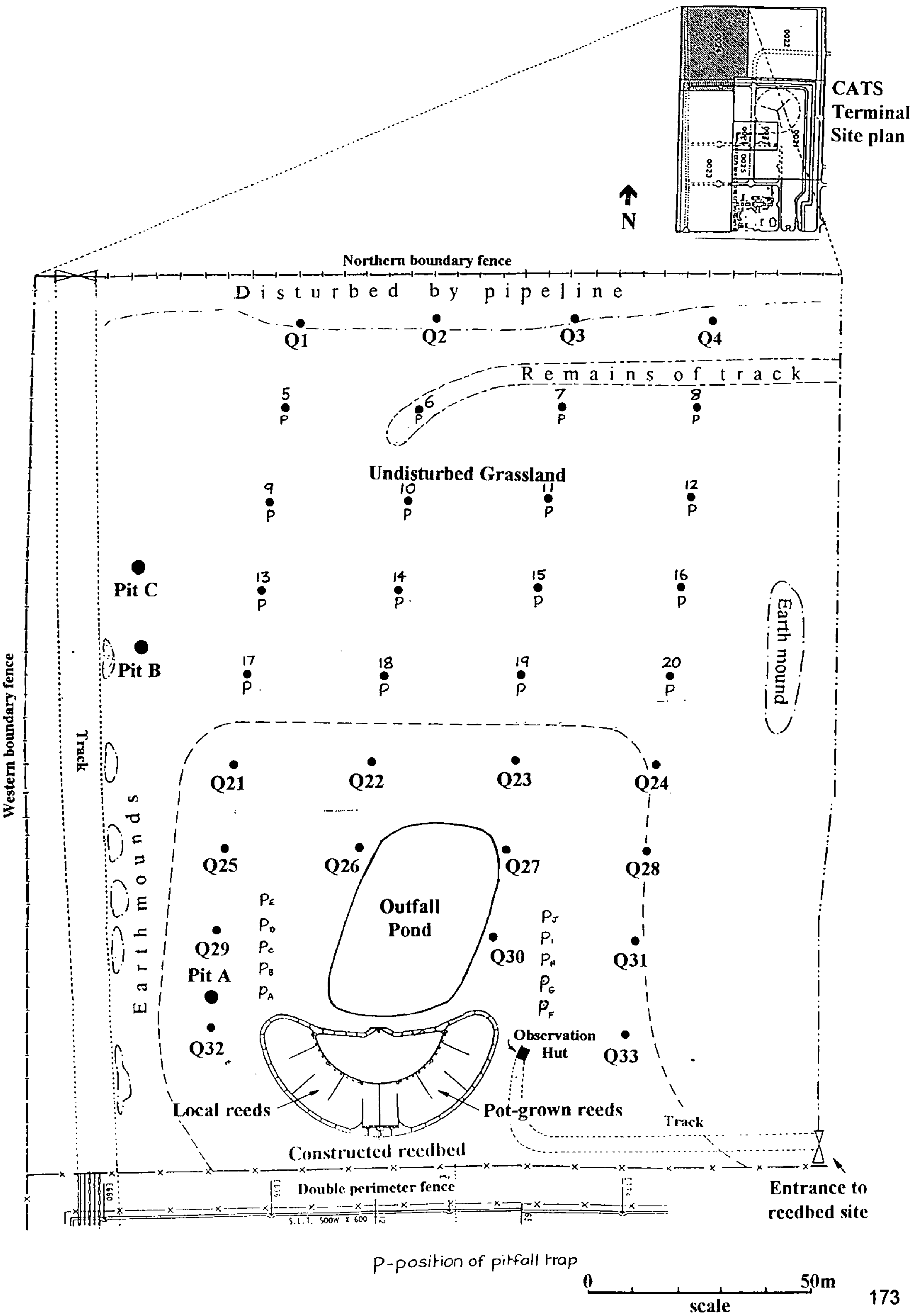
7.1. Methods

7.1.1. Grassland invertebrate sampling

Terrestrial invertebrates within the herb-rich grassland and re-seeded area were collected with the use of 26 pitfall traps, set for 14 days duration, on two separate occasions. Holes were made with a soil auger to allow the insertion within the grassland area of sixteen - 7 cm diameter plastic vending machine cups, the top of the cup being at ground level. The traps were filled to a depth of 5 cm with Ethylene glycol and 10 x 10 cm squares of chicken wire were secured over the surface of the traps to prevent mammal and amphibian captures. Within the grassland area, pitfalls were positioned one metre to the south of each of the permanent Quadrats 5 to 20 (16 pitfalls). Accurate positioning details will allow for comparative future studies (Plate 19). Quadrats 1 to 4 were situated on disturbed ground and were not sampled for invertebrates. Within the re-seeded area, 5 pitfall traps (A-E) were positioned 5 m apart forming a north-south transect to the east of the Outfall Pond. 5 further traps (F-J) formed a transect to the west of the pond. Figure 44 shows the locations of the 26 pitfall traps.

The pitfall traps were set on 13/5/97 and collected on 27/5/97, forming the late-spring sample, and between 24/6/97 to 8/7/97 forming the summer sample. The samples

Figure 44. CATS Terminal constructed reedbed and grassland site showing location of pitfall traps.



were collected and transferred to 70 % alcohol in labelled containers at the laboratory prior to identification.

7.1.2. Aquatic Invertebrate sampling

The Intermediate Pond and Outfall Pond associated with the reedbed, and the ICI No.6 brinefield reedbed pond were sampled for invertebrates between 13/5/97 and 9/7/97 on four occasions. A hand net with a mesh aperture size of 0.8 mm was held vertically in the water and 16 'figure-of-eight' sweeps were made directly above the bed of the pond. Three areas of each pond were sampled in this way and invertebrates from the net were collected and stored in 70 % alcohol.

7.1.3. Reedbed gravel invertebrate sampling

During the first season of growth in the reedbed it was not possible to employ standard methods such as flight-interceptor traps, to monitor the invertebrate population of the reedbed. A method was devised to collect the invertebrate species within the gravel in order to determine any differences between the inlet and outlet areas, and also to provide a baseline for later studies. A plastic cylindrical container with a capacity of 532 cm^3 was pressed into the gravel to contain the top 8 cm of material. A 10 cm x 10 cm piece of flexible plastic was used to isolate material and liquid within the container, and after removal from the reedbed, a screw top lid was attached. Three samples were taken at each of the inlet, pot-grown outlet and local reed outlet areas of the reedbed on 16/6/97, 2/7/97 and 16/7/97. On the day of collection, gravel samples were sorted within large white trays, and invertebrates stored in 70 % alcohol in labelled containers.

7.1.4. Invertebrate analysis

The invertebrates were sorted using a low powered, Nikon Stereoscopic microscope and identified, wherever possible to species and family level, using the invertebrate keys listed in the reference section. Abundances were recorded. Many of the corixids, coleoptera and chironomids were juvenilles during the sampling period and were difficult to identify to species level. Difficult species of adult Carabid beetles were identified by Dr.Martin Luff, and water beetles by Dr.Garth Foster. Due to the time constraints of the project, spiders were counted but not identified. Spiders from each pitfall were stored in 70 % alcohol in labelled containers and may be used in future monitoring.

7.2. Results

7.2.1. Grassland invertebrates

A complete list and abundance of invertebrates sampled is given in Appendix 3 for the undisturbed grassland area and Appendix 4 for the seeded grassland area. The taxa and abundance for both sampling periods have been combined in the lists and in analysis. The results therefore relate to a total trapping period of 28 days between 13/5/97 and 8/7/97.

7.2.1.1. The undisturbed grassland area

A total of 9092 invertebrates were collected in the 16 pitfall traps for the undisturbed grassland area, ranging from 48 specimens trapped in the pitfall associated with quadrat 6 (situated on a bare-earth track), to 1052 specimens in an area of predominantly grass near quadrat 9. Of the five pitfalls capturing the highest number of invertebrates, three were dominated by grasses.

Of the 56 invertebrate taxa caught, the most abundant species identified was *Armadillidium vulgare* (Latreille) (Isopoda) accounting for 67 % of specimens collected, and present in all of the pitfall traps. Araneae (spiders) accounted for 16 % of the specimens caught, and were also found in all pitfall traps, but were not identified to species. Two species of Hymenoptera, *Lasius niger* (Linne) and *Myrmica ruginodis* Nylander were caught in all of the pitfall traps, and accounted for 7 % of specimens caught. The most diverse order of invertebrates captured in the pitfalls were Coleoptera, accounting for 3 % of specimens caught. 19 Carabid (Coleptera) species were identified, including species with a prefererence for dry, sandy ground such as *Amara aenea* (Degeer), *Amara tibialis* (Paykull), *Bradycellus harpalinus* (Serville), *Calathus fuscipes* (Goeze), *Calathus melanocephalus* (L.), *Olisthopus rotundatus* (Paykull) and *Trechus obtusus* Erichson. One specimen of a species categorised by Ball (1987) as "Notable b" (thought to occur in 100 or fewer 10 x 10 Km squares in Britain), *Calathus ambiguus* (Paykull), was caught in a pitfall (quadrat 7) in an area dominated by herb-rich vegetation. Previously identified in Coatham Sands, 6 Km to the north-east of the site (Ball, 1987), the ground beetle prefers sandy or chalky places, under stones and leaf rosettes.

7.2.1.2. The seeded area

A total of 370 invertebrates (Appendix 4) were collected in the 10 pitfall traps set in the seeded area. The pitfalls collected between 23 to 61 specimens from 36 different taxa. Hymenoptera, *Lasius niger* and *Myrmica ruginodis* were the most abundant species caught in the traps accounting for 31 % of the total, whereas Coleoptera were the most diverse order accounting for 25 % of taxa caught.

7.2.1.3. Multivariate analyses of the undisturbed grassland

Detrended Correspondence Analysis (DECORANA) was used to ordinate the samples and species in order to identify any ecological gradients determining the distribution of individuals within the grassland. There was no downweighting of rare species, but where a species was present in only one quadrat, it was not included in the ordination (except for carabids). Due to the high and varied numbers of invertebrates collected in the pitfall traps, the species counts were transformed as follows:-

Present in pitfall	Transformed value
1	1
2-10	2
11-100	3
101-999	4
>1000	5

Eigenvalues and variance explained by DECORANA axes 1 to 4 are given in the following table.

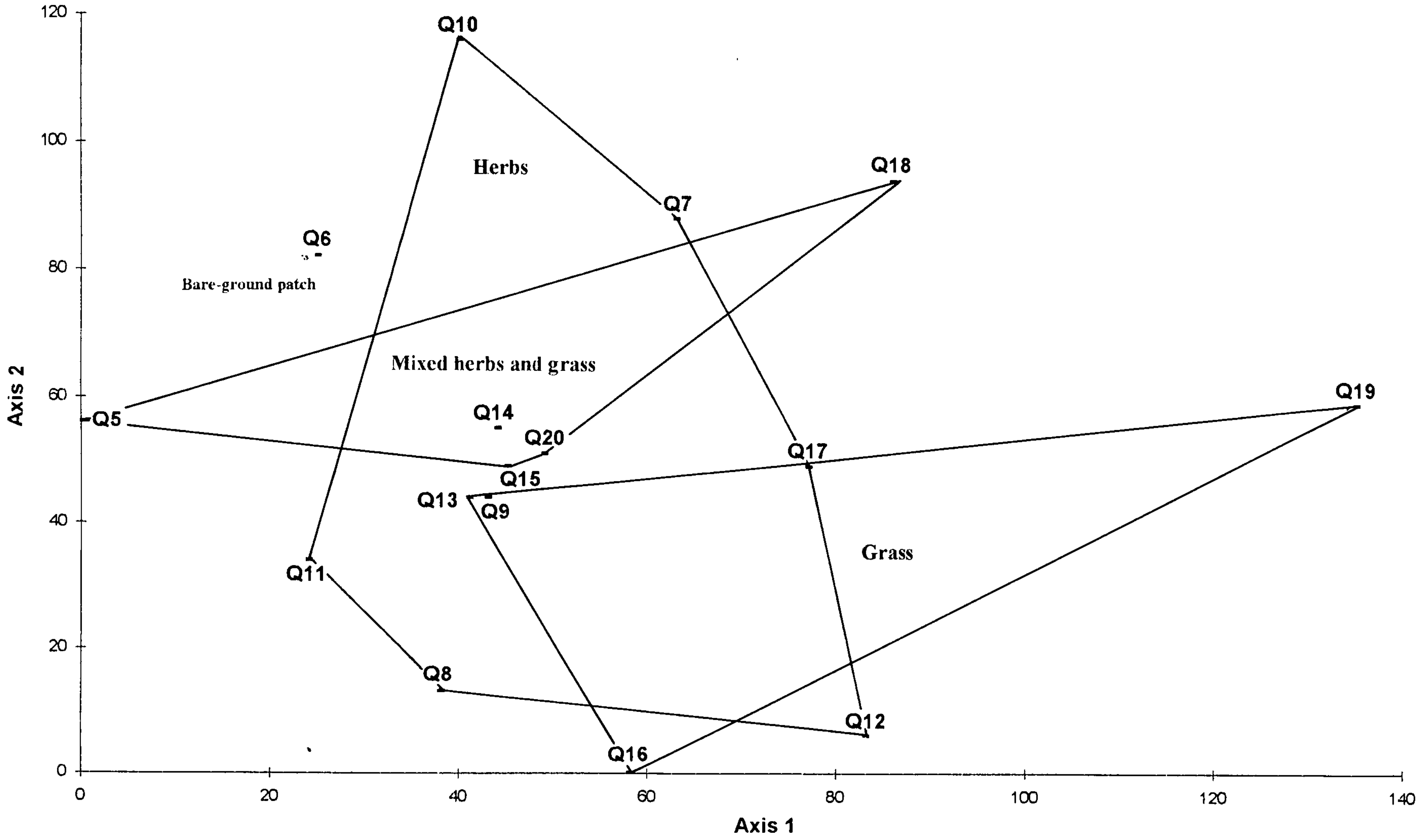
Table 12. Eigenvalues for DECORANA axes generated by analysis of invertebrates collected in pitfall traps for grassland quadrats 5 to 20, at the CATS Terminal grassland, on 27/5/97 and 8/7/97.

DECORANA axis	Eigenvalue	Variance explained
Axis 1	0.1235	44 %
Axis 2	0.0935	33 %
Axis 3	0.0421	15 %
Axis 4	0.0223	8 %

*The variance explained was calculated by dividing the eigenvalue of each axis by the sum of the eigenvalues of all four (Jeffries, 1989).

Axes one and two explained 77 % of the variation and Figure 45 gives the resulting DECORANA ordination of the pitfall quadrats using the first two axes. The quadrats were well distributed with no sign of separation into groups. According to Foster *et al.*(1992), the easiest way to interpret the ordination is by examining the 'sites' occupying the extremes of each axis. Quadrat 19 was located at the higher end of axis one and Quadrat 5 at the lower end of the axis. The pitfall associated with quadrat 5 caught the highest number of ants, (26 % of the total caught) and also the highest number of *Forficula auricularia* (L.) (Dermaptera), whereas the pitfall associated with quadrat 19 collected only one specimen of *Forficula auricularia* and relatively few ants. Axis 1 may be related to density of vegetation cover, with species such as *Forficula auricularia*

Figure 45. DECORANA ordination plot (axis 1 by axis 2) of the CATS Terminal reedbed associated undisturbed grassland quadrats on the basis of invertebrate species data. Polygons based on 3 vegetation types identified visually on site.



preferring open areas, being more active in quadrats towards the lower end of the axis. However, polygons based on the three vegetation types identified visually on site (chapter six), shown superimposed in the ordination (Figure 45), did not separate any groups clearly, indicating that distinctly different habitats could not be determined.

Figure 46 shows the ordination of invertebrate taxa. Data are ordinated so that the least similar taxonomic associations are placed at either end of an axis, thus identifying any ecological gradient which may be present (Rushton, 1987). However, within the ordination, the taxa located towards the extremes of axes 1 and 2 were all typical of invertebrates found in dry, sandy, grass habitats. These outliers were collected in relatively few quadrats, whilst invertebrates collected in many of the pitfalls were located closer in ordination space. It therefore appears that all invertebrates moved freely within the grassland and no separate species assemblages were detected.

Ordination of Carabid species.

The species of Carabid beetles were ordinated by DECORANA in order to determine the presence of a gradient which might explain differences in species location. Transformation or downweighting of data were not applied in the ordination of Carabid species and quadrats 6 and 9 were excluded as Carabids were not present in these pitfall traps on either sampling occasion. Eigenvalues and variance explained by DECORANA axes 1 to 4 are given in the following table.

Figure 46. DECORANA ordination plot (axis 1 by axis 2) of invertebrates collected in pitfalls at the CATS Terminal grassland quadrats

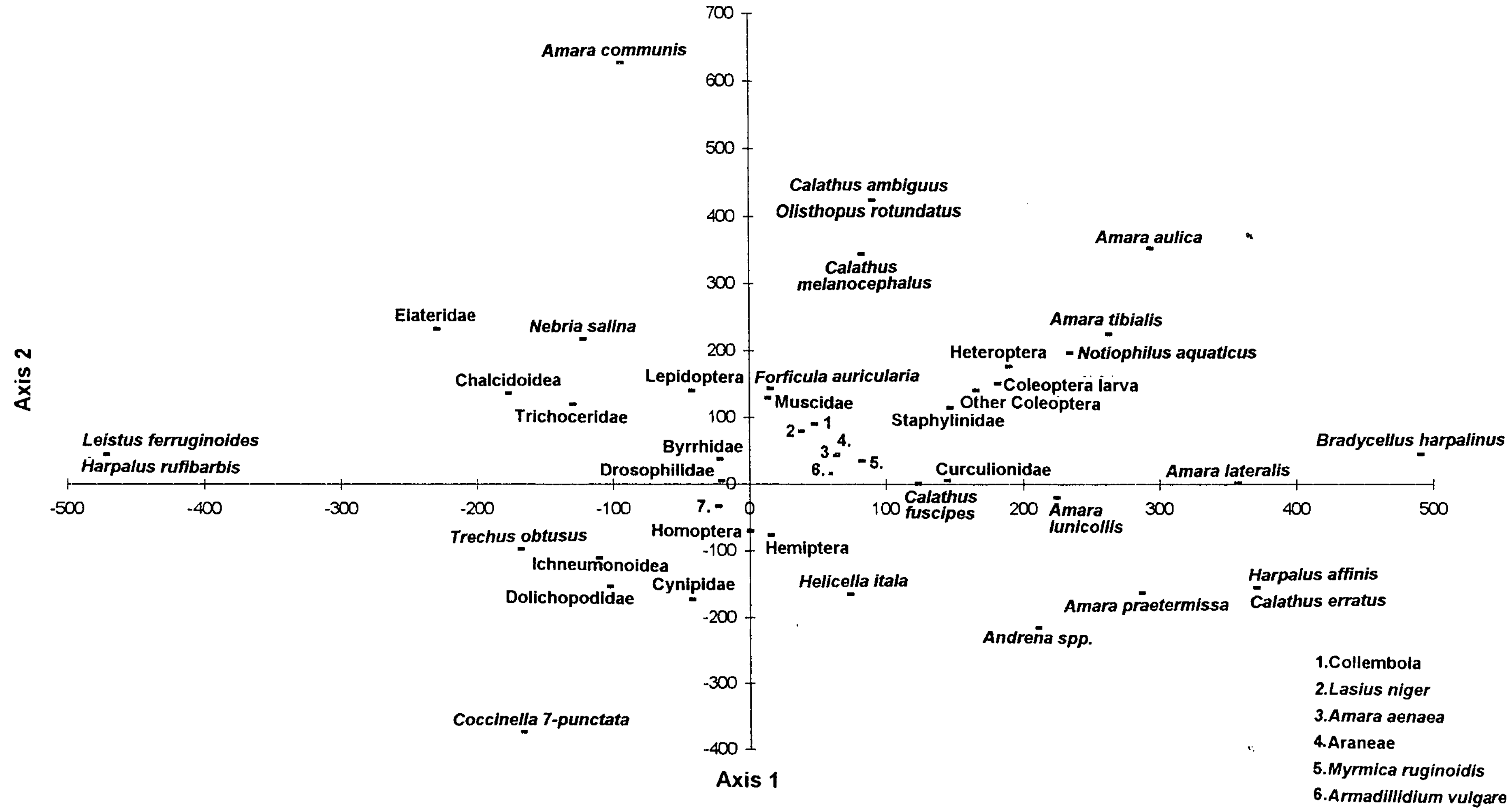


Table 13. Eigenvalues for DECORANA axes generated by analysis of Carabid species, collected in pitfall traps for grassland quadrats 5 to 20, at the CATS Terminal grassland, on 27/5/97 and 8/7/97.

DECORANA axis	Eigenvalue	Variance explained
Axis 1	0.4502	59 %
Axis 2	0.2064	27 %
Axis 3	0.0826	10 %
Axis 4	0.0234	4 %

Axes one and two explained 86 % of the variation and Figure 47 gives the resulting DECORANA ordination of the pitfall quadrats based on the Carabid species collected using the first two axes. The ordination includes polygons based on the three vegetation types identified visually on site (chapter six). The gradient explained by the first principle axis may be one of decreasing cover as quadrats positioned in predominantly grassy areas were located towards the lower end of the first principal axis, and quadrats situated in areas of patchy bare ground and short-herb vegetation were located towards the higher end of the axis. The quadrats which lay closest together, towards the centre in DECORANA space were those situated in areas of mixed grass and herb vegetation.

Figure 48 shows the ordination of Carabid species data. Most of the species present could typically be found in dry, sandy soils in open grassland habitats and were either predators or seed-eaters, and it was not possible to relate either axis one or axis two to any environmental parameter. Species may have been able to move around more freely within the short, herb-rich vegetation, but the pitfall data suggests that the carabid populations were active in all areas of the grassland.

Figure 47. DECORANA ordination plot (axis 1 by axis 2) of the CATS Terminal reedbed associated undisturbed grassland quadrats on the basis of Carabid species data. Polygons based on 3 vegetation types identified visually on site. (Quadrats 6 and 9 excluded)

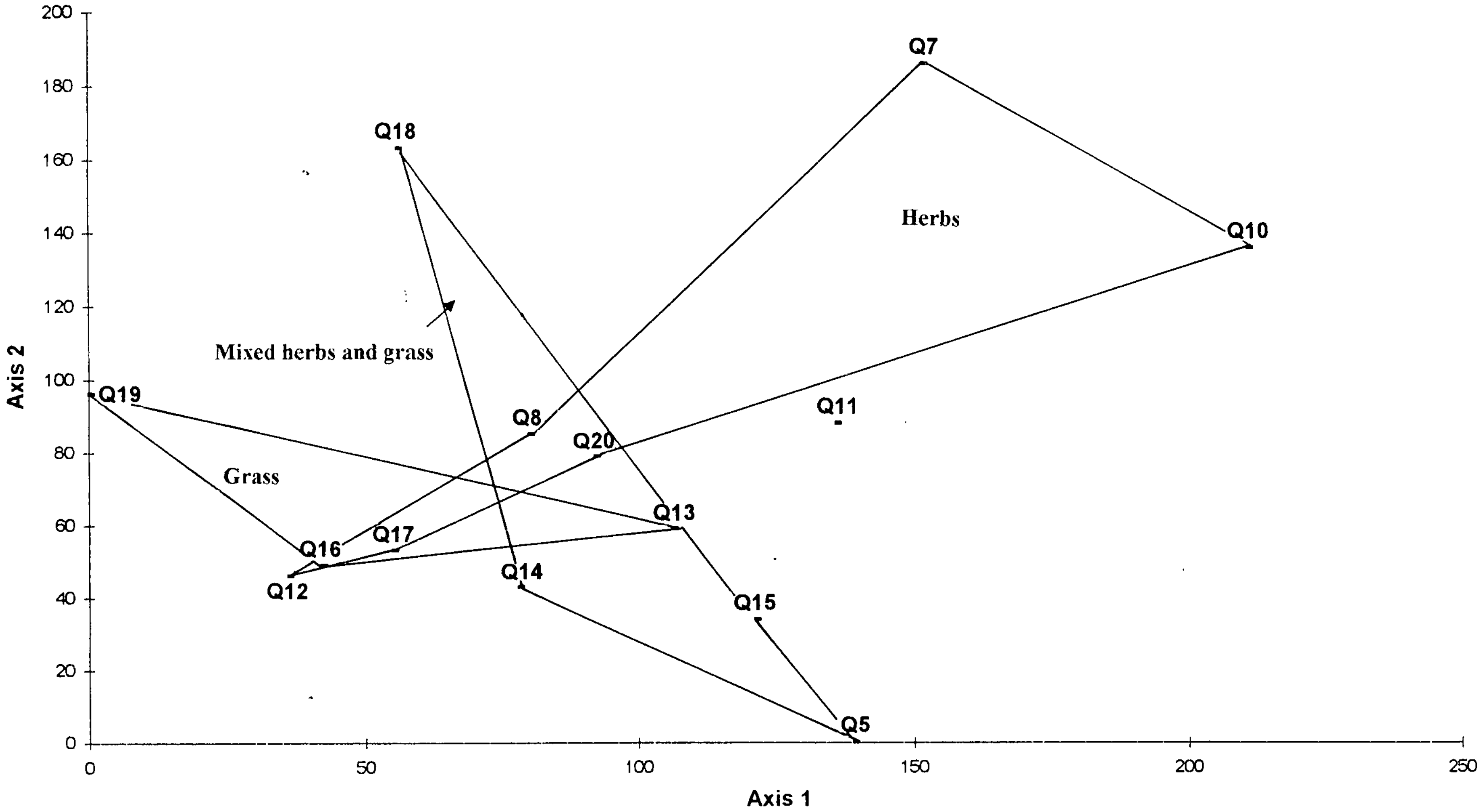
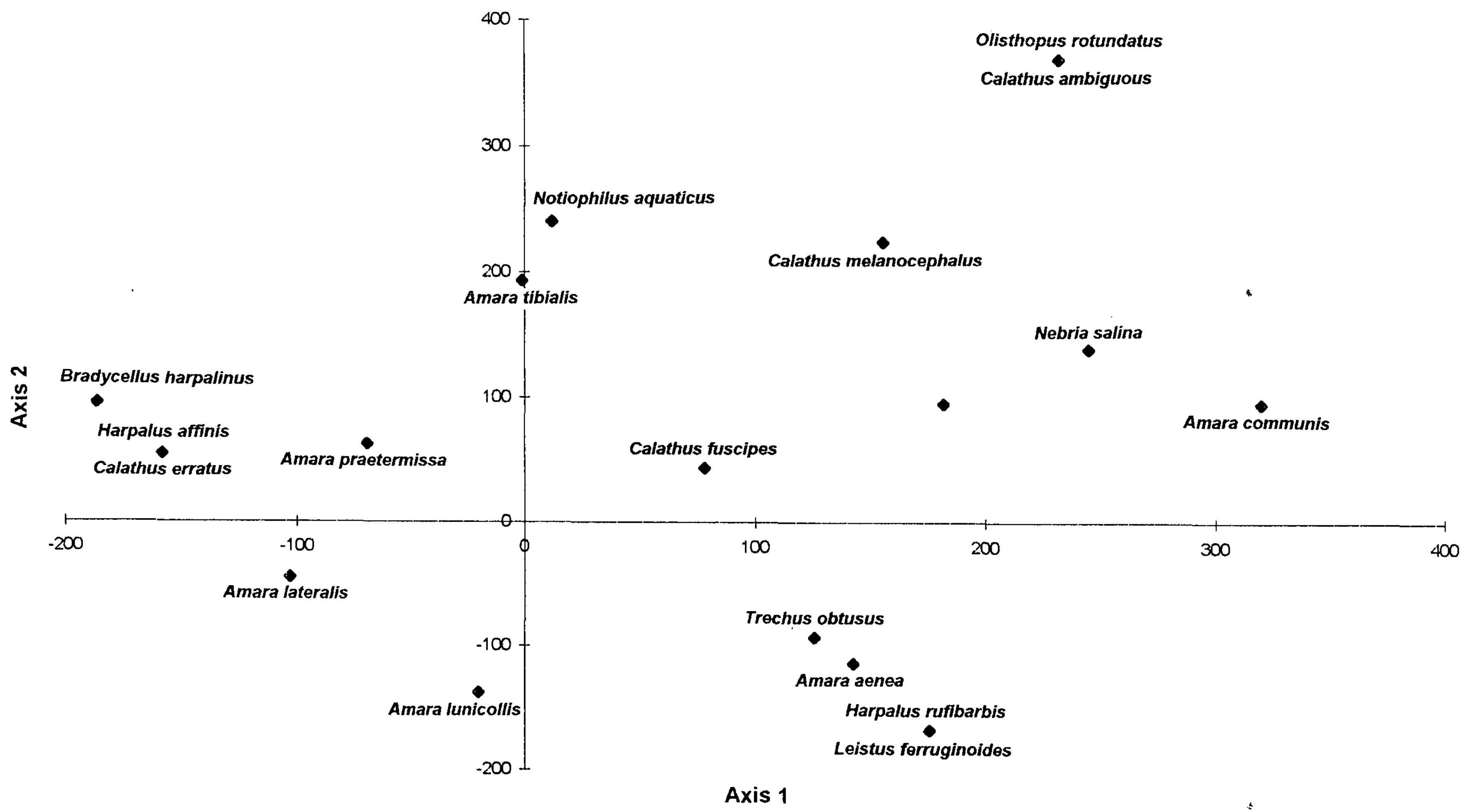


Figure 48. DECORANA ordination plot (axis 1 by axis 2) of Carabids collected in pitfalls at the CATS Terminal grassland quadrats.



7.2.2. Pond invertebrates

A comparison of physical and chemical properties of the reedbed system ponds and the ICI No. 6 brinefield pond, can be made with reference to Table 14.

Table 14. Age, and mean DO, pH and conductivity values of the Intermediate and Outfall Ponds at the CATS Terminal and the ICI No.6 brinefield pond, between February to July 1997. (n=3 for each sample tested on each sampling occasion)

	Int. pond	Outfall pond	ICI pond
Age of pond when sampled	6 months	1 years	>10 years
Dissolved oxygen (mg l^{-1})	8.23	10.15	10.68
pH	8.01	8.10	8.44
Conductivity (µS cm^{-1})	1189	930	4156

The ICI No.6 brinefield pond was consistantly saline during the monitoring period, while the Intermediate Pond and Outfall Pond contained brackish water. The brinefield pond was an established water body, while the Intermediate and Outfall ponds were relatively immature as wetland habitats. Both the differences in conductivity and age could influence the invertebrate composition and diversity of each pond.

A complete list and abundance of invertebrates sampled is given in Appendix 5. *Daphnia magna* Straus (Cladocera) were so abundant in the Intermediate and Outfall ponds that it was not attempted to count specimens. Over 772 invertebrates were sampled from 9 different taxa during the monitoring period in the Intermediate Pond; over 590 invertebrates from 11 taxa in the Outfall Pond, and over 132 invertebrates from 14 taxa were sampled in the ICI No.6 brinefield pond.

Table 15 shows a list of all invertebrates identified to species level during the monitoring period, plus the richness and diversity indices calculated from the data. Chironomidae were treated as a single 'species' in the analysis.

Table 15. Abundance of species collected from the Intermediate and Outfall Ponds at the CATS Terminal, and the ICI No.6 brinefield pond, on 13/5/97, 12/6/97, 25/6/97 and 9/7/97.

				ICI	I.pond	O.pond
ORDER	FAMILY	GENUS/SPECIES	Life-stage			
Pulmonata	Limnaeidae	*Limnaea pereger*		46		
		Limnaea truncatula		11		
Odonata						
sub-order Anisoptera	Libellulidae	*Sympetrum striolatum*	Nymph	1		
sub-order Zygoptera	Coenagrionidae	*Ishnura elegans*	Nymph	7		
Trichoptera		*Agrypnia spp.*	cased	1		
Hemiptera	Corixidae	*Callicorixa praeusta*	Adult			1
		Corixa punctata	Nymph		13	
		Sigara concinna	Adult			4
		Sigara lateralis	Adult	5	6	12
Coleoptera	Carabidae	*Bembidion* spp.	Adult	1		
	Dytiscidae	*Agabus nebulosus*	Adult		1	3
		Hydroporus planus	Adult		4	1
		Hygrotus confluens	Adult		2	6
		Hygrotus inaequalis	Adult	2		
	Haliplidae	*Haliplus apicalis*	Adult	20	4	5
Diptera						
sub-order Nematocera	Chironomidae	*species 1 (pale)*	all	10	265	9
Cladocera	Daphniidae	*Daphnia magna*		>10	>100	>100
Total number of species sampled				**11**	**8**	**9**
Total number of invertebrates collected				**114**	**395**	**141**
Species richness-Margalef's diversity (D_{mg})				**2.11**	**1.17**	**1.62**
Species diversity-Shannon diversity (H')				**H'=-1.83**	**H'=-0.93**	**H'=-1.03**
Species equitability-Shannon equitability (E)				**E=0.76**	**E=0.45**	**E=0.47**

In the Intermediate Pond, Chironomidae and Corixidae were the most abundant invertebrates collected apart from *Daphnia magna*. Four species of aquatic Coleoptera from the families Dytiscidae and Haliplidae were collected, as were two species of Corixidae (Hemiptera).

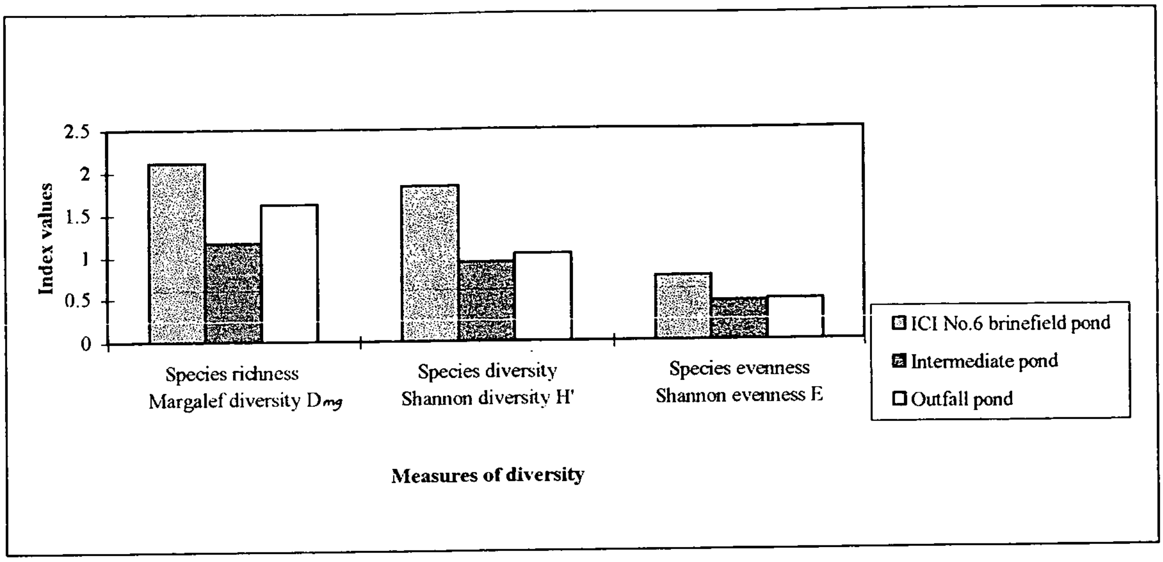
In the Outfall Pond nymphs of Corixidae were the most abundant invertebrates collected apart from *Daphnia magna*. Four species of aquatic Coleoptera were collected (the same species as in the Intermediate Pond), and three species of Corixidae (Hemiptera) were found - the species *Sigaria lateralis* (Leach) being found also in the Intermediate Pond. Nine individuals of Chironomidae (Diptera) were also collected.

In the ICI No.6 brinefield pool, Molluscs were the most abundant group accounting for 50 % of the invertebrates sampled. Odonata, Corixidae (Hemiptera), aquatic Coleoptera, Trichoptera, and species of Chironomidae (Diptera) were also present in low numbers. *Daphnia magna* (Cladocera), were also abundant.

Of the nine species sampled in the Intermediate and Outfall Ponds, 7 (78 %) were common to both pools. Of the 15 species sampled in the Intermediate Pond and the ICI No.6 brinefield pond, four (27 %) were common to both pools, and of a total of the sixteen species sampled in the ICI No.6 brinefield pond and the outfall pond, four (25 %) were common to both pools. The four species common to all three pools were *Sigara lateralis* (Hemiptera), *Haliplus apicalis* Thomson (Coleoptera), Chironomidae spp. (Diptera), and *Daphnia magna* (Cladocera).

It can be seen from Table 15 and Figure 49 that the highest species richness, diversity and evenness were recorded in the longest established pond, the ICI No.6 brinefield pond. The lowest species richness, diversity and evenness were recorded in the youngest pond, the Intermediate Pond. The three ponds were significantly different ($p < 0.001$) in terms of the diversity of invertebrates occuring in them, the ICI pond was more diverse than the CATS Terminal ponds.

Figure 49. Species richness, diversity and evenness of invertebrates collected at the ICI No.6 brinefield pond, and at the Intermediate and Outfall ponds at the CATS Terminal. (Data represent samples taken on 13/5/97, 12/6/97, 25/6/97 and 9/7/97)



7.2.3. Reedbed gravel invertebrates

A complete list and abundance of invertebrates collected, is given in Appendix 6. Table 16 shows the total gravel invertebrates collected (x 3) from the inlet section and the pot-grown and local reed outlet sections of the CATS Terminal reedbed, on three occasions on 16/6/97, 2/7/97, and 16/7/97.

Table 16. Total invertebrates collected (n=3 for each sample) on 16/6/97, 2/7/97, and 16/7/97, in gravel, at the inlet, local reed outlet, and pot-grown reed outlet sections of the CATS Terminal reedbed

ORDER	FAMILY	GENUS/SPECIES	Life-stage	Inlet	LR outlet	PG outlet
	Lumbricidae	*Dendrobaena octaedra*		4		
Odonata						
sub-order Zygoptera	Coenagrionidae	*Ischnura elegans*	Larva			1
Hemiptera	Aphididae					2
sub-order Polyphaga	Chrysomeloidae		Adult	1		
Thysanoptera	Thripidae					1
Coleoptera	Hydrophilidae	*Helophorus aequalis*	Adult	1		
		Helophorus rufipes	Adult		1	
	Coccinellidae	*Coccinella 7-punctata*				1
			Larva	1		
Diptera			Pupa			
sub-order Nematocera	Chironomidae	*species 1 (pale)*	Larva	118	57	
			Pupa	3	1	
		species 2 (dark)	Larva	17	62	13
			Pupa		5	6
			Adult	3		
	Tipulidae		Larva		2	
sub-order Cyclorrhapha	Muscidae		Adult		3	
		species 1	Pupa	21	11	7
		species 2	Pupa	1		
Hymenoptera						
sub-order Apocrita	SF-Formicoidea	*Lasius niger*			2	

A total of 182 invertebrates were collected from 9 different taxa during the monitoring period in the inlet section of the reedbed; 174 invertebrates from 6 taxa in the local reed outlet section, and 31 invertebrates from 6 taxa were collected in the pot-grown reed outlet section of the reedbed.

Diptera were the dominant invertebrate group with Chironomid larvae being most abundant. Chironomids were not identified but there appeared to be at least two species collected, referred to as 'light' and 'dark' in Table 16. Chironomids accounted for 77 % of the total number of invertebrates collected in the inlet section of the reedbed, 73 % of the total collected in the local reed outlet section, and 61 % of invertebrates collected in the pot-grown outlet area of the reedbed. The highest number of chironomids (98), were collected in the inlet section of the reedbed gravel on 2/7/97. Other aquatic invertebrates collected included 43 specimens from at least three species of Muscidae, 4 Lumbricidae, 4 Coleoptera, 1 Odonata, 1 Corixidae, 1 Tipulidae and 2 *Lasius niger* (Hymenoptera).

Differences between the inlet and outlet sections of the reedbed

As wastewater passed through the reedbed, the organic and nutrient content of the water was significantly reduced (chapter 3). However, although the organic content was reduced throughout the reedbed, dissolved oxygen levels remained low due to inorganic nitrogen transformations. Therefore, biotic indices would not be relevant to compare the water quality between the inlet and outlet areas, as cleaner water 'indicator' species would be unlikely to tolerate low dissolved oxygen conditions. Chironomid species are generally tolerant of low dissolved oxygen conditions and in addition are able to exploit any organic matter in the reedbed gravel. Although the total Chironomids collected were similar in the inlet and local section of the reedbed, few were collected in the pot-grown half of the reedbed. Organic deposition from the Klargester in the inlet section of the reedbed may also account for the presence of the Lumbricidae *Dendrobaena octaedra* (Savigny), a surface-dwelling worm often found associated with dung and occasionally limnic (Sims & Gerard, 1983).

Differences between the pot-grown and locally transplanted sections of the reedbed

The quality of the water in both the local reed and pot-grown outlet sections of the reedbed was not statistically different (chapter 3). However , it can be seen from Table 16, that although the number of different taxa caught in each outlet area was the same (6), relatively few invertebrates were caught in the pot-grown outlet (31) compared with invertebrates caught in the local reed outlet gravel (174), although this was mostly due to lower numbers collected of the dominant group, Chironomids.

The sampling method collected surface dwelling invertebrates such as *Coccinella 7-punctata* L. (Coleoptera, Coccinellidae) and Aphids (Aphididae), predator and prey respectively. Aphids were noticably abundant during the summer months, after the monitoring ceased, feeding on the reeds.

The results refer to the first four months growth of reeds after establishment only. The reeds themselves were not sampled for invertebrates as this would have damaged them unacceptably.

7.3. Discussion

7.3.1. Grassland invertebrates.

It is accepted that pitfall traps do not catch a representative sample of the fauna within a habitat because some groups are more likely to be caught than others (Greenslade, 1964; Southwood, 1978, & Disney, 1986). However the base line survey of terrestrial invertebrates was undertaken using pitfall traps as they provided a convenient and easily repeatable method of investigating the ground dwelling inhabitats of the grassland. Sweep nets and Flight Interceptor Traps (FIT's) could be used in the future to collect invertebrates present in the upper canopy of the vegetation.

The botanical composition of the site achieved low biomass due to the exposed position and the excessively drained, nutrient poor substrate. As with the plant species found on the site, many of the invertebrates sampled were species adapted to drier habitats.

Isopods were the most abundant order of ground invertebrate within the grassland. *Armadillidium vulgare* are a species adapted to drier habitats, and often confined to calcareous grassland (Curry, 1994). A total of 3 *Armadillidium vulgare* were caught in the bare-earth track quadrat (Q6), whereas a total of 868 individuals were trapped in the same period in the pitfall associated with quadrat 9, in a predominantly grass area. The vegetated areas provided protection from desiccation and abundant organic matter for food. The millipede *Julus scandinavius* Latzel, is generally found in drier habitats than the flat millipedes (Polydesmoidea) (Curry, 1994), and was present in 11 of the 16 quadrats.

Spiders (Araneae) were very abundant and active within the vegetation. The grassland has not been managed by grazing or cutting, and the vegetation has a complex structural architecture suitable for web attachment. Curry (1994), suggested that the reduction in sward complexity associated with grazing has a pronounced effect on the number of spiders present. Within the site, only 5 spiders were caught during both trapping periods in the pitfall associated with quadrat 6, situated on a bare-earth track. Whereas a total of 122 spiders were trapped over the same period in pitfall 9, in an area of dense grass cover.

Although not achieving a high biomass or height (the grass swards rarely exceeded 0.4 m in height), the unmanaged grassland provided a variety of structural habitats for the different invertebrate requirements. Grass stems are the larval habitat of a number of Diptera and according to Morris (1969), ungrazed grasslands have more potential oviposition sites. Tussocks of the rank grass *Dactylis glomerata* L. are common within the grassland and Luff (1966, cited in Curry, 1994) found a greater density of beetles in tussocks of *Dactylis glomerata* and *Deschampsia cespitosa* (L.) Beauv. than occurred between tussocks. The difference was particularly marked in winter, reflecting the more favourable temperature and humidity conditions within the tussock during dry, warm lived (Eyre *et al.*, 1986). Because of their relative abundance and diversity, Coleoptera would be a suitable group to monitor in future.

7.3.3. Reedbed gravel invertebrates

The relatively high number of Chironomid larvae (84) sampled in the inlet section of the reedbed gravel on 2/7/97 were likely to have been flushed from the Klargester along with the re-suspended sludge on 1/7/97 (chapter two). Unfortunately, due to difficulty in identification of the larvae, the Chironomids were not identified to species level, but were clearly tolerant of poorly-oxygenated conditions.

It is generally accepted that sub-surface treatment wetlands support fewer aquatic-based invertebrates when compared to surface-flow wetlands (Knight, 1997). Few invertebrates were caught in the pot-grown outlet section gravel compared with invertebrates caught in the local reed outlet. The local reeds were transplanted into the reedbed gravel with soil from their original pond, which probably contained invertebrate species.

The 1997 study of the reedbed gravel was undertaken whilst the reeds were becoming established, in order to determine the first macro-invertebrate colonizers of the bed, and in addition, whether any differences in invertebrate composition between the inlet and outlet sections of the reedbed could indicate an improvement in water quality. However, although organic pollution-tolerating Chironomids were present in the inlet section, and although the water quality improved as it passed through the reedbed, very low levels of dissolved oxygen in the water proved inhospitable to 'cleaner water' indicator organisms.

In the future, as litter begins to accumulate on the surface of the gravel, any differences betwen the inlet and outlet areas of the reedbed associated with improvements in water quality are likely to be masked by the similarity in decomposer invertebrates within the litter. Ditlhogo (1992) used water traps to collect above-ground invertebrates within a reedstand at Hickling Broad, Norfolk, and found that the traps mainly contained Diptera.

Flight Interception Traps (FIT's) were successfully used to monitor the invertebrate populations of the ICI Billingham Treatment Reedbeds by Jessop in 1993, 1994, and 1995 (Jessop, 1997). The three year study of two beds in the reedbed complex provided valuable data on the colonisation of reedbeds by invertebrates and specifically on the range of beetle species inhabiting reedbeds. The ICI treatment reedbeds were planted in 1991 and the reeds were therefore well established before monitoring began. FIT's could be considered for monitoring at the CATS reedbed in the future.

7.3.4. The influence of the reedbed on the species richness and composition of the invertebrates of the site within a herb-rich grassland.

Short-term cyclical changes in species composition and relative abundance are associated with changes in the weather, seasonal cycles of growth and the life-histories of species in the community (Luken, 1990). However, the changes in species composition and community structure associated with succession are more marked (Curry, 1994). Primary succession - the process of change in the composition and structure of the community that develops when a new habitat becomes available for colonisation (Curry, 1994) has been taking place in the recently created wetland habitats. Not in terms of the flora, which have been planted, but in terms of the invertebrate populations which have, and are, naturally colonising the site. Secondary succession - where a previous community has been disrupted is taking place in the seeded area. As with plant succession, the rate and extent of faunal establishment depends on the suitability of the site and the proximity of suitable colonisers (Southwood, 1977). The ICI Billingham Treatment Reedbeds, like the CATS Terminal Reedbed, were constructed wetlands, superimposed on undeveloped (dry) land. Yet according to Jessop (1997), the *Phragmites* beds at Billingham were rapidly colonised by wetland invertebrates. Aquatic invertebrates have probably colonised the Intermediate Pond during 1997 from the Outfall Pond, however, the mosaic of wetlands to the north, west and south of the CATS Terminal are all potential sources of invertebrates, and future colonosation from these sources will continue.

The successional changes in the botanical composition of the seeded grassland adjacent to the reedbed site may be paralleled by changes in the invertebrate community, although the use of areas of bare-ground by invertebrates in the first year after creation was suprisingly low. The variation in the stage of succession between the seeded area and the undisturbed grassland and within the undisturbed grassland (chapter 6), will serve to increase the invertebrate diversity of the site. An extra source of diversity will develop as the margins of the Outfall Pond increasingly favour invertebrates which inhabit emergent aquatic vegetation and damp-substrates.

The reedbed has become established during the summer of 1997, and although monodominant stands of *Phragmites* have low botanical diversity, the invertebrate interest of the habitat can be high (Ward, 1991). Studies in East Anglia by Foster & Procter (Fojt & Foster, 1991) have recorded over 700 species of invertebrates from reed dominated plant communities. At least 64 species of British insects are reported to feed on reed during at least one stage of their life-cycle, although not all are solely dependent upon reed, having alternate host plants. For example, eleven species of moth (Lepidoptera) are known to have larval stages feeding only on reed (Fojt & Foster, 1991). Non-phytophagous invertebrates are also associated with reedbeds, either predators such as beetles and spiders, or parasites such as gall-forming flies and solitary wasps - or they may be detritivores found in the developing litter layer and dead reed stems (Burgess *et al,* 1995). Such an environment is likely to develop within the CATS Terminal reedbed, as it is not planned to harvest the reeds. Simply by leaving the dead stems and not cutting back promotes greater species diversity and encourages species which overwinter on or inside the reed in non-mobile stages of their life-cycle (Fojt & Foster,1991).

Aphids thrive when the cell sap in plants has high levels of soluble nitrogen. The leaf tissue of the CATS Terminal reeds contains comparatively high levels of total nitrogen (chapter four) and although not sampled, it was clear that aphids became abundant on the reeds as the summer of 1997 progressed. It is suggested (K.Smith, INCA, personal communication) that high nitrate concentrations in reed tissue in the ICI Billingham Treatment Redbeds stimulated aphid population growth during August and September of 1993, and 1995. Aphids may attract birds during the late summer-early autumn, and they form the main prey item for Reed warblers. The superabundance of aphids at the ICI Billingham Treatment Reedbeds may explain the significant numbers of Reedwarblers breeding at the site (K.Smith, personal communication). Aphids feeding on the reeds at the CATS Terminal should attract predators such as *Forficula auricularia* (Dermaptera) and *Coccinella 7-punctata* (Coleoptera), already present within the grassland but only in small numbers.

Many of the invertebrate species present within the existing grassland are those which tolerate dry conditions. The introduction of the wetland habitats associated with the reedbed will increase the habitat diversity for a wider range of invertebrates both in terms of moisture regime and structural niches, as well as the range of food resources available (Knight, 1997). The survey of the ICI treatment reedbeds (Jessop, 1997) recorded 50 species of beetle with a preference for damp and marshy substrates, despite the lack of a surface water component at the treatment reedbeds.

The baseline survey has helped to compile a list of taxa for each of the newly created wetland habitats, the existing grassland and the seeded grassland area. The lists are not exhaustive but give an indication of the taxa present in each habitat. It also helped to identify which taxa will be most useful in future monitoring. Rather than sample all of the invertebrates on the site, selective sampling of the Coleoptera and Corixids in the ponds; Carabids and Araneae in the grasslands; and Aphids in the reedbed, could be used to determine the long-term influence of the reedbed on the invertebrate diversity of the site.

The development of invertebrate communities may eventually influence the activities of birds and mammals within the site, which are the subject of the following chapter.

CHAPTER EIGHT

8. SMALL MAMMALS & BIRDS

An ornithological survey of the whole of the CATS Terminal site was undertaken in August,1990, by Environmental Resources Limited (ERL), before the site was developed, in order to assess the impacts of the proposed plant. It was reported that the area was not of high ornithological interest, compared to the nearby Seal Sands mudflats, and although migrant species passed through the site, the grassland habitat would not be likely to hold many species (Anon, 1990). It was hoped that the introduction of the reedbed and permanent wetland areas would increase the habitat value and species diversity of birds and small mammals at the site. Surveys of birds and small mammals within the reedbed system and associated grassland area during the present study, will serve as a baseline, to compare species composition and diversity in the future, due to the introduction of the reedbed system.

8.1. Methods

8.1.1. Small mammals

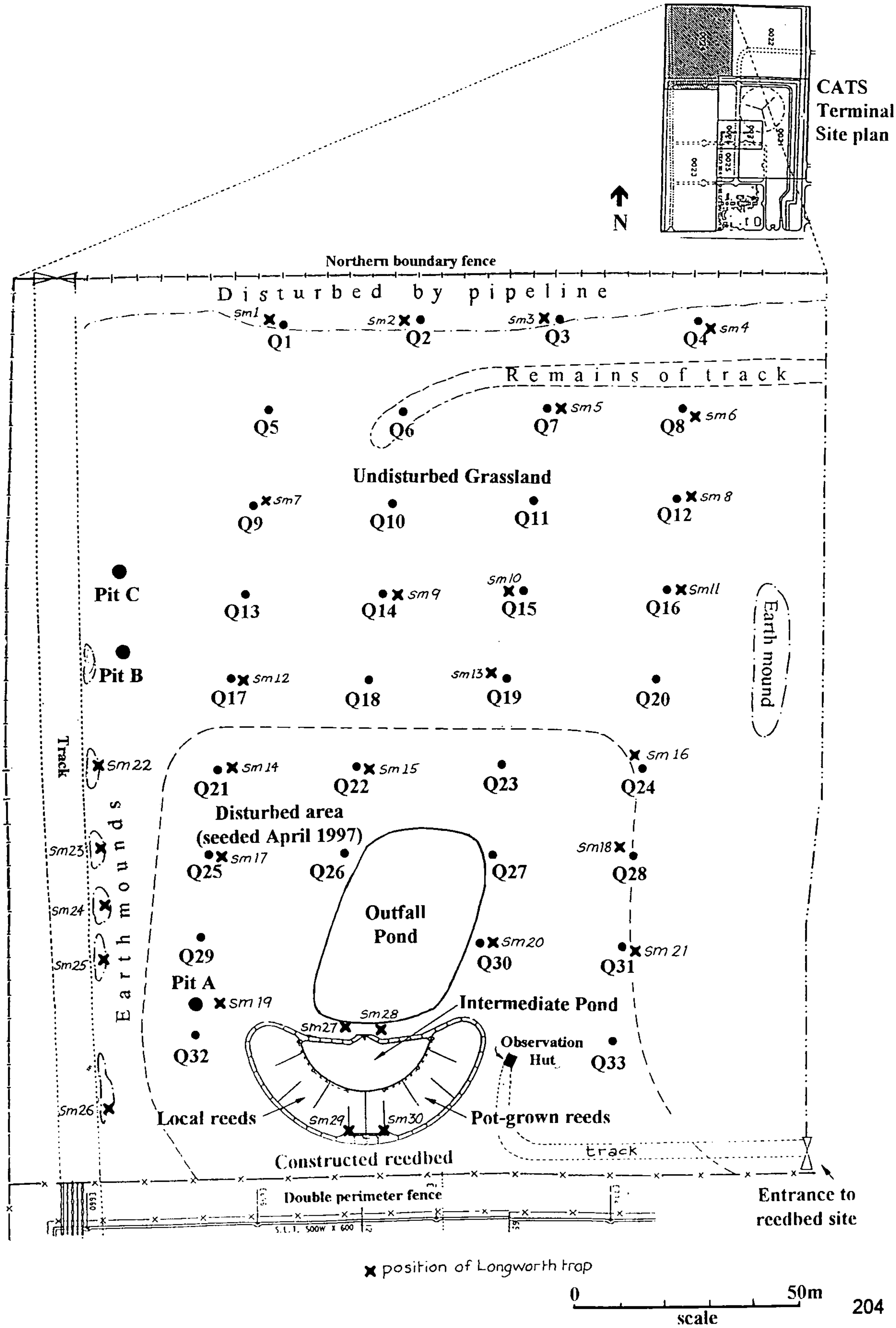
Two small-mammal surveys were carried out between 12th to 14th May 1997, and between 30th June to 2nd July,1997. Corbet (1989) classed small-mammals as having a head and body less than 130 mm. As the surveys intended to capture and examine any shrews (Family Soricidae) present on the site, a licence was obtained from English Nature (Peterborough), under the Wildlife and Countryside Act, 1981 (amended by the Environmental Protection Act 1990). The surveys involved live-trapping of small-mammals using Longworth traps (Penlon Ltd., Abingdon).

The traps comprised a tunnel, in which the door tripping mechanism was housed, and a nest box attached to the back of the tunnel (Gurnell & Flowerdew, 1982). As *Sorex minutus* L. (Pygmy shrews) may have been present on the site, the treadle tension of each Longworth trap was adjusted so that the weight required to depress the treadle and release the trap door was only 2 to 4 g. Food (corn and Blowfly pupae) and dry bedding (straw) were placed in the nest boxes of each trap.

Of the 30 Longworth traps which were employed in each survey, 13 were positioned in the grassland area (sm 1-13), 8 in the seeded area (sm 14-21), 5 within the vegetated mounds to the west of the site (sm 22-26), 2 along the southern margin of the Outfall Pond (sm 27-28), and 2 were placed on the rock gabions of the reedbed inlet area (sm 29-30) (Figure 50). The traps were covered wherever possible with vegetation so as to be concealed from predators, and protected from extremes of heat or cold. The traps were also placed with the tunnel sloping down towards the entrance in order to prevent water ingress. Bait (corn and Blowfly pupae) was arranged at the entrance and in the tunnel of each trap.

Mr. Donald Griss who had carried out small-mammal surveys at the ICI Billingham treatment reedbeds (1995, 1997) and at the ICI No.6 brinefield reedbed (1996) was present for the first survey at the CATS Terminal. During the first small-mammal survey, it was decided to prebait the traps. Prebaiting consisted of placing bait at the trap entrance and in the trap tunnel with the door fixed open, from 21.00 hours on 12th May to 06.00 hours on 13th May. Prebaiting allowed small-mammals the chance to become familiar with the traps, and representative catches would be obtained once the traps were set (Gurnell & Flowerdew, 1982). The traps were set at 06.00 hours on 13th May, 1997, and checked every three hours until 21.00 hours, when they were disarmed until 06.00 hours the following morning. As shrews need to feed every 3 to 4 hours (Gurnell & Flowerdew, 1982), it was necessary to visit the traps regularly. Following each check, food and dry bedding were replaced, and the door tripping mechanisms were checked. The 5 traps situated within the vegetated mounds (Figure 50) remained set during the evening of 13th May. The 25 traps were reset at 06.00 hours on 14th May and checked on a three hourly basis until they were collected at 21.00 hours.

Figure 50. CATS Terminal constructed reedbed and grassland site showing location of Longworth traps.



When a trap was found with the door closed, the trap was placed inside a large, clear polythene bag, into which the nest box was released with all of its contents, and the trap was removed. The animal was isolated in the corner of the bag where features such as species, sex, breeding and general body condition (visible markings, wounds and/or parasites) were noted. The contents of the bag were weighed with a 50 g balance, and re-weighed following the release of the animal. For the purpose of the survey, mammals were identified, and juvenilles and adults were differentiated by weight with reference to Gurnell & Flowerdew (1982) and Corbet (1989).

Due to the low trapping success of the first small-mammal survey, prebaiting was not employed during the second survey. At 21.00 hours on 30th June, 1997, all 30 traps were set overnight. The traps were checked every three hours between 06.00 hours until 21.00 hours on 1st July, and left set until the following morning. At 06.00 hours on 2nd July, the traps were checked regularly until they were collected at 21.00 hours.

8.1.2. Birds

During each visit to the site between January and early July of 1997, bird observations were made for a period of ten minutes, at both the start and end of each visit using field binoculars, identified using Gooders (1995), and marked on a plan of the site.

A more detailed baseline survey of the birds present within the project site was undertaken using the British Trust for Ornithology's (BTO) Common Birds Census (CBC) (Marchant, 1983). The CBC was based on the mapping method, in which a series of nine surveys were made of the site, and bird identifications (by sight and/or sound), were recorded on plans of the site. Each survey involved slowly walking along a route which covered the whole of the reedbed grassland site (3.4 ha). The surveys were undertaken at weekly intervals between 15/4/97 to 8/7/97 in order to cover the main breeding season. Since time of day and differences in effort could cause bias (Bibby *et al.*, 1992, Spellerberg, 1994), these variables were standardised in that all nine surveys were undertaken from 09.30 am to 11.30 am, although the route varied each visit.

A field map was generated for each survey and contained a record of all species, not just those thought to breed within the site. The recording conventions for species and activity codes followed those compiled by the BTO (Marchant, 1983).

The nine survey field maps were converted into individual breeding bird species maps following Marchant (1983). The weekly surveys were identified by the letters A to I. For any one species, the species code was replaced by the survey letter. In order to interpret the registrations on the species map, non-overlapping 'rings' were drawn around clusters of registrations that referred to one pair of breeding birds (Bibby *et al.*, 1992). Three separate survey registrations of a species were required to define a breeding pair cluster. Searching for the nests of breeding pairs was not recommended (Marchant, 1983). The clusters did not necessarily indicate territory boundaries but served to indicate the number and distribution of territory-holding birds within the site.

8.2. Results

8.2.1. Small mammals

The small-mammals captured during the two surveys are listed in the following table

Table 17. Longworth trap captures during two small-mammal surveys at the CATS Terminal reedbed site in May and July,1997. (For trap locations refer to Figure 50)

Trap	Date/time	Species	Observations (sex, wt. condition)
SURVEY ONE (12- 14/5/97)			
sm23	13/5/97 09.00 hours	Field vole (*Microtus agrestis*)	Male, 24 g. No wounds or parasites
sm24	09.00 hours	Wood mouse (*Apodemus sylvaticus*)	Male, 21.5 g. No wounds or parasites
sm24	14/5/97 21.00 hours	Wood mouse (*Apodemus sylvaticus*)	Male. 20.3 g. No wounds or parasites. *May be same mouse as earlier.
		Total number of small-mammals caught	**3 (*or 2)**
		Total number of trap hours (hours x traps set)	**945**
SURVEY TWO (30/6 - 2/7/97)			
sm24	1/7/97 06.00 hours	Trap empty	Food inside and outside trap nibbled.
sm14	06.00 hours	Wood mouse (*Apodemus sylvaticus*)	Male. 21.5 g. No wounds or parasites
sm17	06.00 hours	Trap empty	Corn outside trap nibbled.
sm23	2/7/97 06.00 hours	Wood mouse (*Apodemus sylvaticus*)	Male. 22.0 g. No wounds or parasites .
sm24	06.00 hours	Wood mouse (*Apodemus sylvaticus*)	Juvenile. 12.5 g. No wounds or parasites
sm16	06.00 hours	Toad (*Bufo bufo*)	
		Total number of small-mammals caught	**3**
		Total number of trap hours (hours x traps set)	**1440**

All of the small-mammals caught during the first survey were taken from the traps placed within the vegetated mounds along the western margin of the grassland. Trap sm 24 was positioned near the entrance to a small tunnel. The two adult male *Apodemus sylvaticus* (L. 1758) (Wood mouse) may have been the same individual as the captured small-mammals were not marked during the survey, and they were caught with the same trap. One *Apodemus sylvaticus* and one *Microtus agrestis* (L. 1761) (Field vole) entered the traps during the early morning between 06.00 to 09.00 hours. A further *Apodemus sylvaticus* was captured during the early evening, between 18.00 to 21.00 hours. The 30 Longworth traps were set for a total trapping period of 945 hours, amounting to 315 hours per capture.

The results of the second survey show that an adult *Apodemus sylvaticus* was caught in trap sm 14 positioned in the seeded area during the late evening of 30/6/97 or the early morning of 1/7/97. During the evening of 1/7/97 or early morning of 2/7/97, two *Apodemus sylvaticus* (adult and juvenile) were caught in traps sm 23 and sm 24 respectively, within the western vegetated mounds.The 30 Longworth traps were set for a total trapping period of 1440 hours, amounting to 480 hours per capture.

8.2.2. Other mammal observations.

Vulpes vulpes (L. 1758) (Fox) were regularly seen within the project site and processing plant by the site security guards, mainly during the evening shift. Fox faeces were identified on the reed bed gravel, on the reed bed paving and in the natural grassland. Fox foot-prints were identified around the Outfall Pond. *Lepus europaeus* Pallas 1778 (Brown hare) were regularly disturbed in the natural grassland, leaving the site under the north-west boundary gate.

8.2.3. Amphibians

During the spring of 1997, the Outfall Pond contained many tadpoles of the species *Bufo bufo* (Common toad). During June, 1997, many juveniles of the species were found foraging on the reedbed gravel, and several were caught in the seeded area pitfall traps, adjacent to the Outfall Pond.

8.2.4. Birds

Observations between January and early-July revealed 26 species of birds within the area of the project site which are shown in the following table.

Table 18. Observations of bird activity on CATS Terminal reed bed project site, January - 9th July 1997. (* species thought to breed on site)

Latin name	Common name	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY
Alauda arvensis	*Skylark		✓	✓	✓	✓	✓	
Anas platyrhynchos	Mallard			✓	✓			
Anser spp.	Goose		✓	✓	✓			
Anthus pratensis	*Meadow pipit		✓	✓	✓	✓	✓	✓
Aythya fuligula	Tufted duck						✓	
Carduelis cannabina	Linnet		✓	✓	✓	✓	✓	
Columba oenas	Stock dove				✓	✓	✓	
Columba palumbus	Wood pigeon		✓	✓	✓	✓	✓	✓
Corvus corone	Carrion crow	✓	✓	✓	✓	✓	✓	✓
Corvus frugilegus	Rook	✓	✓	✓	✓	✓	✓	✓
Corvus monedula	Jackdaw					✓		
Cuculus canorus	Cuckoo					✓		
Falco peregrinus	Peregrine Falcon					✓		
Falco tinnunculus	Kestrel					✓		
Hirundo rustica	Swallow					✓	✓	✓
Larus argentatus	Herring gull	✓	✓	✓	✓	✓	✓	✓
Larus canus	Common gull	✓	✓	✓	✓	✓		
Motacilla alba	Pied wagtail		✓	✓	✓	✓	✓	✓
Numenius arquata	Curlew	✓	✓	✓	✓			
Oenanthe oenanthe	Wheatear					✓		
Phasianus colchicus	Pheasant			✓			✓	
Pica pica	Magpie	✓	✓	✓	✓	✓	✓	
Sturnus vulgaris	Common starling				✓	✓	✓	✓
Tadorna tadorna	Shelduck					✓	✓	
Tringa totanus	Common redshank	✓						
Vanellus vanellus	Lapwing				✓			✓

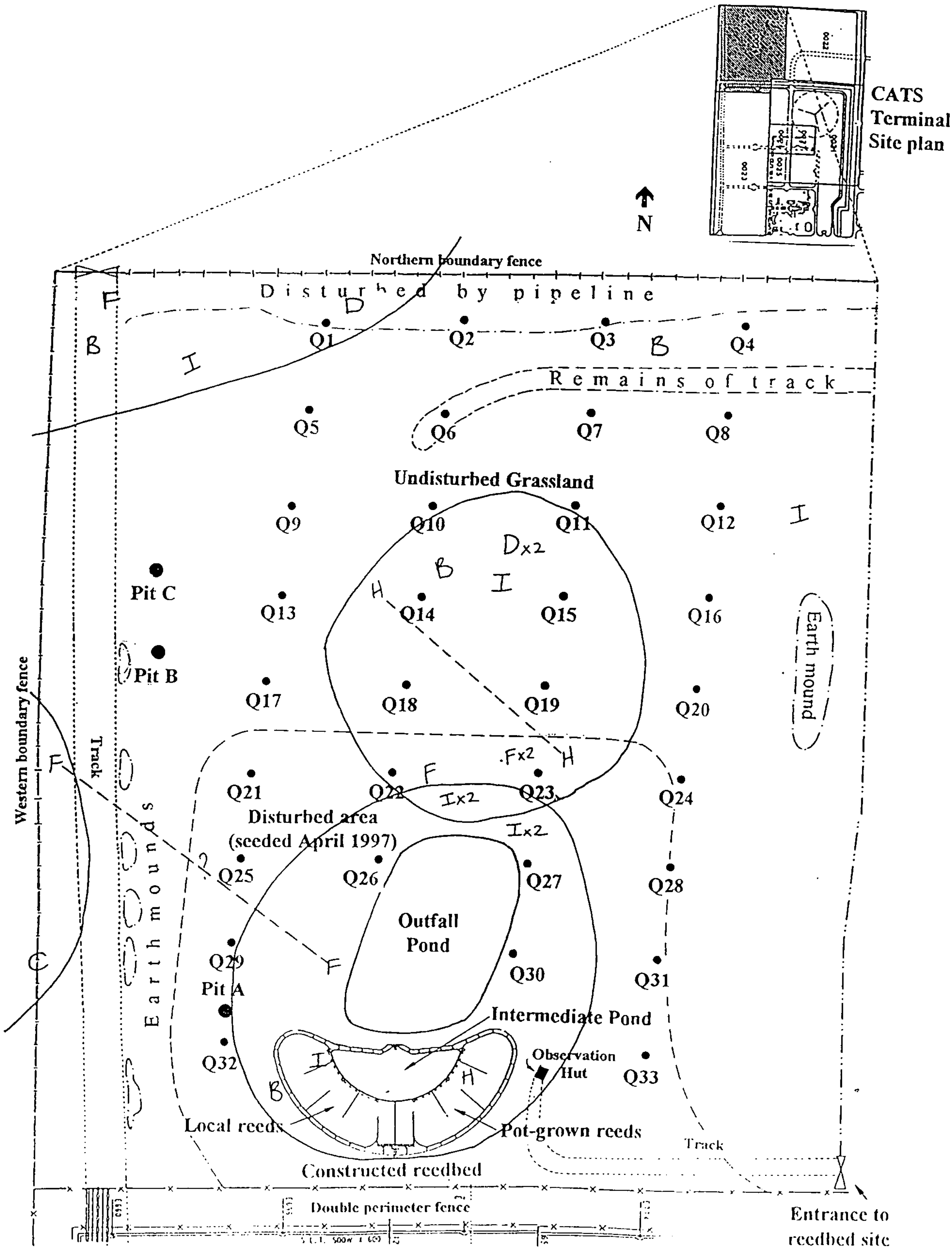
Of the species present, the CBC indicated that during the 1997 season, both *Anthus pratensis* Linnaeus, 1758 (Meadow Pippit) and *Alauda arvensis* Linnaeus, 1758

(Skylark) were considered to have bred in the grassland area of the site. Figures 51 and 52 show the respective species maps produced from the CBS survey. Four pairs of breeding Skylark occupied territories which were mainly within the grassland area. One pair of Skylark appeared to occupy a territory wholly within the site. Three pairs of Meadow Pippit held territories which included the site and adjacent grassland. Skylark were the most audible species present during the CBS survey, with males frequently displaying above the site. Both Skylark and Meadow Pippit were also considered to be breeding in the adjacent grassland to the west and north of the site. During May, a male *Cuculus canorus* Linnaeus, 1758 (Cuckoo) was frequently heard, and often spotted perching on the western boundary fence. According to Morrison (1989), the cuckoo parasitises the nests of Meadow Pippits more frequently than those of any other bird.

Information on non-breeding birds from the CBS survey was included in Table 18. An example of a survey map showing the route walked (for future surveys) is shown in Appendix 7. Some species recorded on the site were likely to have bred in adjacent areas, especially in the area of reedbeds and willow scrub of the ICI No.6 brinefield, to the west of the site, and in the rough, open grassland to the north. These species included *Columba oenas* Linnaeus, 1758 (Stock Dove), *Carduelis cannabina* Linnaeus, 1758 (Linnet), *Motacilla alba* Linnaeus, 1758 (Pied Wagtail), *Corvus corone* Linnaeus, 1758 (Carrion Crow), *Corvus frugilegus* Linnaeus, 1758 (Rook), *Pica pica* Linnaeus, 1758 (Magpie), *Sturnus vulgaris* Linnaeus, 1758 (Starling), and *Vanellus vanellus* Linnaeus, 1758 (Lapwing).

The ruderal vegetation in the seeded area provided food for flocks of Starling, Linnets, Meadow Pippit and Stock Dove from late-July onwards.The reedbed itself was regularly visited from January onwards by at least one breeding pair of Pied Wagtail. From May, once the reeds had started to grow, Meadow Pippit also foraged in the reedbed. During the summer and early autumn of 1997, aphids were noticably abundant on the reed leaves, which may have attracted birds to feed in the reedbed.

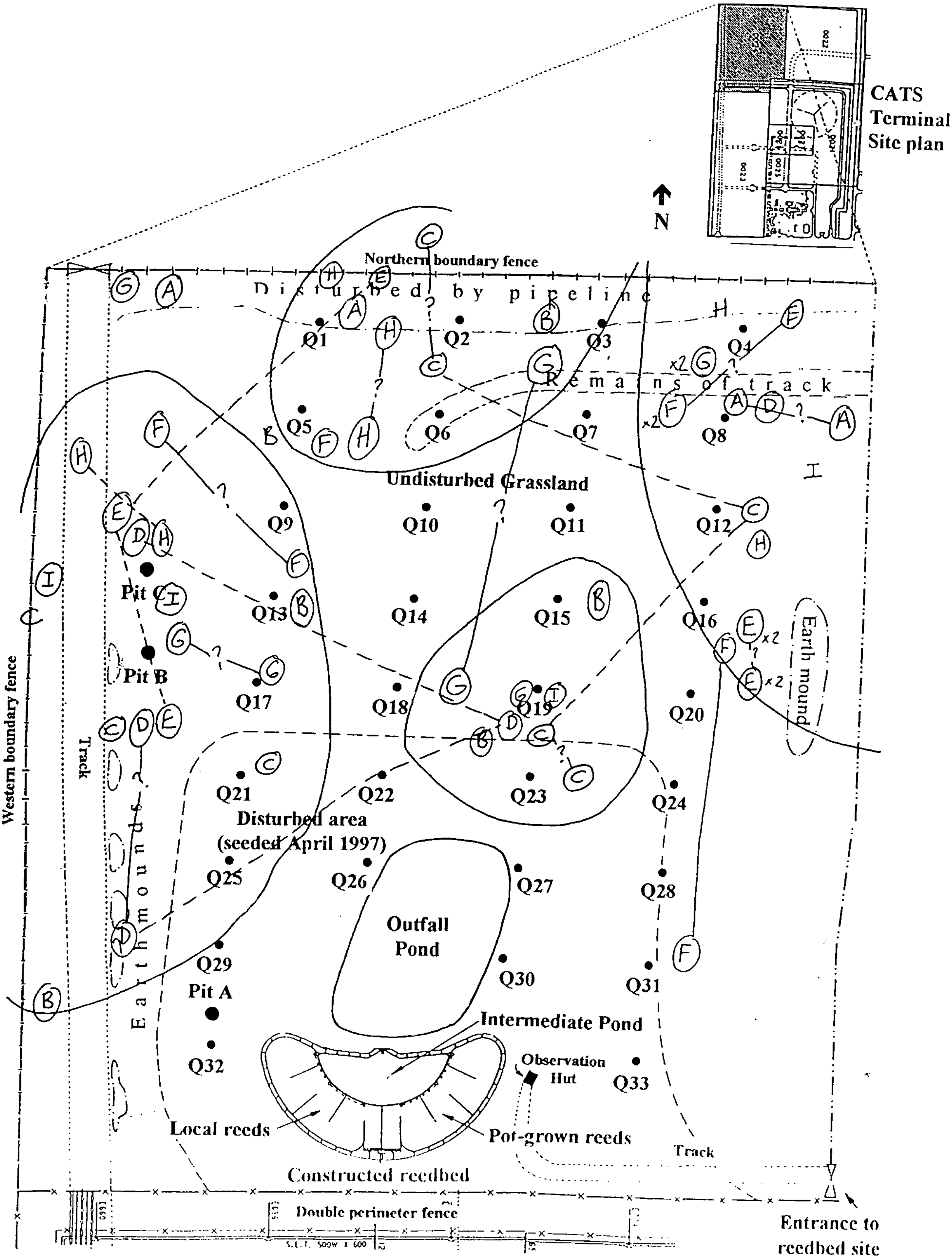
Figure 51. Meadow Pippit (*Anthus pratensis*) species map from the CBC at the CATS Terminal reedbed and grassland site between 15/4/97 to 8/7/97.



For activity codes refer to Marchant (1983)

Letters refer to weekly survey codes (see text)

Figure 52. Skylark (*Alauda arvensis*) species map from the CBC at the CATS Terminal reedbed and grassland site between 15/4/97 to 8/7/97.



For species and activity codes refer to Marchant (1983)
Letters refer to weekly survey codes (see text)

The Outfall and Intermediate Ponds provided open water habitats rich in aquatic and flying invertebrates (Chapter seven). Species seen feeding in and over the water areas included Pied Wagtail, Linnet, Meadow Pippit, *Hirundo rustica* Linnaeus, 1758 (Swallow), and *Tringa totanus* Linnaeus, 1758 (Redshank). *Anas platyrhynchos* Linnaeus, 1758 (Mallard), and a pair of *Tadorna tadorna* Linnaeus, 1758 (Shelduck) were regularly seen on the Outfall Pond during May and June. An *Aythya fuligula* Linnaeus, 1758 (Tufted Duck) was observed feeding in the Intermediate Pond during June.

8.3. Discussion

8.3.1. Small mammals

The results of the two surveys at the CATS Terminal reedbed site indicate a low density and diversity of small-mammals using the site during the survey periods. Although damp weather conditions during the second survey may have temporarily restricted the feeding activity of mice and voles, any shrews present on the site would need to be actively searching for food during some part of the 48 hour survey period. Neither *Sorex araneus* L.1758 (Common shrew) nor *Sorex minutus* L.1766 (Pygmy shrew) were captured during the two surveys, indicating that they were either absent from the site, or only present in small numbers. Both species are insectivorous, feeding on invertebrates of soil and litter (Corbet & Southern, 1977), and invertebrates were shown to be abundant within the grassland (chapter seven). However, the grassland area did not have a well-developed litter layer (chapter six), and the open vegetation was unlikely to provide the cover that according to Lawrence and Brown (1967), both species prefer.

Field voles may be common in rough, ungrazed grassland in open habitats where they feed on green leaves and stems of grasses. Several individuals may inhabit a particular grassland as their range is small, not more than 10 metres (Lawrence & Brown, 1967). According to Corbet and Harris, (1991), grasslands may support a maximum of 12 ha^{-1}.

However, only one adult Field vole was captured in a total of 2385 trapping hours at the CATS Terminal site.

Wood mice may be common in fields and grass, especially if Field voles are absent (Corbet & Southern, 1977). Population densities vary seasonally, with spring/summer lows, where in arable land, density has been reported by Corbett & Harris (1991) as varying from 0.5 ha^{-1} in summer to 17.5 ha^{-1} in winter. Predominantly nocturnal, they usually nest underground in varied habitats providing there is sufficient cover (Lawrence & Brown, 1967). It was likely that the traps sm 23 and sm 24 were close to a nest(s), probably situated within the vegetated mounds of earth. During the July small-mammal survey, the seeded area supported a high cover of *Sinapis arvensis* and *Sisymbrium altissimum* and one adult Wood mouse was caught overnight in trap sm 14, within the protective cover of the seeded area.

A study by Gibson (1989) on the distribution and abundance of small mammals in Sitka Spruce plantations in northern England found the population density of mice and voles highly variable. Populations of Field voles in the study varied from 0 to 51 ha^{-1} (Gibson, 1989).There was no evidence of activity, such as runways in the vegetation, or droppings or tunnels, within the open grassland, which supports trapping evidence of a low density of small mammals in the grassland.

Butterfield and Coulson (1981) during studies on the distribution and relative abundance of the Pygmy and Common shrews in upland areas of northern England, found a correlation between the numbers of shrews captured at a site and the abundance of invertebrates revealed by pitfall trapping. As food for shrews, voles and mice appears to be plentiful, low numbers may be due to the immaturity of the vegetation litter layer.

8.3.2. Birds

The species maps produced from the CBC show the approximate number and location of territorial breeding pairs using the site, showing the preferred sites of each species in relation to the habitat. The method provided a baseline of breeding and non-breeding species which can be repeated in order to determine the change in bird species visiting and inhabiting the site,which may arise due to the maturation of the reedbed and wetland habitats. Breeding pairs of Skylark and Meadow Pippit were associated with the grassland habitat, although Meadow Pippit regularly fed within the seeded area and the reedbed itself. Both species are common within grasslands of the Tees Estuary, but according to the RSPB, Skylark are a species in decline.

The CBC mapping technique of drawing clusters did not work well for birds such as Linnet which do not show much territorial behaviour (Bibby & Burgess, 1992). Linnets were frequently identified feeding on and flying over all parts of the site, but as they tend to nest in bushes, it is likely that they were nesting in the willow scrub to the west of the site (K.Smith, personal communication). During visits to the ICI No. 4 & 6 brinefields during 1997, Lapwing were regularly seen in the damper short-grassland, but they were rarely seen in the drier CATS grassland.

8.3.3. The influence of the reedbed on species composition and habitat value for small-mammals and birds

8.3.3.1.Small-mammals

The open grassland to the north of the reedbed system may be too exposed a habitat for small-mammals compared to the ICI No.6 brinefield reedbed and associated grass and shrub area to the West of the site. Field Voles, present in the taller vegetation of the brinefields are, according to Smith, (1989), the main diet of owls at Teesmouth. Once the reeds becomes established they will provide a dense, year round cover of vegetation with an increasing litter layer. Common and Pygmy shrews have been captured in traps set in reedbed litter at the ICI Billingham treatment reedbeds (D.Griss, personal communication), and in the 1995 survey, a single *Neomys fodiens* (Pennant, 1771) (Water shrew) was also captured (Griss, 1996). However, unlike the ICI Billingham treatment reedbeds, which have no areas of open water, the Intermediate and Outfall Ponds at the CATS Terminal may attract species of mammal which are associated with wetland habitats such as *Arvicola terrestris* (L. 1758) (Water vole), and *Rattus norvegicus* (Berkenhout, 1769) (Brown rat). The reeds at the CATS Terminal are unlikely to be harvested, therefore, when the reeds mature, a high reed seed set should provide food for voles and mice during the autumn and winter (D. Griss, personal communication).

The small-mammal surveys provided an indication of the diversity and abundance of small-mammals on the site, prior to the reedbed becoming established. The surveys can be repeated using the same locations for the Longworth traps, in order to determine the effect of the reedbed and wetland habitats on the diversity and abundance of small-mammals on the site in the future.

Foxes visit the site as they are regularly fed by site security staff. They may also be attracted by the presence of Brown hares which feed on the vegetation of the grassland, helping to maintain the species-rich botanical composition of the site. As the reedbed matures, any increase in the small-mammal population is likely to attract predators such as foxes, *Mustela nivalis* L. 1766 (Weasel), *Falco tinnunculus* Linnaeus, 1758 (Kestrel) and owls (families Tytonidae and Strigidae).

8.3.3.2. Birds

The Seal Sands mudflats (294.4 ha) to the north of the site are of national importance for wader and wildfowl populations, especially during winter months (Anon, 1990) and are a designated Site of Special Scientific Interest (SSSI). The Seal Sands area, along with three other SSSIs in the Tees Estuary, are known as the 'Teesmouth Flats and Marshes' which are of international importance (Ratcliffe, 1977). They meet the European Union criteria for Special Protection Area designation and inclusion on the list of Wetlands of International Importance under the Ramsar Convention (Anon, 1997c). Parts of the Seal Sands area are included in the Teesmouth National Nature Reserve (M.Leakey, Teesmouth National Nature Reserve, personal communication). The ICI No.6 brinefield reedbeds immediately south of the Seal Sands SSSI, are used by birds during high tide, and the rough grasslands of the estuary provide nesting and roosting sites (D. Griss, personal communication). The introduction of the reedbed wetland system at the CATS Terminal, should extend the wetland habitat, thereby increasing the species diversity of birds at the site.

The habitat value of natural and constructed reedbeds for birds has been well documented both in the UK and the USA (Bibby & Lunn, 1982, Burgess & Evans, 1989, Feierabend, 1989, Tyler, 1992, Ward, 1992, Merritt, 1994, Kadlec & Knight, 1996, and Knight, 1997). However, many studies such as that by Bibby & Lunn (1982) have concentrated on reedbeds greater than 2 ha, commenting that the attractiveness of the habitat to birds is largely dependent upon the size, structure and availability of food. Many reedbeds constructed for the tertiary treatment of wastewater are small, and have been designed purely to treat wastewater. The range and extent of habitats provided by small reedbeds, such as at the CATS Terminal (area 500 m^2) would be unsuitable for many birds which require large home ranges, for example *Botaurus stellaris* (Bittern) (Bibby & Lunn, 1982; Hawke & Jose, 1996). Yet, according to Merritt (1994), small reedbeds are able to support species such as *Emberiza schoeniclus* (Reed Bunting), and *Rallus aquaticus* (Water Rail), although Tyler (1992) suggests that it is only the warblers, such as *Acrocephalus schoenobaenus* (Sedge Warbler) and *Acrocephalus scirpaceus* (Reed Warbler), that would find reedbeds less than 1 ha suitable. Of the 26 species of bird identified on the site during the first half of 1997, none were specifically reedbed species, and the breeding birds were associated with the grassland. The reedbed is expected to take around three years to achieve full growth (C.Weedon, personal communication), therefore its wildlife potential should increase as the system matures.

Three years after the ICI Billingham treatment reedbeds were planted, the first phase of a three year ecological monitoring programme was completed in 1993 by INCA.

The ornithological monitoring consisted of a Common Bird Census, a bird trapping and ringing programme and an autumn bird survey (INCA, 1994). Within three years, 18 species of breeding birds and 29 species of non-breeding birds were recorded on the 5 ha site (Smith, 1993). The 1993 CBC was repeated in 1994, 1995 and 1996 by Donald Griss on behalf of INCA. He found that the number of Sedge Warblers breeding in the reedbeds had increased from 13 pairs in 1993 to 36 pairs in 1996; 35 pairs of Reed Bunting were breeding in 1996 compared to 9 pairs in 1993, 6 pairs of Reed Warbler were breeding in 1996 where none had been recorded in 1993, and in 1996 the first breeding pair of Water Rail was recorded.

The CATS Terminal reedbed may quickly become colonised by Reed Warbler, Sedge Warbler, and Reed Bunting, as these species are successfully breeding in the ICI brinefield reedbeds to the west of the site (D.Griss, personal communication). The Reed Warbler population is at the northern edge of its breeding range at Teesmouth (Smith, 1993). The species have adapted to spending most of their lives in reedbeds, placing their nests high in the reed stems (Tyler, 1992). They feed around the reed water interface where their diet is comprised mainly of insects (Tyler, 1992). It has been suggested that the Reed Warblers have successfully colonised the ICI Billingham treatment reedbeds due to the high nitrate content in reed stems and leaves, which appears to have stimulated aphid population growth during some years at the site (K.Smith, personal communication). The total nitrogen concentration of the reeds at the CATS Terminal was significantly higher than concentrations found in natural local reeds, at the ICI No.6 brinefield, during the first half of 1997 (chapter four), and aphids were abundant, though not monitored on the reeds during the summer and autumn. The unharvested reed stems, increasing litter layer and maturing seed heads are likely to result in an abundant and diverse reedbed invertebrate population (chapter seven), therefore, although the CATS Terminal reedbed may not support many breeding bird pairs due to its size, the close proximity of the brinefield reedbeds should make the reedbed a valuable feeding area for

Sedge Warbler and Reed Warbler populations prior to migration, and for birds overwintering in the area. For example, *Parus caeruleus* (Blue-tits), *Parus major* (Great-tits) and *Troglodytes troglodytes* (Wrens) may feed on insects that overwinter within the reed stem, or on the seed-heads of the reed, which mature around November (Haslam, 1972).

The reedbed may introduce autumn and winter roosting sites for species such as Pied Wagtail, Reed Bunting and Starling. Also, unharvested reed stems are required for nests and cover from predators, especially early in the season (Tyler, 1992). Whether the reedbed will be large enough to provide protected nesting sites away from predators will become apparent in the future. Monodominant stands of reeds provide little structural diversity (Lane, 1992). However, structural diversity has been achieved inadvertantly in the CATS Terminal reedbed during 1997, with the rapid establishment of the pot-grown reeds and the low cover achieved by the locally-transplanted reeds (chapter two). According to A.Snape, from the Teesmouth Ringing Group, the variation in the structure and density of the reeds will improve the habitat diversity of the reedbed for birds, the dense reed stands providing abundant aphids, and the sparse areas providing areas for ground-foraging birds.

(Ward, 1992) suggests that to increase the wildlife value of reedbed treatment systems, they should have areas of open water adjacent to the reeds, and wherever possible, be associated with wet-meadow, grassland and/or scrub, providing alternate habitats for birds. The CATS Terminal reedbed covers an area of only 500 m^2, but unlike the ICI Billingham treatment reedbeds, the Intermediate and Outfall Ponds provide open-water area, which unlike some of the ponds associated with the nearby brinefield reedbeds, are unlikely to dry out during hot, dry summers. Smith (1993) and Tyler (1992), report that Reed Warblers prefer reed stands adjacent to open water. During 1997, the small Intermediate Pond quickly developed an aquatic invertebrate population (chapter seven) which provided food for juvenile toads, and many species of bird, including a visiting Tufted Duck (*Aythya fuligula*). The aquatic and marginal vegetation also developed during the year, providing associated invertebrate species, green vegetation and seeds as food for birds.

The Outfall Pond attracted Mallard and Shelduck, feeding on aquatic invertebrates, and flocks of Swallows feeding on insects above the water. The area around the Outfall Pond was re-graded to provide gently sloping margins to attract visiting waders and wildfowl to feed at the site (chapter two). However, marginal vegetation naturally developed around the pool during 1997, making the area less attractive to waders who according to Merritt (1994), prefer muddy shores with very short or no vegetation, and an open aspect for the detection of predators. However, marginal and aquatic vegetation are important for species of dabbling duck (Andrews, 1995), and birds that feed on the vegetation and its invertebrates.

Merritt (1994), also suggests that the success of wetland areas as sites for breeding birds can be enhanced by providing islands which are less accessible to predators. The idea of providing a Tern raft for the Outfall Pond was investigated by Jane Lacey of the Cleveland Wildlife Trust, during the spring of 1997, but it was decided that the pool was too small to support the raft.

The bird community of the site will change with the seasons, with some species visiting for the breeding season, some for the winter, and some stopping to feed while on migration. Generally, a broader range of species of birds and mammals will be encouraged by providing a variety of habitats.

That the reedbed system is not isolated, but situated in the immediate vicinity of the Seal Sands SSSI and the brinefield reedbeds, can only serve to complement the existing habitat value for birds, mammals and amphibians, broadening the ecological resources and niches of the area.

CHAPTER NINE

9. THE EFFECTIVENESS OF THE MONITORING PROGRAMME AND FUTURE RESEARCH AND MONITORING REQUIREMENTS.

The monitoring programme was designed 'to determine both the performance of the reedbed in treating site wastewater, and also the ecological impact of the constructed reedbed on the surrounding herb-rich grassland'. During the first six months of operation, water quality monitoring has shown that the reedbed was successfully reducing the environmental impact of the site effluent, discharging a consistently high quality of wastewater. This was achieved even while not operating at the required depth of gravel, and despite higher than specified effluent loading to the bed. The ecological impact of the reedbed on the herb-rich grassland, outlined within the chapters of section two, will be determined from the results of future monitoring, using the data collected during 1997 as a baseline for comparison.

The monitoring programme itself was designed to be reliably repeated in the future to provide a long-term assessment of the performance and ecological impact of the reedbed at the CATS Terminal site. The effectiveness of the methods used and variations to the initial techniques are discussed below. Recommendations for further work are presented within boxes for clarity.

9.1. The establishment of the reedbed

During the first season of reed growth in the reedbed, it was relatively easy to count each viable planted pot-grown and transplanted reed. This provided valuable information on the effectiveness of different planting techniques, and supported studies by the ITE that pot-grown reeds are the most reliable means of reedbed establishment. Once the reeds began to develop, the determination of percentage of ground covered proved to be a successful method of assessing the establishment of the reeds.

Continue to determine the establishment of the reeds using the technique of assessing percentage ground cover.

9.2. The performance of the reedbed in treating site effluent.

The methods used were successful in assessing the performance of the reedbed in the treatment of site effluent, and could be repeated reliably by a single operator. A major drawback was that all of the determinands could not be tested on the same day as most determinands required almost immediate testing once in the laboratory. Therefore, different determinands were sampled on different days. However, it was essential that those determining nitrogen transformation (NH_4^+, NO_3^- and NO_2^-) were sampled on the same day.

The second drawback was the absence of a flow-meter at the inlet to the reedbed. Mass balance and loading rates to the reedbed could not be determined. A flow meter should be operational during future monitoring. Calculations for performance evaluation using wastewater flow measurements are detailed in Cooper *et al.*(1996) and Tchobanoglous and Burton (1991).

Of the water quality determinands monitored, chloride, although useful, was not essential. However, in future, total Kjeldahl Nitrogen should be determined in case organic nitrogen is not completely mineralised to ammonium in the Klargester. Also, decaying reed litter (and microbial matter) will contribute organic nitrogen to the reedbed in the future.
In order to comply with the Environmental Agency wastewater discharge consent (BOD_5 100 mg O_2 l^{-1} and SS 50 mg l^{-1}) a water sample is taken by site personnel, from the inlet pipe from the Klargester to the reedbed, to ITS Testing Services (UK) Ltd. Middlesbrough, for analysis every quarter. It would seem more appropriate to sample the wastewater as it leaves the reedbed system, at sample point 6 (Figure 7), or at both the

inlet and outlet of the reedbed system. Robert Hudson (Environment Agency) will review the sampling regime during 1998.

A more thorough evaluation of the performance of the reedbed requires the following:-

Continued monitoring of the water quality determinands, BOD_5, DO, COD, SS, pH, conductivity, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-} (each x 3) at sample points 1, 3, 5, 6 and 7 (Figure 7), and at points 2 and 4 if possible. Sampling should cover the periods January to July to be comparable with 1997 results. However, samples taken throughout the year may be used to assess the performance of the reedbed, and may highlight any seasonal variations in performance.

Determine the Total Kjeldahl Nitrogen when water samples are taken for NH_4^+, NO_2^- and NO_3^- analysis.

9.3. The influence of nitrogen and phosphorus on reed growth and development.

Measurements of phosphorus and nitrogen content of reed leaf tissue were valuable in assessing the effect of variation in input of these nutrients on reed growth and development. However, the contribution of nutrient reserves from the previous season, present in the rhizomes of the locally transplanted reeds may have masked differences in the uptake of nutrients from different areas of the reedbed. This may explain why locally transplanted reeds showed little variation in height between the inlet (receiving nutrient rich effluent) and outlet sections of the reedbed. It is established that the tissue nutrient concentration of *Phragmites* shows seasonal variation, both in terms of uptake and nutrient partitioning within the plant. Sampling during the autumn period may show a reduction in the nitrogen and phosphorus content of the leaf tissue due to translocation of these nutrients to the storage organs of the reed (the rhizomes). Due to the immaturity of the reedbed during 1997, it was not possible to remove whole plants for analysis. Therefore, the seasonal effect of nutrient translocation could not be studied during 1997, but should be possible from 1998.

Kuhl and Kohl (1993) found in their studies that increased and sustained nitrogen availability delayed reed senescence and the onset of translocation of nitrogen and phosphorus to the rhizomes, whereas, in naturally occurring reed stands, they found that there was an earlier termination of the development cycle. Further research is required to establish whether nitrogen translocation to the rhizome is delayed in the nutrient enriched CATS Terminal reedbed.

Determine the nitrogen and phosphorus concentrations within the reed tissues of the leaves, shoots and rhizomes, in the pot-grown and locally transplanted reeds at the CATS Terminal, over different seasons. Reeds at the ICI Wilton natural reedbed (5 km east of site - the source of the local reeds) could be sampled in order to determine any differences in the timing of nutrient translocation to the rhizomes.

Although reed growth during 1997 was determined by measurement of shoot height, future measurements should include the following:-

Determine reed growth by the measurements of shoot height, shoot basal diameter, and shoot density per 0.25m² quadrat, at the inlet, middle and outlet areas of both the pot-grown and locally transplanted sections of the reedbed.

Following the successful establishment of the pot-grown reeds, it should be possible, from 1998 to investigate any differences in the root:shoot ratios of reeds receiving different concentrations of nitrogen. Investigating the possible increase in above ground biomass with higher concentrations of available wastewater nitrogen.

Investigate any variation in above and below ground biomass (root:shoot ratio) between the inlet, middle and outlet areas of the pot-grown section of the reedbed.

Concentrations of dry depositions of atmospheric NO_2 monitored at the site between January to July 1997, were below levels considered as being harmful to vegetation. However, atmospheric NO_2 should continue to be monitored at the site, at the ICI No.6 brinefield reedbed, and at a site further west such as the ICI No.4 brinefield, in order to quantify the contribution of atmospheric NO_2 from the CATS Terminal site emissions on ground level concentrations of NO_2.

9.4. The ecological impact of the reedbed on the site.

It was envisaged that the construction of the reedbed and associated Intermediate and Outfall Ponds, would introduce a wetland habitat that would serve to increase the habitat and species diversity of the site. The surveys carried out between January to July 1997, will serve as a baseline for future monitoring in order to be able to determine the ecological impact of the reedbed on the project site.

9.4.1. Botanical composition

The baseline survey of vegetation communities within the reedbed project site identified a range of habitats, structural diversity and sucessional stages of grassland development. The network of permanent quadrat markers cover a range of habitats and should be used in future botanical, surveys. The TWINSPAN classification differentiated successional stages in the undisturbed grassland. Multivariate analysis would be a suitable tool to use to identify future changes, such as increasing dominance of competitive grass species

The botanical composition of the site should be monitored in the future to address the following issues:-

1) Ruderals present on the disturbed site should be monitored with respect to invading the herb-rich grassland. Although ruderals developing on areas of past disturbance will have affected the natural grassland, the large area disturbed during 1997 may have a greater

effect on the botanical composition of the site, especially over the next few years. If the site remains undisturbed in the future, long-term monitoring of the disturbed site will provide valuable data on colonisation in a nutrient and moisture-stressed environment.

2) The 1997 botanical survey identified species of interest such as Rough Hawk's-beard (*Crepis biennis*) and the nationally uncommon species of Hawkweed, Yellow Fox-and cubs (*Pilosella praelta* subsp.*praelta*). The two species occur within the grassland and should not be affected by maintenance of the reedbed, but as they are not found within any of the permanent quadrat areas, their status should be monitored whenever a botanical survey is carried out.

3) A group of Northern Marsh Orchids were translocated in 1995 from an area of the Terminal which was required for development to an identified site to the east of permanent quadrat 8. Between October 1996 to September 1997, no spikes of the orchid were observed. During any botanical monitoring of the site, the translocation area should be surveyed.

A general botanical survey of the project site should be undertaken during the summer of 2003, paying particular attention to the composition of the reedbed, the intermediate and outfall ponds, and the orchid translocation site. The survey should assess the status of Rough Hawk's-beard and Yellow Fox-and-cubs.

A detailed botanical survey should be undertaken during the summer of 2003 using the framework of 33 permanent quadrat markers.

9.4.2. Invertebrates

Terrestrial invertebrates of the grassland

Multivariate analysis (DECORANA) was undertaken only on lists of general taxa and Carabid species trapped in the undisturbed grassland, in order to identify any differences in invertebrate assemblages in areas of different vegetation. In future pitfall trapping surveys, all of the permanent quadrat areas could be employed, to determine whether changes in the composition and distribution of invertebrates have occurred since the construction of the reedbed, although cause and effect could not be established. The baseline survey helped to identify the taxa which would be of most use in future monitoring work (Coleoptera and Araneae) Subtle differences in habitat preference can only be determined with species level knowledge and more detailed identification is required in the future. The method of using pitfall traps, although selective in terms of species represented, should be continued at the site as it appears from the 1997 study to be highly efficient at collecting ground dwelling invertebrates. Disney (1986) reported that, for certain families of Coleoptera, such as Carabidae, pit-fall traps are very effective in terms of collecting efficiency (the proportion of the total number of species present that are actually caught).

A series pitfall trapping surveys should be carried out to cover as many seasons as possible using the framework of 33 permanent quadrat markers. Sampling should be selective, concentrating on species of Coleoptera and Araneae.

Aquatic invertebrates

Diversity indices were effective when comparing the species richness, evenness and abundance of aquatic invertebrates between the three survey pools, although it is likely that all species have not been sampled and the indices were biased towards an under-estimation of diversity. Despite the immaturity of the intermediate and outfall ponds, a good range of aquatic invertebrates appear to have colonised the pools from surrounding wetland sources, and others are likely to follow. However, as the ponds mature, species composition is likely to change. As the marginal plants develop in size and species composition, a wider range of terrestrial and aquatic invertebrate species will be attracted to the Intermediate Pond. The habitat should encourage amphibians to breed, probably attracting further predators.

Following from the baseline surveys during 1997, future aquatic invertebrate monitoring could concentrate on aquatic Coleoptera, due to their relative abundance, diversity, and their presence in the water body at all times of the year. Species of both aquatic and terrestrial Coleoptera have been monitored at the ICI Billingham reedbed between 1993-1995 (Jessop, 1997) and at the ICI No.6 brinefield reedbed during 1996 (Griss, 1996). It would seem sensible to monitor Coleoptera in the future.

A series of surveys of the Intermediate and Outfall Ponds are required, in order to assess the abundance and composition of species of aquatic Coleoptera.

Reedbed invertebrates

The method of sorting the aquatic gravel invertebrates sampled in the reedbed gravel proved to be difficult and time consuming, and the differences it identified in invertebrate abundance and composition were most likely due to the material planted with the roots of the two sources of reed, rather than highlighting any difference in water quality. Flight interception traps have successfully been used to monitor surface reedbed invertebrate populations in the ICI Billinghham reedbeds and should be used at the CATS Terminal reedbed from the early summer of 1999. Observations during the late summer and autumn of 1997, showed abundant populations of aphids feeding on the reeds. Aphids were also abundant on the ICI Billingham reedbeds during 1993-1995. There is scope for research into the link between the relatively high concentrations of nitrogen in constructed reedbed plant shoots, and aphid infestation. Such a link would increase the ornithological habitat value of the reedbed as aphids are a valuable food resource for pre-migrating Sedge-warblers and other species.

A flight interception trap should be positioned in either side of the reedbed from May to September, 1999. Collecting trays should be emptied and replaced at intervals of three weeks as outlined by Jessop (1997). All invertebrates should be identified during the first year, and species of Homoptera and Coleoptera compared with data from other local studies.

9.4.3. Birds

The Common Bird Census was undertaken during the later part of the breeding season between March and July,1997. The CBS was more thorough than the casual observations of birds between January and March. However, neither survey was able to assess visits to the site by autumn migratory birds and species of waders and wildfowl present in the estuary during winter months which may roost in the grassland. Therefore, in order to assess the range of birds using the site over the whole year, the route walked during the CBS should be repeated during autumn and winter.

The need to harvest the reeds in March 1998, has implications for bird monitoring during the year. The Tees ringing group are keen to survey and document the establishment of the bird population in a newly constructed reedbed, but this would require at least one years growth for the trapping equipment to be effective. Alan Snape of the Tees Ringing Group is aware of the unsuitability of the site in 1998, but would like to begin monitoring the bird colonisation of the reedbed from 1999. Such a survey will compliment the survey work undertaken at the ICI Billingham reedbeds, which commenced three years after planting. An early colonisation study of the CATS reedbed is therefore of great ornithological value. Although the reedbed system is small, its importance as a feeding resource for a range of bird species at critical times of the year could be considerable. Future ornithological monitoring should follow the programme carried out at the ICI Billingham reedbed.

An ornithological study of the CATS Terminal reedbed project area should be undertaken during 1999 to include:-

1) A Common Bird Census (spring and early summer) of the whole project site.

2) A trapping and ringing programme of birds within the reedbed.

3) An autumn Common Bird Census of the whole project site.

9.4.4. Small mammals

The Longworth traps during the two survey periods in 1997 were located throughout the grassland, and areas such as the mounds, where small mammals, if present, could be expected to be found. The traps positioned within the reedbed did not trap any small mammals. The low capture rate may reflect the exposed situation of the site and the immature litter layer, rather than the lack of food. The survey was carried out using the same timescale and materials as in previous local surveys at the ICI Billingham reedbed and at the ICI No.6 brinefield reedbed.

A small mammal survey should be undertaken using the 1997 Longworth trap locations, in the year 2000 or later when the reedbed has matured and a litter layer has become established

9.5. Environmental education

In addition to the research potential of the site for undergraduates, a CATS Terminal Reedbed notice board was prepared during the 1997 monitoring period in order to explain the principles of the reedbed wastewater treatment system, to the workforce and their families. There is potential to develop an educational package for use by schoolchildren visiting the reedbed. Although children are aware of the need to improve their natural and built environment, for example, by the construction of wildlife pools or nature reserves, they may be less able to make a link between theoretical science and its practical application. An understanding of the chemical and biological processes occurring within the 'environmentally-friendly' reedbed system, should reinforce school taught science.

9.6. Integration with other ecological research on Teesside

Throughout the development of a monitoring programme for the site, methods used during other ecological surveys of the Tees estuary were developed in an attempt to standardise methods and produce comparable data wherever possible. The need to improve co-ordination between all establishments carrying out research and monitoring in the area was highlighted in the State of the Natural Environment of Teesside (SONNET) report, prepared by INCA (Parnham, 1996). The SONNET report gathered together existing chemical and ecological data to provide a baseline against which improvements to the Teesside area could be measured. The report concentrated mainly on the effects of environmental improvements to the estuary indicated by studies on benthic macroinvertebrates, birds and seals. However, a larger collaborative venture, the Tees Estuary Management Plan (TEMP) (INCA, 1997), has recently been prepared as part of English Nature's 'Estuaries Initiative'. The TEMP, although non-statutory, is a strategy for the sustainable development of the area and contains the following objectives that are directly relevant to the CATS Terminal:-

Nature conservation	
Objective NCV 2	*To maintain and increase the area of important habitats on the Tees Estuary including salt marsh, dune and dune slack, inter-tidal areas, and grasslands on reclaimed ground. (Action- maintain and enhance the diversity and character of the natural ecosystem and to promote the concept of habitat creation)*
Objective NCV 3	*To protect and enhance populations of important rare or vulnerable species. The abundance and diversity of terrestrial invertebrate species on the estuary should be protected and enhanced.*
Objective NCV 5	*To protect and enhance reptile and amphibian populations of the Tees Estuary area. (Action - encourage the provision of freshwater pools suitable for amphibians, and ensuring that related terrestrial habitats are conserved adjacent to breeding sites.*
Objective NCV 6	*To maintain and improve suitable feeding, roosting and breeding habitats for important bird populations.*
Objective NCV 16	*To monitor effects of water quality on wildlife populations and to seek to minimise any adverse effects.*

(INCA, 1997)

As part of the brief, INCA hope to encourage and co-ordinate monitoring and research undertaken by organisations associated with the TEMP. Coordination should maximise the amount of useful research carried out within the time and resources available, and ensure the comparability of data generated. Members of the TEMP group include The Environment Agency, who intend to continue and expand monitoring as part of their Local Area Action Plan (LEAP) Programme, and the Cleveland Wildlife Trust, who are preparing the Local Biodiversity Action Plan (J.Lacey, personal communication). Within the Teesside conurbation, both horizontal and vertical flow reedbeds have been constructed to treat both industrial and domestic waste water. There is clearly scope for further research into how these reedbeds, constructed in close proximity to natural wetlands, affect the invertebrate and ornithological diversity of the area.

As part of a joint initiative, The Natural Environment Research Council and the Social and Economic Research Council, are hoping to conduct a pilot study on the 'Public and scientific perceptions of the chemical industry on the Teesside environment'. During a scoping report for the scheme in 1997, INCA identified a need for more data on terrestrial invertebrates, and other primary indicators of environmental improvement (D. Muir, personal communication). Continued monitoring at the CATS Terminal reedbed could provide data for the pilot study.

It is clear therefore, that as with this study, INCA should be aware of, and possibly advise on, any future monitoring carried out at the CATS Terminal.

CHAPTER TEN

10. A FUTURE MANAGEMENT STRATEGY FOR THE SITE

A management strategy for the site is required to maintain and enhance the natural diversity of the site whilst being appropriate to the requirements of the company.

Figure 53 shows a 5 year Management Plan for the CATS Terminal reedbed and associated grassland site. It has been designed to be of practical use for site personnel. Activities are outlined and allocated a two-tier priority ranking.

Priority 1. To meet legal obligations and ensure the efficient treatment performance of the reedbed.

Priority 2. To maintain and enhance the conservation value of the site.

The management requirements have been designed to be minimal, however the following principles should be considered:-

- Manual rather than mechanical techniques should be used to avoid disturbance. This strategy could encourage more community involvement.
- Any vegetation cut or thinned should be removed from the site, to prevent debris accumulating, and to reduce the spread of ruderal species.
- Chemicals should not be used.

10.1. Management requirements for the reedbed system

Reedbed

The relatively sparse locally transplanted section of the reedbed should be allowed to regenerate naturally. The spread of reeds can be accelerated by pinning down overground runners (stolons/legelhalme) at nodes which should then root. According to

Figure 53 CATS Terminal reedbed & associated grassland - 5 year management plan

	1998				1999				2000				2001				2002			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
AREA & ACTIVITY																				
REEDBED																				
① Water samples required by Environment Agency. Take 1 l sample of wastewater at the inlet to the reedbed and the outlet of the Intermediate pond, to ITS Testing Services (UK) Ltd. for analysis of BOD_5 and TSS.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
① Water level. Operate the reedbed water level at 50 mm below the level of the gravel.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
① Weed reedbed (both sides)and remove material from site. * Remove shrubby species only and leave all aquatic species.	✓	✓	✓	✓	✓	✓	✓	✓		*	*			*	*			*	*	
① Check inlet distribution pipes to both sides of reedbed. Clean out if necessary	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
①Check rock gabions at inlet to both sides of reedbed. Remove and replace if becoming clogged	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
① Reedbed density. Increase the density of the local reed section by pinning down (at the nodes) overground runners or reed shoots to produce new shoots.			✓				✓				✓				✓					
INTERMEDIATE POND																				
①② Thin out vegetation and leave material on paving overnight. Remove material next day.					✓				✓					✓			✓			
GRASSLAND																				
② Remove heads from thistles and ragwort and remove material from site			✓	✓			✓	✓			✓	✓			✓	✓			✓	✓
② Remove seedlings of woody species to prevent shrub establishment			✓				✓				✓				✓				✓	

Priority ① To meet legal obligations and ensure the efficient treatment performance of the reedbed.
Priority ② To maintain the conservation value of the site.

Burgess and Evans (1989), mature shoots can also be pinned down in this way if stolons are infrequent.

In order to maintain a monoculture of *Phragmites*, it is important to remove invading species by hand. A monthly weeding regime for the reedbed has already been established. Within a couple of years (around 2000), only shrubby species should be removed (these would reduce reed growth by increasing shading), allowing a more diverse aquatic community, dominated by *Phragmites* to develop.

Efficient distribution of the waste water entering the reedbed requires that the inlet distribution pipes are cleaned periodically to prevent blockages. The rock gabions should also be inspected for evidence of becoming clogged with sediment. If the gabions do become clogged, they should be removed (in their baskets) and replaced.

For the optimum treatment of waste water, the water level of the reedbed should be approximately 50 mm below the surface of the gravel. It is important for the health of the reeds that this water level is not allowed to fall.

Intermediate pond

Although a good range of aquatic plants were introduced to the margins and water of the Intermediate Pond, no attempt was made to remove colonising species during 1997. This allowed a self-sustaining community of aquatic macrophytes to develop. There will be a need to thin out the vegetation at the beginning of each year to prevent a reduction in the water-holding, and therefore, treatment capacity of the pond. Selective thinning could also reduce the dominance of certain species, or remove those which are inappropriate, such as *Phragmites australis*.

Outfall pond

Aquatic macrophytes were not introduced along the margins of the outfall pond during 1997. It was hoped that the exposed mud shores of the outfall pond would attract feeding wading birds. However, marginal vegetation quickly became established during 1997. In the interests of minimal maintenance, this vegetation should be allowed to develop naturally.

10.2. Management requirements for the herb-rich grassland

The slow progress of successional stages since the area was reclaimed in 1974 indicate that minimal management of the grassland would be appropriate. On the advice of English Nature and INCA, the herb-rich grassland should be assessed in approximately five years time, (the year 2003) with regard to the management regime. Allowing the grassland to develop naturally without grazing or cutting will eventually result in a change from open grassland to scrub. A botanical survey of the site can be compared to the 1997 baseline data. This should identify changes in species composition and species diversity associated both with the introduction of the wetland habitat, and with the natural changes associated with succession. If species diversity is found to have decreased, small areas of 'introduced disturbance' such as scrapes could be implemented.

Careful management of the natural area surrounding the reedbed can increase the ecological value of the constructed reedbed system, which is also enhanced by the adjacent ICI No.6 brinefield wetland complex. The site would be of far less importance if it was isolated. In fact, the main ecological significance of the reedbed apart from its importance to birds and invertebrates, is its contribution to a wetland habitat mosaic in the Seal Sands hinterland. All data collected during the monitoring programme should be seen as a valuable contribution to the collection of ecological data for the Tees Estuary as a whole.

Although management of the constructed reedbed system must primarily be concerned with the aim of water purification, its biodiversity potential can clearly be enhanced if approached from an ecological, rather than a strictly engineering perspective.

APPENDICES

APPENDIX 1. Plant species recorded in the 33 permanent quadrats at the CATS Terminal reedbed associated grassland between 1-12/7/97. Estimates of abundance follow the Domin scale (see text)

Shaded quadrats, 5-20, were those used in the National Vegetation Classification and in the Multivariate analysis.

Botanical data	Quadrats																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	28	29	30	31	32	33
Bare ground	5	5	9	4	1	9	8	5	1	5	4	2	1	1	4	1	6	5	1	1	7	6	8	7	5	7	5	9	6	7	7
Agropyron repens	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	2	0	0	1	0	4	4	0	4	0	0
Agrostis stolonifera	4	5	3	0	0	5	5	4	1	5	5	5	0	8	4	0	4	4	4	3	0	0	0	1	0	4	0	0	0	0	0
Anagallis arvensis	0	0	0	0	0	0	0	0	0	0	0		4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Anthyllis vulneraria	4	0	1	0	5	5	0	1	0	7	7	7	0	5	5	0	4	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Arrhenatherum elatius	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0
Artemisia vulgaris	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Atriplex littoralis	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	1	0	0	0	0
Blackstonia perfoliata	0	1	0	2	1	0	1	0	0	1	1	1	0	4	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Bromus mollis	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Bromus sterilis	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	0	0
Capsella bursa-pastoris	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	4	0	1	0	0
Catapodium rigidum	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	2
Centaurium erythraea	0	0	0	1	2	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chamaenerion angustifolium	0	0	4	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
Chenopodium album	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	4	0	0	0	0
Chrysanthemum segetum	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	0
Cirsium arvense	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	0	4	1	0	0	1	0	1
Cirsium vulgare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	4
Conium maculatum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	4	1	4	4	3	5	4	0
Dactylis glomerata	4	2	0	0	4	0	4	0	0	0	0	4	0	0	0	0	0	4	1	0	0	0	1	0	2	0	0	0	0	0	0
Diplotaxis tenuifolia	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	0
Erigeron acer	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euphrasia nemorosa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Festuca rubra	6	6	0	8	9	0	4	4	9	0	0	4	9	1	8	9	7	8	9	7	0	1	4	5	5	0	0	0	2	5	5
Hieracium spp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	5
Hieracium pilosella	0	4	0	4	1	0	5	0	2	4	4	0	2	5	5	1	4	4	0	4	0	0	0	0	0	0	0	0	0	0	0
Holcus lanatus	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hypochoeris radicata	4	4	0	2	1	0	1	4	0	0	4	4	1	1	2	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	0

Botanical data	Quadrats																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	28	29	30	31	32	33
Leontodon autumnalis	0	0	0	0	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Linaria vulgaris	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	0	0
Linum catharticum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lolium perenne	0	0	0	0	0	0	0	0	1	0	2	4	0	0	0	0	0	0	0	1	0	0	2	0	1	0	0	0	0	5	0
Lotus corniculatus	0	0	0	5	4	5	0	8	5	4	0	6	5	4	0	5	0	4	0	7	0	0	0	0	0	0	0	0	0	0	0
Medicago lupulina	4	5	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	0	1	0	0	4	0	0	0	0	0	1	4
Odontites verna	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	0
Plantago lanceolata	5	1	4	0	4	0	0	5	4	0	0	0	2	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
Polygonum aviculare	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	4	0	0	4	4	2	1	4	0
Ranunculus repens	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0
Senecio jacobaea	0	2	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
Senecio squalidus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	1	1	0
Senecio vulgaris	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	0	0	0
Sinapis arvensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	0	1	4	5	4	0	6	4	0
Sisymbrium altissimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	7	7	8	4	6	0	0
Stellaria media	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0
Taraxacum officinale agg.	1	0	0	0	0	2	1	0	0	4	4	4	1	0	2	0	1	2	0	1	0	0	0	0	0	0	0	0	1	0	0
Trifolium arvense	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	1	0	0
Trifolium pratense	0	0	0	4	0	0	4	0	0	0	0	4	6	4	0	0	4	6	0	0	5	0	0	0	4	0	0	0	1	4	0
Trifolium repens	0	0	0	0	2	0	0	0	0	0	0	0	0	4	0	0	0	4	4	4	0	0	0	0	0	0	0	0	0	0	4
Tripleurospermum maritimum	0	0	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0	0	0	0	4	0	4	5	4	1	0	0	1	5	0
Tussilago farfara	0	4	0	0	0	4	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
Vicia sativa	2	4	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	4

APPENDIX 2

Plant species recorded from the grassland associated with the CATS Terminal reedbed, between 1-12/7/97.

Estimates of species abundance within the site were made using a modified DAFOR scale. The abundance classes are represented in the table by symbols as follows:
A = abundant; F = frequent; O = occasional; and R = rare.
These classes apply only to the abundance of the species in the recorded sites; they do not refer to their abundance at large.
County status (C = common, L = localized distribution), was determined by comparison against a plants presence in the 191 tetrads (2 x 2 km squares) which cover, or border, the county of Cleveland (Garside, 1995).

		Status		
Botanical name	**Common name**	**Grassland**	**Re-seeded**	**County**
Achillea millefolium	Yarrow	F	F	C
Agrostis stolonifera	Creeping Bent	A	F	C
Anagallis arvensis	Scarlet Pimpernel	R	R	L
Anthyllis vulneraria	Kidney Vetch	A	-	C
Anthriscus sylvestris	Cow Parsley	O	O	C
Arenaria serpyllifolia	Thyme-leaved Sandwort	R	R	L
Arrhenatherum elatius	False Oat Grass	F	F	C
Artemisia vulgaris	Mugwort	F	O	C
Aster spp.	Michaelmas Daisy	O	-	L
Atriplex littoralis	Grass-leaved Orache	-	O	L
Bellis perennis	Daisy	O	O	C
Blackstonia perfoliata	Yellow Wort	F	-	C
Bromus mollis	Lop-grass	R	-	L
Bromus sterilis	Barren Brome	-	R	L
Cakile maritima	Sea Rocket	R	-	L
Capsella bursa-pastoris	Shepherd's-purse	-	F	C
Carduus nutans	Musk Thistle	R	O	L
Carlina vulgaris	Carline Thistle	O	R	C
Carpinus betulus	Hornbeam	R	-	L
Centaurea cyanus	Cornflower	-	O	L
Centaurium erythraea	Common Centaury	O	-	C
Cerastium holosteoides	Common Mouse-ear	A	-	C
Cerastium tomentosum	Snow in summer	R	-	L
Chamaenerion angustifolium	Rosebay Willowherb	F	F	C
Chenopodium album	Fat-hen	-	F	C
Chrysanthemum segetum	Corn Marigold	-	O	L
Cirsium arvense	Creeping Thistle	O	F	C
Cirsium vulgare	Spear Thistle	R	R	C

Conium maculatum	Hemlock	-	A	C
Crepis biennis	Rough Hawk's-beard	R	-	*L
Dactylis glomerata	Cock's-foot	A	O	C
Daucus carota	Wild carrot	-	O	C
Desmazeria rigida	Fern-grass	-	O	C
Diplotaxis muralis	Annual Wall-rocket	-	O	L
Diplotaxis tenuifolia	Perennial Wall-rocket	R	O	C
Elymus repens	Couch	A	A	C
Erigeron acer	Blue Fleabane	R	-	L
Euphrasia nemorosa	Common Eyebright	R	-	L
Festuca rubra	Red Fescue	A	A	C
Geranium molle	Dove's-foot Crane's-bill	-	R	
Gymnadenia conopsea subsp.*densiflora*	Fragrant Orchid	R	-	L
Hieracium spp.	Hawkweed	O	O	C
Hieracium eboracense	Hawkweed	R	-	L
Hieracium pilosella	Mouse-ear Hawkweed	A	R	C
Hieracium vulgatum	Common Hawkweed	O	-	C
Holcus lanatus	Yorkshire Fog	O	O	C
Hypochoeris radicata	Common Cat's-ear	O	R	C
Lactuca virosa	Great lettuce	-	R	L
Leontodon autumnalis	Autumn Hawkbit	O	-	C
Leontodon taraxacoides	Lesser Hawkbit	R	-	C
Leucanthemum vulgare	Oxeye Daisy	O	O	C
Linaria purpurea	Purple Toadflax	R	-	L
Linaria vulgaris	Common Toadflax	O	O	C
Linum catharticum	Fairy Flax	O	-	C
Lolium perenne	Perennial Ryegrass	F	A	C
Lotus corniculatus	Bird's Foot Trefoil	A	A	C
Medicago lupulina	Black Medick	A	O	C
Medicago sativa	Lucerne	R	-	L
Melilotus alba	White Melilot	R	-	L
Odontites verna	Red Bartsia	R	R	L
Papaver rhoeas	Common Poppy	-	O	C
Pastinaca sativa	Wild Parsnip	-	O	C
Pilosella praelta subsp. *praelta*	Yellow Fox-and-Cubs	R	-	**
Plantago lanceolata	Ribwort Plantain	F	R	C
Polygonum aviculare	Knotgrass	R	A	C
Ranunculus repens	Creeping Buttercup	O	O	C
Raphanus raphanistrum	Wild Radish	R	O	C
Reseda luteola	Weld	R	O	C
Rosa agg.	Rose	R	-	C

Rumex obtusifolius	Broad-leaved Dock	R	O	C
Salix spp	Willow	R	-	C
Senecio jacobaea	Common Ragwort	O	O	C
Senecio squalidus	Oxford Ragwort	O	O	C
Senecio vulgaris	Groundsel	R	R	C
Sinapis arvensis	Charlock	-	A	C
Sisymbrium altissimum	Tall Rocket	-	A	C
Sonchus asper	Prickly Sow-thistle	R	R	C
Sonchus arvensis	Perennial Sow-thistle	R	R	C
Stellaria media	Common Chickweed	R	O	C
Taraxacum officinale agg.	Dandelion	F	F	C
Thlaspi arvense	Field Penny-cress	R	R	L
Tragopogon pratensis agg.	Goat's-beard	R	-	C
Trifolium arvense	Hare's-foot Clover	R	O	L
Trifolium campestre	Hop Trefoil	R	-	C
Trifolium pratense	Red Clover	A	A	C
Trifolium repens	White Clover	F	O	C
Tripleurospermum maritimum	Sea Mayweed	O	F	C
Tussilago farfara	Coltsfoot	F	A	C
Urtica dioica	Common Nettle	R	O	C
Vicia cracca	Tufted Vetch	O	-	C
Vicia sativa	Common Vetch	A	A	C

Notes:

* *Crepis biennis* has not previously been recorded in the Tees estuary area (I.Lawrence, personal communication).

** *Pilosella praelta* subsp. *praelta,* a nationally uncommon plant which has not previously been recorded in the county (V.Jones, personal communication). Specimens were identified in an area between quadrats 12 and 16, and appeared to be regenerating well.

APPENDIX 3. Abundance of invertebrates collected in 16 pitfall traps set for two periods of 14 days duration and collected on 27/5/97 and 8/7/97, at the CATS Terminal reedbed grassland site.

CATS Terminal reedbed project-Pitfall samples (27/5/97& 8/7/97).			Quadrats															
ORDER	FAMILY	GENUS/SPECIES	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	Lumbricidae		0	0	0	0	1	1	1	0	0	1	2	0	0	1	0	0
		Lumbricus rubellus	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Araneae			91	5	70	143	122	81	87	65	101	126	71	50	78	102	107	138
Isopoda	Armadillidiidae	*Armadillidium vulgare*	507	3	24	561	868	339	387	408	542	501	282	331	655	333	227	129
		Philoscia muscorum	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Chilopoda		*Lithobius spp.*	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Diplopoda	Julidae	*Julus scandinavius*	2	0	3	2	0	1	2	4	0	0	3	2	1	1	0	1
Collembola			14	24	23	5	14	14	12	8	7	14	9	7	8	11	11	8
Dermaptera		*Forficula auricularia*	28	2	5	1	0	23	16	6	0	2	3	1	23	15	1	4
Orthoptera	Acrididae		0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Hemiptera	Aphididae		2	1	1	5	0	0	2	2	0	3	1	5	3	0	1	2
sub-order Heteroptera	Tingidae		0	0	0	0	0	1	0	0	0	1	1	1	0	1	1	0
sub-order Homoptera	Cercopidae		3	0	1	4	1	1	4	3	2	1	1	3	2	0	1	1
Thysanoptera			0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Lepidoptera			1	4	1	0	0	3	2	4	0	0	2	1	0	1	0	0
Diptera (True flies)																		
sub-order Nematocera	Ceratopogonidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Mycetophilidae	*Sciara*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	Tipulidae		0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Trichoceridae		0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
sub-order Cyclorrhapha	Muscidae		3	4	1	5	2	3	11	0	2	1	0	0	2	3	5	5
	Drosophilidae		1	0	1	6	5	2	4	1	6	4	4	6	0	4	1	2
sub-order Brachycera	Dolichopodidae		0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Hymenoptera	SF-Ichneumonoidea		1	0	0	1	0	0	1	1	0	1	0	0	0	0	0	1
	SF-Cynipidae		0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
	SF-Chalcidoidea		0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0
sub-order Apocrita	Formicidae	*Lasius niger*	165	2	11	2	7	4	6	5	7	24	15	4	15	17	9	8
		Myrmica ruginodis	15	1	7	7	31	51	45	31	3	44	33	35	16	21	12	27
	SF-Apoidea	*Andrena spp.*	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
Gastropoda	Helicidae	*Helicella itala*	0	0	0	8	0	0	4	10	0	0	1	16	0	1	0	5

CATS Terminal reedbed project-Pitfall samples (27/5/97& 8/7/97).

ORDER	FAMILY	GENUS/SPECIES	Quadrats 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gastropoda	Helicidae	*Trichia hispida*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Coleoptera	Carabidae	*Amara aenea*	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Amara aulica	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
		Amara communis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
		Amara lateralis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Amara lunicollis	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
		Amara praetermissa	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
		Amara tibialis	0	0	0	0	0	0	1	2	0	0	0	1	0	0	3	0
		Bradycellus harpulinus	0	0	1	0	0	1	0	0	0	0	0	1	2	4	6	0
		Calathus ambiguus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
		Calathus erratus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
		Calathus fuscipes	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
		Calathus melanocephalus	9	0	2	7	0	2	4	14	5	3	3	2	7	5	6	16
		Harpalus affinis	0	0	0	1	0	2	0	0	1	0	0	0	0	3	0	1
		Harpalus rufibarbis	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0
		Leistus ferrugineus	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Nebria salina	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Notiophilus aquaticus	4	0	3	0	0	0	4	0	1	0	0	0	1	0	0	2
		Olisthopus rotundatus	0	0	1	1	0	0	0	0	0	0	0	0	0	4	2	2
		Trechus obtusus	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
sub-order Polyphaga	Staphylinidae		1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
	Byrrhidae		4	1	6	6	0	2	0	5	1	4	1	0	4	3	2	0
	Coccinellidae	*Coccinella 7-punctata*	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	3
	Elateridae		0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
	Curculionidae		3	0	0	0	0	3	0	0	1	2	0	0	0	0	0	0
Other coleoptera			3	0	4	2	0	5	0	4	2	1	0	1	1	0	2	0
			1	0	5	1	0	2	0	2	0	2	2	1	0	3	2	3
		beetle larvae	1	0	0	1	0	2	0	1	1	0	1	0	1	2	2	2

Appendix 4. Abundance of invertebrates collected in 10 pitfall traps set for two periods of 14 days duration and collected on 27/5/97 and 8/7/97, in the CATS Terminal reedbed re-seeded area.

			Quadrats									
ORDER	FAMILY	GENUS/SPECIES	A	B	C	D	E	F	G	H	I	J
	Lumbricidae		0	0	1	2	2	0	0	1	2	0
Araneae			3	4	2	1	1	3	4	5	5	7
Isopoda	Armadillidiidae	*Armadillidium vulgare*	0	3	6	0	1	4	3	1	1	0
		Lithobius spp.	0	0	0	0	0	1	0	0	0	0
Diplopoda	Julidae	*Julus scandinavius*	0	0	0	0	0	0	1	0	0	0
Collembola			1	2	0	0	0	0	2	1	0	0
Hemiptera	Aphididae		0	1	0	0	0	0	1	0	0	0
sub-order Heteroptera			0	0	1	0	0	0	0	0	0	0
	Tingidae		0	0	1	0	0	0	0	1	0	0
sub-order Homoptera	Cercopidae		0	0	1	0	0	0	1	0	0	0
	Aleyrodidae		0	0	0	0	0	0	0	0	2	0
Thysanoptera			1	0	0	0	0	0	0	0	0	0
Lepidoptera			0	0	0	0	1	0	0	0	1	1
Diptera (True flies)												
sub-order Nematocera	Mycetophilidae	*Sciara*	0	1	4	2	3	0	3	3	0	2
	Trichoceridae		4	4	2	0	2	5	2	4	2	3
	Chironomidae		0	0	0	0	0	0	3	0	0	1
sub-order Cyclorrhapha	Muscidae		0	2	2	0	0	3	3	0	3	4
	Drosophilidae		0	0	0	1	0	1	3	1	0	0
Hymenoptera	SF-Ichneumonoidea		0	0	0	0	1	0	0	0	0	1
	SF-Cynipidae		0	0	0	1	0	1	0	0	1	0
	SF-Chalcidoidea		0	0	0	0	1	0	0	0	0	0
sub-order Apocrita	Formicidae	*Lasius niger*	7	4	7	2	4	6	2	3	6	3
		Myrmica ruginodis	4	9	5	7	3	7	7	7	22	1
	SF-Apoidea	*Bombus lucorum*	0	0	0	0	0	0	1	0	0	0
Coleoptera	Carabidae	*Amara praetermissa*	0	1	0	0	0	0	1	0	1	0
		Bembidion femoratum	0	0	0	1	0	0	0	0	0	0
		Bembidion obtusum	0	0	1	0	0	1	1	0	0	0
		Bembidion quadrimaculatum	0	1	4	5	3	0	2	0	0	0
		Calathus fuscipes	0	0	1	0	0	1	0	0	1	0
		Harpalus affinis	0	0	0	1	0	3	2	0	0	0

							Quadrats					
ORDER	**FAMILY**	**GENUS/SPECIES**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Coleoptera	Carabidae	*Nebria salina*	0	0	0	0	0	1	0	0	0	0
		larvae	0	0	1	0	1	1	1	0	0	0
sub-order Polyphaga	Staphylinidae		3	0	3	1	0	3	3	3	2	3
	Chrysomelidae		0	0	2	0	1	1	0	1	1	1
	Coccinellidae	*Coccinella 7-punctata*	0	0	0	0	0	2	0	2	0	0
	Curculionidae		0	1	0	0	0	0	0	0	0	0
Other coleoptera			0	0	1	2	0	4	3	0	11	1

APPENDIX 5. Abundance of taxa collected from the Intermediate and Outfall ponds at the CATS Terminal, and the ICI No.6 brinefield pond,on 13/5/97, 12/6/97, 25/6/97 and 9/7/97

				ICI	INTERMEDIATE	OUTFALL
ORDER	**FAMILY**	**GENUS/SPECIES**	**Life-stage**			
Pulmonata	Limnaeidae	*Limnaea pereger*		46		
		Limnaea truncatula		11		
Odonata						
sub-order Anisoptera	Libellulidae	*Sympetrum striolatum*	Nymph	1		
sub-order Zygoptera	Coenagrionidae	*Ishnura elegans*	Nymph	7		
Trichoptera		*Agrypnia spp.*	cased	1		
Hemiptera	Corixidae	*Callicorixa praeusta*	Adult			1
		Corixa punctata	Nymph		13	
		Sigara concinna	Adult			4
		Sigara lateralis	Adult	5	6	12
	Corixidae		Nymph	12	286	436
Coleoptera	Carabidae	*Bembidion* spp.	Adult	1		
	Dytiscidae	*Agabus nebulosus*	Adult		1	3
		Hydroporus planus	Adult		4	1
		Hygrotus confluens	Adult		2	6
		Hygrotus inaequalis	Adult	2		
	Haliplidae	*Haliplus apicalis*	Adult	20	4	5
Coleoptera			Larva	2	86	9
Diptera						
sub-order Nematocera	Chironomidae	*species 1 (pale)*	Larva	7	206	5
			cased	3		
			Pupa		58	1
			Adult		3	3
	Ceratopogonidae		Adult			3
Hymenoptera						
sub-order Apocrita	SF-Chalcidoidea		Adult	1		
Hydracarina				3	3	1
Cladocera	Daphniidae	*Daphnia magna*		>10	>100	>100
Araneae				1		
Total number of invertebrates sampled				**132**	**772**	**590**
Total number of taxa sampled				**14**	**9**	**11**

APPENDIX 6. Gravel invertebrates collected (n=3 for each area) from the CATS Terminal reedbed gravel on 16/6/97, 2/7/97 and 16/7/97.

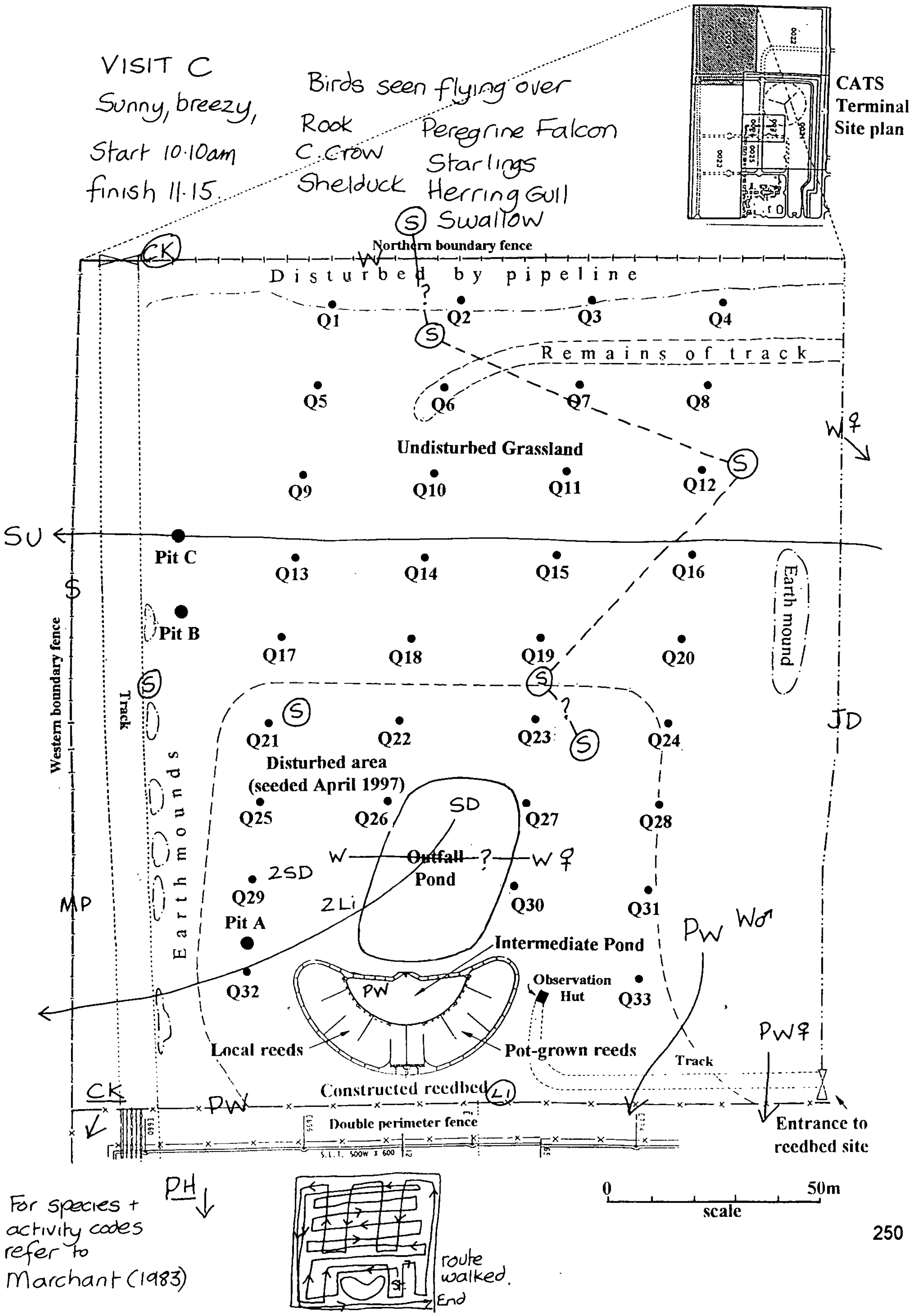
Gravel invertebrates sampled on 16/6/97 (n=3)				Inlet	L-reed outlet	PG-reed outlet
ORDER	**FAMILY**	**GENUS/SPECIES**	**Life-stage**			
	Lumbricidae	*Dendrobaena octaedra*		4		
Odonata						
sub-order Zygoptera	Coenagrionidae	*Ischnura elegans*	Larva			1
Coleoptera			Larva	1		
Diptera (True flies)						
sub-order Nematocera	Chironomidae	*species 1 (pale)*	Larva	22	5	
		species 2 (dark)	Larva	8	37	7
	Tipulidae		Larva		1	
sub-order Cyclorrhapha	Muscidae		Pupa	1	1	
			Adult		3	

Gravel invertebrates sampled on 2/7/97 (n=3)				Inlet	L-reed outlet	PG-reed outlet
ORDER	**FAMILY**	**GENUS/SPECIES**	**Life-stage**			
Hemiptera	Corixidae		Nymph	1		
	Aphididae			2		
sub-order Polyphaga	Chrysomelidae		Adult	1		
Diptera (True flies)			Pupa	9	30	
sub-order Nematocera	Chironomidae	*species 1 (pale)*	Larva	84	5	
			Pupa	2		
		species 2 (dark)	Larva	9	18	
			Pupa			1
			Adult	3		
	Tipulidae		Larva		1	

Gravel invertebrates sampled on 16/7/97 (n=3)				Inlet	L-reed outlet	PG-reed outlet
ORDER	**FAMILY**	**GENUS/SPECIES**	**Life-stage**			
Hemiptera	Aphididae					2
Thysanoptera	Thripidae					1
Coleoptera	Hydrophilidae	*Helophorus aequalis*	Adult	1		
		Helophorus rufipes	Adult		1	
	Coccinellidae	*Coccinella 7-punctata*				1
Diptera						
sub-order Nematocera	Chironomidae	*species 1 (pale)*	Larva	12	47	
			Pupa	1	1	
		species 2 (dark)	Larva		7	6
			Pupa		5	5
			Adult			
sub-order Cyclorrhapha	Muscidae	*species 1*	Pupa	20	10	7
		species 2	Pupa	1		
Hymenoptera						
sub-order Apocrita	SF-Formicoidea	*Lasius niger*			2	

APPENDIX 7

Survey field map from the CBC of the CATS Terminal reedbed and grassland site for 13/5/97.



REFERENCES

Adcock, P.W. & Ganf, G.G. (1994). ***Growth characteristics of three macrophyte species growing in a natural and constructed wetland system.*** Water Science & Technology. **29**, No.4, pp.95-102.

Allen, S.E., Grimshaw, H., Parkinson, J. & Quarmby, C. (1974). ***Chemical analysis of ecological materials.*** Blackwell Scientific Publication, Oxford.

Andrews, J. (1995). ***Waterbodies.*** In Sutherland, W.J. & Hill, D.A. (Eds.) ***Managing habitats for conservation.*** Cambridge University Press, Cambridge.

Anon (1990) ***Amoco CATS Gas Terminal: Environmental Statement.*** Environmental Resources Limited, London.

Anon (1991) ***Particle size analysis.*** Leaflet, Department of Geography, University of Northumbria.

Anon (1992). ***Munsell soil color charts.*** Munsell Color, New York, USA.

Anon (1994a). ***G-range carbonaceous biodisc / managed flow system.*** Technical data sheet GB, Klargester Environmental Engineering Ltd., Aylesbury.

Anon (1994b). ***Ecological monitoring and management of ICI Billingham's reedbeds. Progress report No. 1-1993.*** INCA Projects Ltd.

Anon (1997b). ***Air quality in the Tees Valley 1992-1996.*** Tees Valley Environmental Protection Group, Middlesbrough Borough Council, Middlesbrough.

Anon (1997c). ***Tees Local Environment Agency Plan.*** Environment Agency, York.

APHA (1992) ***Standard Methods for the Examination of Water and Wastewater: 18th edition.*** American Public Health Association (APHA), American Water Works Association (AWWA), Water Pollution Control Federation (WPCF), Washington DC.

Armstrong, J. & Armstrong, W. (1988). ***Phragmites australis - a preliminary study of soil oxidising sites and internal gas transport pathways.*** New Phytologist. **108**, pp.373-382.

Armstrong, J. & Armstrong, W. (1990a). ***Pathways and mechanisms of Oxygen transport in Phragmites australis.*** In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Armstrong, W., Armstrong, J. & Beckett, P.M. (1990b). ***Measurement and modelling of oxygen release from roots of Phragmites australis.*** In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Arnold, H.R. (1993). ***Atlas of mammals in Britain.*** Joint Nature Conservation Committee/Institute of Terrestrial Ecology. HMSO, London.

Ashenden, T.W. & Bell, S.A. (1988). ***Measuring field concentrations of nitrogen dioxide using diffusion tubes.*** Bangor occasional paper No.19. Institute of Terrestrial Ecology, Bangor.

Ashenden, T.W. & Mansfield, T.A. (1978). ***Extreme pollution sensitivity of grasses when SO_2 and NO_2 are present in the atmosphere together.*** Nature, **273**, pp. 142-143.

Athie, D. & Cerri, C.C. (Eds.) (1987). ***The use of macrophytes in water pollution control.*** Proceedings of an IAWPRC specialized seminar held in Piracicaba, Brazil, 21-28 August, 1986. Pergamon Press, Oxford.

Auclair, A.N.D. (1979). ***Factors affecting tissue nutrient concentrations in a Scirpus-Equisetum wetland.*** Ecology, **60**, No.2, pp.337-348.

Ball, S.G.(1987). ***Invertebrate site register:Regional review of rare and notable invertebrates in north-east England.*** Report No.72. Nature Conservancy Council, Peterborough.

Bannister, P. (1976). ***Introduction to physiological plant ecology.***Blackwell Scientific Publications, Oxford.

Bavor, H.J., Roser, D.J., Fisher, P.J. & Smalls, I.C. (1989). ***Performance of solid-matrix wetland systems viewed as fixed-film bioreactors.*** In Hammer, D.A. (Ed.). ***Constructed wetlands for wastewater treatment : Municipal, industrial and agricultural.*** Lewis Publishers, Michigan, USA.

Bibby, C.J., Burgess,N.D. & Hill, D.A. (1992). ***Bird Census Techniques.*** Academic Press, London.

Bibby, C.J. & Lunn, J (1982). ***Conservation of Reed beds and their avifauna in England and Wales.*** Biological Conservation **23**, pp. 167-186.

Billcliffe, L. (1997). Personal communication. Environmental Services Department, Stockton-on-Tees Borough Council.

Boar,R.R., Leeming, D.J. & Moss,B. (1991) ***The quality of thatching reed and its impact on the thatching industry: The links between water and sediment chemistry and reed quality.*** Report No.138. English Nature ,Peterborough.

Boar, R.R.(1992). ***Factors which affect the growth of Phragmites australis.*** In Ward, D.(Ed.) ***Reedbeds for Wildlife : Proceedings of a conference on creating and managing reedbeds with value to wildlife, 15 November,1991.*** Nature Conservation Bureau Ltd, Newbury.

Boon,A.G. (1985) ***Report of a visit by members and staff of WRc to Germany (GFR) to investigate the Root Zone method for treatment of waste waters.*** WRc Report 425-S. WRc Stevenage.

Boyce, D.V.M. (1995). ***The establishment, management, and composition of a species-rich haymeadow on land restored after opencast coal-mining.*** Journal of Practical Ecology and Conservation. **1**, No.1, pp. 6-11.

Brix, H. (1990). ***Gas exchange through the soil-atmosphere interphase and through dead culms of Phragmites australis in a constructed reed bed receiving domestic sewage.*** Water Research. **24**, pp.259-266.

Brix, H. (1993). ***Macrophyte-mediated oxygen transfer in wetlands : Transport mechanisms and rates.*** In Moshiri, G.A. (Ed.) ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton.

Brix, H.(1994 a). ***Use of constructed wetlands in water pollution control:Historical development, present status, and future perspectives.*** Water Science & Technology. **30**. No.8,pp.209-223.

Brix, H. (1997). ***Do macrophytes play a role in constructed treatment wetlands?.*** Water Science & Technology. **35**, No.5, pp.11-17.

Brix, H. & Schierup, H. (1989). ***The use of aquatic macrophytes in water-pollution control.*** Ambio. **18**, pp.100-107.

Brix, H.& Schierup, H.(1990).***Soil oxygenation in constructed reed beds:The role of macrophyte and soil-atmosphere interface oxygen transport.*** In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Burgess, N., Ward, D., Hobbs, R. & Bellamy, D.(1995). ***Reedbeds, fens and acid bogs.*** In Sutherland, W.J. & Hill, D.A. (Eds.) ***Managing habitats for conservation.*** Cambridge University Press, Cambridge.

Burgess,N. D. & Evans,C. E.(1989) ***The management of reedbeds for birds.*** Birdlife International.

Burgess, N., Ward, D., Hobbs, R. & Bellamy, D. (1995). ***Reedbeds, fens and acid bogs.*** In Sutherland, W.J. & Hill, D.A. (Eds.). ***Managing habitats for conservation.*** Cambridge University Press, Cambridge.

Burka,U. & Lawrence,P.C. (1990). ***A new community approach to wastewater treatment with higher water plants.*** In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Butterfield, J., Coulson, J.C. & Wanless, S. (1981). ***Studies on the distribution, food, breeding biology and relative abundance of the Pygmy and Common shrews (Sorex minutus and S. araneus) in upland areas of northern England.*** J. Zool., Lond. **195**, pp.169-180.

Chinery, M. (1993). ***Insects of Britain and Northern Europe.*** 3rd. Edition. Harper Collins, London.

Clapham, A.R., Tutin, T.G. & Moore, D.M. (1989). ***Flora of the British Isles.*** 3rd Edition. Cambridge University Press, Cambridge.

Collinson, N.H., Biggs, J., Corfield, A., Hodson,M.J., Walker,D., Whitfield, M. & Williams, P.J.(1995).***Temporary and permanent ponds: An assessment of the effects of drying out on the conservation value of aquatic macroinvertebrate communities.*** Biological Conservation, **74**, pp 125-133.

Cooper,P.F.(ed) (1990) ***European design and operations guidelines for reed bed treatment systems.*** Water Research Council. UI 17. Water Research Centre, Swindon, December 1990.

Cooper, P.F. & Findlater, B.C. (Eds.) (1990a) ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Cooper,P. & Green,B. (1995) ***Reed Bed treatment systems for sewage treatment in the United Kingdom - The first 10 years' experience.*** Water Science & Technology. **32**.No.3.pp.317 - 327

Cooper, P.F., Job,G.D., Green,M.B. & Shutes,R.B.E. (Eds.) (1996). ***Reed beds and constructed wetlands for wastewater treatment.*** Water Research Centre, Swindon.

Corbet,G.B. & Southern,H.N. (1977) ***The handbook of British mammals.***(2nd edition). Blackwell Scientific Publications,Oxford.

Corbett, G.B. (1989). ***Finding and identifying mammals.*** British Museum (Natural History), London.

Corbet, G. & Harris, S.(1991). ***The handbook of British Mammals.*** 3rd. Edition. Blackwell Scientific Publications, Oxford.

Cramp, S., Simmons, K.E.L., Ferguson-Lees, I.J., Gillmor, R., Hollom, P.A.D., Hudson, R., Nicholson, E.M., Olney, P.J.S., Voous, K.H., & Wattel, J. (Eds.) (1980). ***Handbook of the birds of Europe, the Middle East and North Africa. The birds of the Western Palearctic.*** Oxford University Press, Oxford.

Curry,J.P. (1994) ***Grassland invertebrates:Ecology,influence on soil fertility and effects on plant growth.*** Chapman & Hall, London.

Davis, B.N.K. (1986). ***Colonization of newly created habitats by plants and animals.*** Journal of Environmental Management. **22**, pp. 361-371.

Davis.T.H. & Hart,B.T.(1990a). ***Use of aeration to promote nitrification in reed beds treating wastewater.*** pp.77-84. In Cooper, P.F. & Findlater, B.C. (Eds.) ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Davies, T.H. & Hart, B.T.(1990b). ***Reed bed treatment of wastewater in a pilot-scale facility.*** In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Ditlhogo, K.M., James, R., Laurence, B.R. & Sutherland, W.J. (1992). ***The effects of conservation management of reed beds. 1-The Invertebrates.*** Journal of Applied Ecology. **29**, pp.265-276.

Disney, R.H. (1986). ***Assessments using invertebrates:posing the problem.*** In Usher, M.B. (Ed).***Wildlife conservation evaluation.*** Chapman & Hall, London.

DoE (1979) ***Dissolved Oxygen in Natural and Waste Waters.***Book No.16, Methods for the Examination of Waters and Associated Materials, HMSO , London.

DoE (1988) ***5 Day Biochemical Oxygen Demand (BOD_5).***Second edition, with Dissolved Oxygen in Waters, amendments 1988), Book No.130, Methods for the Examination of Waters and Associated Materials, HMSO, London.

DoE (1994).***Impacts of Nitrogen deposition in terrestrial ecosystems.*** Report of the United Kingdom Review Group on Impacts of Atmospheric Nitrogen, London.

Duffield, J.A. & Luke, A.W. (1995). ***A review of air quality - 1995.*** Public Protection & Trading Standards department, Middlesbrough Borough Council, Middlesbrough.

Edwards,M.E., Brinkmann,K.C. & Watson,J.T. (1993). ***Growth of soft-stem bulrush (Scirpus validus) plants in a gravel-based subsurface flow constructed wetland.*** In

Moshiri, G.A. (Ed.). ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton, USA.

Eyre, M.D., Carr, R., McBlane,R.P. & Foster, G.N. (1992). ***The effects of varying site-water duration on the distribution of water beetle assemblages, adults and larvae (Coleoptera: Haliplidae, Dytiscidae,Hydrophilidae).*** Arch.Hydrobiol.**124**, No.3, pp 281-291.

Eyre, M.D., Luff, M.L. & Ball, S.G. (1986). ***An Atlas of the Carabidae (ground beetles) of Northumberland and Durham.*** Hancock Museum Special Publication No.2, Northumberland Biological Records Centre, The Hancock Museum, Newcastle upon Tyne.

Feierabend, J.S. (1989). ***Wetlands:The lifeblood of wildlife.*** In Hammer, D.A. (Ed.) ***Constructed wetlands for wastewater treatment : Municipal, industrial and agricultural.*** Lewis Publishers, Michigan, USA.

Fojt, W. & Foster, A. (1992). ***Reedbeds, their wildlife and requirements. Botanical and invertebrate aspects of reedbeds, their ecological requirements and conservation significance.*** In Ward, D.(Ed.) ***Reedbeds for Wildlife : Proceedings of a conference on creating and managing reedbeds with value to wildlife, 15 November,1991.*** Nature Conservation Bureau Ltd, Newbury.

Foster, G.N., Nelson, B.H., Bilton, D.T., Lott,D.A., Merritt, R., Weyl, R.S. & Eyre,M.D. (1992). ***A classification and evaluation of Irish water beetle assemblages.*** Aquatic Conservation: Marine and Freshwater Ecosystems,**2**, pp 185-208.

Friday, L.E.(1988).***A Key to the adults of British water beetles.*** Field Studies Council Publication. **189**, Taunton, Somerset.

Garside, J. (1995). ***Botanical survey of Amoco Seal Sands CATS Terminal.*** Report by Cleveland Environmental Consultants Limited (Unpublished).

Gibson, S.M. (1989). ***The distribution and abundance of small mammals in second-rotation Sitka Spruce plantations in Northern England.*** M.Sc. dissertation, Department of Biological Sciences, University of Durham.

Goldsmith, A. (1986). ***Measurements of nitrogen dioxide at rural sites using passive diffusion samples.*** Warren Spring Laboratory, Stevenage.

Gooders, J. (1995). ***Field guide to the birds of Britain and Europe.*** Larousse, London.

Graham, G.G. (1988). ***The flora and vegetation of County Durham.*** The Durham Flora Committee and the Durham County Conservation Trust.

Graneli, W. (1985). ***Biomass response after nutrient addition to natural stands of reed Phragmites australis***. Ver.Internat.Verein.Limnol. **22**, pp.2956-2961.

Graneli, W., Weisner, S.E.B. & Sytsma, M.D. (1992). ***Rhizome dynamics and resource storage in Phragmites australis.*** Wetlands Ecology & Management, **1**, No.4, pp.239-247.
Grant, N., Moodie, M. & Weedon, C. (1996). ***Sewage Solutions : Answering the call of nature.*** Centre for Alternative Technology Publications, Machynlleth, Powys.

Gray, N.F. (1989). ***Biology of wastewater treatment.*** Oxford University Press, Oxford.

Gray, K.R., Biddlestone, A.J., Job,G. and Galanos, E. (1991). ***The use of reedbeds for the treatment of agricultural effluent.*** In Cooper, P.F., Findlater, B.C. (eds) *Constructed Wetlands in Water Pollution Control.* Pergamon Press, Oxford.

Green, M.B. (1993). ***Growing confidence in the use of constructed reed beds for polishing wastewater effluents.*** Proceedings of the Water Environment Federation 66th Annual Conference and Exposition. **9**, pp.86-96.

Green, B., Griffin, P., Jennings, P. & Upton, J. (1997). ***Removal of nitrogen by the combination of mechanical / biological treatment and constructed reed beds.*** Unpublished report by Severn Trent Water Ltd.

Green,M.B. & Upton,J. (1994) ***Constructed reed beds : A cost-effective way to polish wastewater effluents for small communities.*** Water Environment Research. **66.**No.3. pp.188-192.

Greenslade, P.J.M. (1964). ***Pitfall trapping as a method for studying populations of Carabidae (Coleoptera).*** Journal of Animal Ecology, **33**, pp.301-310.

Griffin, P.(1997). Personal communication. Severn Trent Water Ltd, Coventry.

Grime, J.P. (1979). ***Plant strategies and vegetation processes.*** John Wiley & Sons Ltd, London.

Grime, J.P. & Curtis, A.V.(1976). ***The interaction of drought and mineral nutrient stress in calcareous grassland.*** Journal of Ecology. **64**, No.3, pp. 975-988.

Grime, J.P., Hodgson, J.G. & Hunt, R. (1988). ***Comparative plant ecology: A functional approach to common British species.*** Unwin Hyman Ltd., London.

Grime, J.P. & Hunt. R. (1975).***Relative growth rate, its range and adaptive significance in a local flora.*** Journal of Ecology, **63**, pp.393-422.

Griss, D.(1996).***Wildlife in effluent treatment reedbeds.*** MA. Dissertation, University of Durham.

Griss, D. (1997). Personal communication.
Gurnell, J. & Flowerdew, J.R. (1982). ***Live trapping small mammals.*** The Mammal Society, Read ing.

Haberl, R. & Perfler, R. (1990). ***Seven years of research work and experience with wastewater treatment by a reed bed system.*** In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Haberl, R., Perfler,R., & Mayer,H. (1995) ***Constructed Wetlands in Europe.*** Water Science & Technology. **32**.No.3.pp.305-315.

Hammer, D.A. (Ed.) (1989) ***Constructed wetlands for wastewater treatment : Municipal, industrial and agricultural.*** Lewis Publishers, Michigan, USA.

Harrison, R.M. (Ed.)(1994). ***Pollution: causes, effects, and control.*** 2nd. Edition. Royal Society of Chemistry.

Haslam, S.M. (1972). ***Biological flora of the British Isles <u>Phragmites</u> <u>communis</u> (Cav.)Trin.ex Steudel.*** Journal of Ecology. **60**, pp.585-610.

Hawke, C.J. & Jose, P.V. (1996). ***Reedbed management for commercial and wildlife interests.*** RSPB, Sandy.

Hill, M.O. (1979a). ***TWINSPAN - a FORTRAN programme for arranging multivariate data in an ordered two-way table by classification of the indivisuals and attributes.*** Ecology and Systematics, Cornell University, Ithaca, New York.

Hill, M.O. (1979b). ***DECORANA - a FORTRAN programme for detrended correspondance analysis and reciprocal averaging.*** Ecology and Systematics, Cornell University, Ithaca, New York.

Horan, N.J. (1991) ***Biological wastewater treatment systems : Theory and operation.*** Wiley & Sons, Chichester.

House, C.H., Broome,S.W. & Hoover,M.T. (1994) ***Treatment of nitrogen and phosphorous by a constructed upland-wetland wastewater treatment system.*** Water Science & Technology. **29**.No.4. pp.177-184.

Hubbard, C.E. (1992). ***Grasses, a guide to their structure, identification, uses and distribution in the British Isles.*** Penguin Books.

Hudson, R. (1997). Personal communication. Environment Agency, Stockton-on-Tees.

INCA (1997). ***Tees Estuary Management Plan:A strategy for sustainable development.*** INCA Project Management, Billingham.

Jeffries, M. (1989). ***Measuring Talling's 'element of chance in pond populations'.*** Freshwater Biology. **21**, pp.383-393.

Jenkins, J. (1997). Personal communication.

Jessop, L. (1997). ***Assessment of Coleoptera assemblages in Phragmites reed beds using large area flight interception traps.*** The Vasculum. **82**, No.3, pp.33-60.

Jones, V. (1997). Cleveland Naturalists Field Club. Personal communication.

Kadlec, R.H. & Knight, R.L. (1996). ***Treatment Wetlands.*** Lewis publishers, Boca Raton, USA.

Kirby, P. (1992). ***Habitat management for invertebrates:A practical handbook.*** RSPB, Sandy.

Knees, S.(1989) ***Umbellifers of the British Isles.*** Shire Natural History. Shire Publications Ltd, Aylesbury.

Knight,R.L.(1993) ***Operating experience with constructed wetlands for wastewater treatment.*** Tappi Journal. **76.**(1), pp.109-112.

Knight, R. L. (1997). ***Wildlife habitat and public use benefits of treatment wetlands.*** Water Science & Technology, **35**, No.5, pp.35-43.

Kuehn,E. & Moore, J.A. (1995) ***Variability of treatment performance in constructed wetlands.*** Wat. Sci. Tech., **32** (3), pp.241-250.

Kuhl, H. & Kohl, J.G. (1993). ***Seasonal nitrogen dynamics in reed beds (Phragmites australis (Cav.) Trin.ex.Steudel) in relation to productivity.*** Hydrobiologia, **251**, pp.1-12.

Lacey, J. E.(1997). Cleveland Wildlife Trust. Personal Communication.

Lane, A. (1992). ***Practical conservation: Grasslands, heaths and moors.*** Hodder & Stoughton, London.

Lawrence, I. (1994) ***A guide to the wild flowers of Cleveland.*** 1st edition. Cleveland County Council.

Lawrence, I. (1997). Cleveland Naturalists Field Club. Personal communication.

Lawrence, M.J. & Brown, R.W. (1967). ***Mammals of Britain.*** Blandford Press, London.

Leakey, M. (1997). Personal communication. Teesmouth National Nature Reserve.
Lewis, O.A.M. (1986). ***Plants and nitrogen.*** Studies in Biology No.166. Edward Arnold, London.

Lindroth, C.H. (1974). ***Coleoptera:Carabidae. Handbooks for the identification of British Insects Vol IV, Part 2.*** Royal Entomological Society of London.

Luff, M.L., Eyre, M.D. & Rushton, S.P. (1989). ***Classification and ordination of habitats of ground beetles (Coleoptera, Carabidae) in north-east England.*** Journal of Biogeography. **16**, pp.121-130.

Luken, J.O.(1990). ***Directing ecological succession.*** Chapman & Hall, London.

Marchant, J. (1983). ***BTO. Common Birds Census Instructions.*** British Trust for Ornithology, Thetford.

Marschner, H.(1986) ***Mineral nutrition of higher plants.*** Academic Press,London.

Mason, C.F. (1991). ***Biology of freshwater pollution.*** 2nd. edition. Longman Scientific & Technical, Harlow.

Mason, C.F. & Bryant, R.J.(1974). ***The structure and diversity of the animal communities in a broadland reedswamp.*** Journal of Zoology, **172**, pp.289-302.

May,E., Butler,J.E., Ford,M.G., Ashworth,R., Williams,J. & Bahgat,M.M.M. (1990). ***Chemical and microbiological processes in gravel-bed hydroponic (GBH) systems for sewage treatment.*** pp.33-39. In Cooper, P.F. & Findlater, B.C. (Eds.). ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

McEldowney, S., Hardman, D.J. & Waite, S. (1993). ***Pollution:Ecology and Biotreatment.*** Longman Scientific & Technical, Harlow.

Merritt, A.(1994). ***Wetlands, Industry and Wildlife: A manual of principles and practices.*** The Wildfowl and Wetlands Trust, Slimbridge.

Miller, P.L.(1987). ***Dragonflies.*** Naturalists' Handbooks 7. Cambridge University Press, Cambridge.

Morris, M.G. (1969). ***Populations of invertebrate animals and the management of chalk grassland in Britain.*** Biological Conservation, **1**, pp. 225-231.

Morrison, P. (1989). ***Bird habitats of Great Britain and Ireland.*** Penguin, London.

Moshiri, G.A. (Ed.) (1993) ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton, USA.

Muir, D. P.(1997). INCA. Personal communication.

Parnham, M.R. (Ed.)(1996). ***The State of the Natural Environment of the Tees Estuary- A summary of changes in the last 25 years.*** INCA, Billingham.

Parr,T.W.(1990). ***Factors affecting reed (Phragmites australis) growth in UK reed bed treatment systems.*** pp.67-76. In Cooper, P.F. & Findlater, B.C. (Eds.) ***Constructed wetlands in water pollution control.*** Pergamon Press, Oxford.

Pearcy, R.W., Ehleringer, J., Mooney,H.A. & Rundel,P.W. (1989) ***Plant physiological ecology : Field methods and instrumentation.*** Chapman & Hall, London.

Platzer, C. & Netter, R. (1994). ***Factors affecting nitrogen removal in horizontal flow reed beds.*** Water Science & Technology. **29**, No.4, pp.319-324.

Pride, R.E., Nohrstedt, J.S. & Benefield, L.D. (1990).***Utilization of created wetlands to upgrade small municipal wastewater treatment systems.*** Water, Air, and Soil Pollution. **50**, pp.371-385.

Ratcliffe (1997). ***A nature conservation review.*** Cambridge University Press, Cambridge.

Reddy, K.R. (1984). ***Nutrient transformations in aquatic macrophyte filters used for water purification.***Proceedings of American Water Works Association on future of water reuse. No.2.

Reddy, K.R. & D'Angelo, E.M. (1997). ***Biogeochemical indicators to evaluate pollutant removal efficiency in constructed wetlands.*** Water Science & Technology. **35**, No.5, pp.1-10.

Reddy, K.R. & Debusk T.A. (1987). ***Nutrient storage capabilities of aquatic and wetland plants.*** In Reddy, K.R. & Smith, W.H.(Eds.). ***Aquatic plants for water treatment and resource recovery.*** Magnolia Publishing, Orlando, USA, pp.337-357.

Reddy, K.R. & Patrick (1984). ***Nitrogen transformations and loss in flooded soils and sediments.*** CRC Critical Reviews in Environmental Control. **13**, No.4, pp.273-309.

Reddy, K.R. & Smith, W.H.(Eds.)(1987) ***Aquatic plants for water treatment and resource recovery.*** Magnolia Publishing, Orlando, USA.

Robson, A. (1997). ***A study of May Moss : The effects and interaction of nitrogen air pollution within an oligotrophic blanket bog.*** BSc dissertation, University College Stockton.

Rodwell, J.S. (Ed.) (1992a). ***British plant communities, Volume 3, Grasslands and montane communities.*** Cambridge University Press, Cambridge.
Rose, F. (1981). ***The wild flower key.*** Penguin, London.

Rose, F. (1989). ***Colour identification guide to the grasses, sedges, rushes and ferns of the British Isles and north-western Europe.*** Viking, London.

Rowell, D.L. (1994). ***Soil science : methods and applications.*** Longman, Harwell.

Rushton, S.P. (1987). ***A multivariate approach to the assessment of terrestrial sites for conservation.*** In Luff, M.L. (Ed.). ***The use of invertebrates in site assessment for conservation.*** Agricultural Environmental Research Group, University of Newcastle upon Tyne.

Savage, A.A.(1989).***Adults of the British Aquatic Hemiptera Heteroptera :A key with ecological notes.*** Freshwater Biological Association Scientific Publication No.50, Ambleside.

Sikora, F.J., Zhu-Tong, L.L., Behrends, S.L. & Coonrod, H.S.(1995). ***Ammonium removal in constructed wetlands with recirculating subsurface flow:Removal rates and mechanisms.*** Water Science & Technology, **32**, No.3,pp.193-202.

Sims, R.W. & Gerard, B.M. (1983). ***Earthworms.*** Synopses of the British Fauna, No 31. Linnean Society. E.J. Brill / Dr. W. Backhuys.

Smith, J.K. (1989). ***Ecological impacts of extending No.4 brinefield to east of the Long Drag.*** INCA report (unpublished).

Smith, J.K. (1993). ***Ecological monitoring and management of ICI Billingham's reedbeds. Progress report No. 1-1993.*** INCA Projects Ltd, Billingham.

Smith, J.K. (1997). INCA. Personal communication.

Smith, S. (1997). Personal communication. Environmental Services Department, Stockton-on-Tees Borough Council.

Speed, C. (1997). Personal communication. Project manager, 'Air quality today', Middlesbrough Borough Council.

Spellerberg, I.F. (1994). ***Monitoring ecological change.*** Cambridge University Press, Cambridge.

Southwood, T.R.E (1978). ***Ecological methods: With particular reference to the study of insect populations.*** 2nd edition. Chapman & Hall, London.

Surface, J.M., Peverly,J.H., Steenhuis,T.S. & Sanford,W.E.(1993). ***Effect of season, substrate composition, and plant growth on landfill leachate treatment in a constructed wetland.*** In Moshiri, G.A. (Ed.). ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton, USA.

Surrency, D. (1993). ***Evaluation of aquatic plants for constructed wetlands.*** In Moshiri, G.A. (Ed.). ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton, USA.

Tchobanoglous, G. & Burton, F.L. (Eds.)(1991). ***Wastewater Engineering : Treatment, disposal and reuse.*** 3rd. edition. McGraw-Hill, New York, USA.

Thiele, H.-U. (1977). ***Carabid beetles in their environments.*** Springer-Verlag, Berlin.

Thut, R.N.(1993). ***Feasibility of treating pulp mill effluent with a constructed wetland.*** In Moshiri, G.A. (Ed.) ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton, USA

Toorn, van der J. & Mook, J.H. (1982). ***The influence of environmental factors and management of stands of Phragmites australis: II Effects of burning, frost and insect damage on shoot density and shoot size.*** Journal of Applied Ecology. **19**, pp.477-499.

Tyler, G. (1992). ***Requirements of birds in reedbeds.*** In Ward, D.(Ed.) ***Reedbeds for Wildlife : Proceedings of a conference on creating and managing reedbeds with value to wildlife, 15 November,1991.*** Nature Conservation Bureau Ltd, Newbury.

Ulrich, K.E. & Burton, T.M. (1985). ***The effects of nitrate, phosphate and potassium fertilization on growth and nutrient uptake of Phragmites australis.*** Aquatic Botany, **21**, pp.53-62.

Ward, D.(Ed.) (1992) ***Reedbeds for Wildlife : Proceedings of a conference on creating and managing reedbeds with value to wildlife, 15 November,1991.*** Nature Conservation Bureau Ltd, Newbury.

Watson, J.T. & Danzig, A.J. (1993). ***Pilot-scale nitrification studies using vertical-flow and shallow horizontal-flow constructed wetland cells.*** In Moshiri, G.A. (Ed.) ***Constructed wetlands for water quality improvement.*** Lewis Publishers, Boca Raton, USA.

Weedon, C. (1997)..Personal communication. Weedon Water Systems, Bridgewater, Somerset.

Weiner, P. (1997). Personal communication. Parsons Group International Ltd.

Wellburn, A (1994). ***Air pollution and Climate change.*** 2nd edition. Longman Scientific & Technical, Harlow.

van der Werff, M (1991). ***Common reed.*** In Rozema, J. & Verkleij, J.A.C.(Eds.). ***Ecological responses to environmental stresses.*** Kluwer Academic Publishers, London.

Wittgren, H.B. & Maehlum, T. (1997). ***Wastewater treatment wetlands in cold climates.*** Water Science & Technology. **35**, No.5, pp.45-53.

Wood,B. & McAtamney,C. (1994) ***The use of Macrophytes in bioremediation.*** Biotech.Adv. **12.**pp.653-662.

Woolley, M. (1997). Personal communication. Northumbrian Water, Darlington.

Worrall, P., Peberdy, K.J. & Millett, M.C. (1997). ***Constructed wetlands and nature conservation.*** Water Science Technology, **35**, No.5, pp.205-213.

Aspects of the Ecology of a constructed reedbed within herb-rich grassland
Carole Rushall, 1997.

Results of CATS Terminal reedbed and ICI No.6 brinefield reedbed water sampling and reed leaf tissue analysis.

In order that long-term monitoring of the reedbed can be directly comparable with this study, the results from the monitored parameters are tabulated in an EXCEL version 5 for Windows 3.11 formatted disc as follows:

File name	**Contents**
ammonwtr.xls	Reedbed water samples: Ammonium nitrogen (mg/L-N)
bodwtr.xls	Reedbed water samples: BOD (mg Oxygen/L)
careed.xls	Reed leaf tissue: Total calcium content (mg/g dry wt)
cawtr.xls	Reedbed water samples: Calcium (ppm)
chlwtr.xls	Reedbed water samples: Chloride (ppm)
codwtr.xls	Reedbed water samples: COD (mg Oxygen/L)
conwtr.xls	Reedbed water samples: Conductivity (μScm)
dowtr.xls	Reedbed water samples: Dissolved Oxygen (mg/L)
inorgwtr.xls	Reedbed water samples: Inorganic nitrogen (mg/L)
kreed.xls	Reed leaf tissue: Total potassium content (mg/g.dry wt)
kwtr.xls	Reedbed water samples: Potassium (ppm)
mgwtr.xls	Reedbed water samples: Magnesium (ppm)
nawtr.xls	Reedbed water samples: Sodium (ppm)
nitrawtr.xls	Reedbed water samples: Nitrate nitrogen (mg/L)
nitriwtr.xls	Reedbed water samples: Nitrite nitrogen (mg/L)
nreed.xls	Reed leaf tissue: Total nitrogen content as ammonium (mg/g dry wt)
phosreed.xls	Reed leaf tissue: Total phosphorus as phosphate (mg/g dry wt)
phoswtr.xls	Reedbed water samples: Reactive phosphorus (mg/L phosphate-P)
phwtr.xls	Reedbed water samples: pH
rgrowth.xls	Height of tallest shoot (cm)
sswtr.xls	Reedbed water samples: Suspended solids (mg/L)