The Use of Constructed Wetlands to Improve the Water Quality of the Bourne Stream, Dorset.

Kerry Fleet

BSc (Hons) Environmental Protection

Bournemouth University

2002

Abstract

The Bourne Stream, which takes its route through Poole and Bournemouth, finally joins the sea from an outfall pipe at Bournemouth beach. These are bathing waters under strict compliance with the Bathing Water Directive 76/160/EEC. Historically, the stream has had high levels of bacterial contamination, which has caused problems with regards to lack of compliance with the Directive.

Constructed wetlands were built in 2000 using Common Reed *Phragmites australis* and Cattail *Typha latifolia* as part of a water quality improvement measure. These emergent macrophytes are well known for their ability to clean waters, which contain organic pollutants and heavy metals.

A study was conducted over a 6- month period to assess how effective the wetland system was in improving the water quality of the Bourne Stream. Variables tested for were pH, temperature, BOD, dissolved oxygen, conductivity, nitrates, phosphates, turbidity, E. Coli, Total Coliforms and various heavy metals.

Significant improvements were not found. However, some reductions were made in the levels of turbidity, nitrates, phosphates and E.coli. The plants performance was not as well as expected. This was mainly due to the timing of the sampling schedule, which continued into the winter months when plant productivity was becoming lower and dieback becoming prevalent. There is also the possibility of non-point sources of pollution which could be affecting the efficiency of the system.

Contents Page **Page Number**

Note from Webmaster:
Appendices are not included in this copy
of Kerry's dissertation; those interested in viewing them can
contact the author direct at kerryfleet@hotmail.com

Introduction

Background

The Bourne Valley lies at the eastern edge of the Borough of Poole close to the Borough boundary with Bournemouth, Dorset (Bourne Valley Management Plan 2001). Within the valley is The Bourne Stream, which begins south east of Canford Heath and emerges west of Ringwood Road (OS SZ0460094650). It finally reaches the sea at Bournemouth after flowing for approximately 8km.

Fig. 1 UK location

The Bourne stream is set within an urban environment and is susceptible to spells of poor water quality, particularly following rainfall events (Smith, N., personal communication, Oct. 4, 2001). Bacterial contamination of the watercourse and the bathing water quality at Bournemouth Pier has been a problem as this has lead to guideline failures of the Bathing Water Directive 76/160/EEC standards. These failures have consequently resulted in the periodic loss of the Blue Flag Award. This award is only given to those beaches which fulfil strict criteria relating to both the water quality and the surrounding beach area. In particular they must meet the bathing water quality of the mandatory and guideline values of the Bathing Water Directive 76/160/EEC which are displayed below.

Parameter	Guideline standard	% compliance	Mandatory standard	% compliance
Total Coliform	500 per 100ml	80%	10,000per 100ml	95%

Bournemouth Borough Council holds this award with great esteem, as beaches holding it are recognised as having good water quality, beach cleanliness, management and provision facilities. This is important for Bournemouth, as its beach is one of the UK's most popular coastal tourist attractions.

The detrimental effects that poor water quality has upon the wildlife and habitats within the site has also had to be addressed. A watercourse with low levels of oxygen and a high oxygen demand for example, exerts pressure on the biota living in the stream especially for those species which are less tolerant to polluted conditions. This is considered to be one of the most salient issues and has resulted in the collaboration between English Nature, Environment Agency and Poole Borough Council.

A proactive and collective approach was necessary if significant and sustainable improvements were to be made and so in 1999, the Bourne Stream Partnership was established. Members of the partnership are Poole Borough Council, Bournemouth Borough Council, Environment Agency, Bournemouth University, Dorset Coastal Forum, Greenlink, Wessex Water, Bournemouth & West Hampshire Water and English Nature.

This was necessary for a number of reasons. Firstly, due to the area coverage of the stream, i.e., flowing through both Poole and Bournemouth, the two councils needed to form co-operative working relations. Secondly, water quality, ecological and hydrological expertise was required to ensure important decisions, i.e. reed bed construction and water quality tests were carried out correctly. Finally, different people from various organisations had a wealth of information, with regards to a whole range of aspects of the stream, which when pooled together, provide a valuable communication network. All the members have an interest in the Bourne Stream and long-term improvements can only be achieved with the cooperation of everyone within the partnership.

Design of the Bourne Stream Wetland Site

Fig. 2 Site plan.

Figure 2 is a basic plan of the site. A more detailed plan (fig. 3) can be found in the appendix.

The site is adjacent to the main Ringwood Road, Poole. It is opposite a residential area and very close to an industrial site. Before the wetlands were built, the site consisted of woodland, dominated with willow trees. The water, which is a constant flow, flows downstream until it reaches a small dam. The purpose of the dam is to push the water into the first area of water treatment (phase 2 sud site). This consists of an area of approximately 2500 m^3 . The reason for constructing this off-line system was to contain the ‘first-flush after heavy rainfall which can be heavily polluted.

An official plant survey is yet to be carried out, but species currently known to be growing in this area include Broad leafed pond weed *Potamogeton natan*, Amphibious Bistort *Polygonom amphibium*, Water Mint *Mentha aquatica* and Gipsy Wort *Lycopus europaeus*. The water which does not enter this 1st phase, flows further down stream until it reaches the next phase of water treatment (phase 1 sud site).

Phase 1 consists of 5 on-line ponds and 1 deep pond, which are designed to remove sediments form the watercourse and aid sedimentation. This reedbed filtration system was built in the upper catchment in April 2000 area as part of the first phase of water quality improvements. It comprises of a filtration pond, sand filter and a reedbed and pool area of approximately 75 metres long by 30 metres wide (Bourne Valley Management Plan 2001). The dominant species are the emergent macrophytes, Common Reed *Phragmites australis* and Cattail *Typha latifolia*. Although a plant survey of this particular area has not been carried out, Countryside Wardens observations indicate that *Typha latifolia* has become the dominant of the two species. The total area of this 1st phase is approximately 1 hectare.

This treatment area aims to take 75% of the incoming water. The water runs through this online system and then continues to flow downstream towards Bournemouth. The site is opposite a residential area and very close to an industrial site.

Additionally, in October 2001, two online ponds were constructed and are situated after the phase 2 and before phase 1. The purpose of this was to decrease the velocity of water, which aids sedimentation and to provide extra habitats for plants and invertebrates.

Due to these particular features and alterations to the land, it is classed as a constructed wetland site. *Phragmites australis* and *Typha latifolia* both renowned for their ability to improve water quality are both prevalent within the system. However, only *Phragmites australis* was planted and *Typha latifolia* colonised the area by possibly wind dispersion of its seeds or from bird excretions.

A more technical term, Sustainable Drainage Systems (SuDS) has been used to describe the measures implemented in the upper catchment area. Wetlands are not the only type of SuDS; others include, Porous Pavements, Swales and Basins and Infiltration, Trenches, Basins and filter Drains, however wetlands in particular make a significant contribution to visual amenity and biodiversity. All these systems are designed to receive surface water runoff and deliver significant reductions in impact on the watercourse by acting as filters for sediments and other materials which may have an adverse effect on the water quality. South Gloucestershire is another example of a local authority, which have implemented SuDS on a range of projects and share the over-arching aim of seeking to achieve sustainable development, and within this, the conservation and enhancement of the water resource (Environment Agency 1999).

Despite high levels bacteria being a major concern, there are other important variables, which need to be tested for if an overall understanding of the Bourne stream's water quality is to be achieved. The following parameters are to be tested for as they are all significant in establishing water quality.

Dissolved Oxygen

All living organisms in the river are dependent on oxygen to maintain the metabolic processes that produce energy for growth and reproduction. A high level of dissolved oxygen in the water should provide good conditions for a wide range of biota.

Conductivity

Conductivity, with regards to water quality refers to the amount of salts in the water and is a numerical expression of the ability of an aqueous solution to convey an electric current. It is also an approximate indicator of total dissolved ions such as heavy metals and is widely used for pollution monitoring. This property is related to the total concentration of ionised substances (cations) their respective concentrations, mobility and valence (Stednick 1991).

Turbidity

If a water body is cloudy, it is an indication that there are suspended solids present in the water. These solids consist of silt, clay and fine particles of organic compounds and micro-organisms (Gray 1999). High turbidity levels would suggest that there were considerable amounts of suspended solids, from example, either animal waste, run-off from the soil or decomposing leaves. Decreasing the amount sunlight from penetrating the water reduces the photosynthesis process of the submerged aquatic plants and consequently increases the rate at which these plants die off. The dead plant matter, which is suspended in the water, can add to the problem of nutrient enrichment.

BOD_5

Biochemical Oxygen Demand (BOD) is inter-related with the levels of dissolved oxygen in the water. Organic compounds such as carbohydrates, proteins and fats, which can be a result of urban run-off, domestic sewage and industrial effluent, are broken down by the micro-organisms present in the water and this exerts an oxygen demand.

High BOD levels or oxygen depletion in a watercourse can have severe consequences for the stream biota, as they are dependent on oxygen as it is vital for their survival. Results from this test can give an indication of how much organic matter is present in the water (Mason 1996). If a high BOD persists, there is a risk of anaerobic conditions becoming revalent, resulting with the production of toxic gases such as methane, ammonia and hydrogen sulphide.

pH

The amount of hydrogen ions in the water determines its acidity. Water is classified as acidic if it is below 6.0 and alkaline if it is above 8.0. At a low pH, heavy metals for example, can become more toxic as they are mobilized and made readily available.

Temperature

The temperature of the water is closely related with dissolved oxygen. The lower the temperature, the higher the solubility, as cold water holds more oxygen (Gray 1999). Most of the key conditions which are related to dissolved oxygen deficiency occur during the summer months when temperatures are high and the solubility of oxygen is at its lowest.

Total Coliforms and E-coli

Most natural waters contain a variety of micro-organisms (Haslam 1990). However, a number of these micro-organisms are responsible for a variety of diseases and their existence in the watercourses poses a health risk. The Bourne stream has been found to contain high levels E. coli as well as a variety of other coliform bacteria, which indicates that there is faecal contamination in the water.

Bacterial contamination of a watercourse, such as the Bourne stream, which is eventually discharged into bathing waters, poses significant health threats such as gastroenteritis and it is important to minimize this.

Nitrates

Nitrate (NO_3^-) in the form of dissolved nitrate is an important nutrient for plant growth and when these plants die, nitrates are returned to the soil. However, some is lost and leached into the water. Addition of nutrients into watercourses is a natural process, though anthropogenic activities such as farming and sewage inputs, for example have sped up the rate at which this is happening and caused nutrient enrichment, otherwise known as eutrophication. This process involves the increase in aquatic plant growth, which therefore decreases the amount of sunlight able to penetrate the water. As plant biomass increases, submerged plants die-off causing even more nutrients to enter the watercourse.

Phosphates

Phosphates (PO_4^-) are another source of nutrients for plant growth. They are precipitated as an insoluble ion and released much slower to nitrates, which are leached and soluble more readily. Just like nitrates, phosphates, in excessive amounts cause the problems associated with nutrient enrichment as described above.

Heavy Metals

Heavy metals such as copper, lead, cadmium and nickel are natural components of the environment continually being released into the aquatic environment from natural processes such as weathering of rocks (Mason 1996) and in small quantities they should have no detrimental effects on either the water quality (such as acidification) or the aquatic ecosystems. However, once certain levels have entered the stream, these metals can be toxic.

Biological Sampling

A characteristic of most natural freshwater waters is that they provide a habitat for a range of organisms such as freshwater invertebrates. The particular types and numbers of groups of these invertebrates are closely related to water quality. There are certain species, which are sensitive to pollution such as caddisflies and there are others, which are tolerant and survive in water, heavily polluted with organic material such as those species belonging to the Oligochaeta family.

Whereas physical and chemical sampling provides information about the quality of the water at the time of sampling, biological sampling indicates water quality conditions over an extended period of time. Intermittent pollution, which maybe undetected in a chemical sampling programme, can be detected in the biological sample.

An example of this is provided in Mason (1996). A river sampled at station A every Tuesday and analysed for 10 chemical parameters, one of which is zinc. However, on Wednesday morning every fortnight, a factory immediately upstream may be discharging effluent, which contains the same element. The following Tuesday the zinc will have disappeared downstream and the sample analyst will have not found zinc in the sample.

Alternatively, a biological sample may reveal an unexpected decrease in the diversity of the biological community, as some species maybe eliminated and others maybe killed by the zinc.

The objective of this type of sampling is to identify the types of invertebrates living in the stream in order to evaluate the quality of the water. If the wetlands have made a significant improvement to the water quality, this should be reflected in the biota living in the stream, i.e. there maybe more pollutant intolerant species after the wetlands and more pollutant tolerant species in the sampling site before the wetlands.

Reasons for sampling for benthic macroinvertebrates (those which inhabit the stream bed) are firstly, the sampling procedures are simple and relatively well developed and secondly, these type of organisms are reasonably sedentary with comparatively long lives, so that they can be used to assess the water quality at a single site over a long period of time.

Aims and Objectives

The aim of this research project is to determine whether or not the use of constructed wetlands significantly improves the water quality of the Bourne stream. This can be expressed as a hypothesis that can be statistically tested:

Does the use of wetlands make a significant difference to the quality of the water?

Chemical, physical and biological parameters will be tested for at selected sampling sites, both prior to the wetland area and after. Water quality variables selected and tested for include the following: temperature, BOD[5], dissolved oxygen, pH, conductivity, nitrates, phosphates, turbidity, Escherichia coli (E. coli) and Total Coliforms and the following heavy metals: copper, cadmium, nickel and lead.

If there have been historical problems or areas of concern of the stream's water quality, these need to be made aware of as they may be influencing the present state of the stream's water quality which will be established as a result of the various tests named above.

If pollutants/contaminants are present in the water, the source of these needs to be established and ideally measures should be put in place to minimise these inputs i.e., road run-off, sewage, industrial effluent etc.

As the stream finally emerges from an outfall pipe into bathing water's compliance with the EC Bathing Water Directive is required. Information from microbiological tests will show whether or not this standard's requirements are being met.

Wetland Types

The effect of the wetlands on the quality of the water is the focus of this project. The term *wetlands* has been used several times, but what are they? Dobson (1998) defined them as an area of land whose characteristics are determined by the presence of water, either permanent water logging or through regular flooding.

There are many different wetland types, for example, tidal salt marshes and mangrove swamps which are classified as coastal wetlands and there are others such as peatlands and freshwater marshes which as classified as inland wetlands. The Bourne stream is indeed a constructed wetland but it is very low-tech and was built with the idea of being as 'natural' as possible and if it were natural it would best be described as a riparian wetland which is also classified as an inland system.

Riparian wetlands are characterised by an adjacent stream or river and the soils and soil moisture are influenced by this water-body. The riparian zone of a river, stream, or other body of water is the land adjacent to that body of water that is, at least periodically influenced by flooding (Odum 1981 cited Mitsch and Gosslink 2000 page 514) and it is this riparian zone, which is valuable for the animals that inhabit it.

As opposed to natural wetlands, constructed wetlands consist of only two types, surface-flow and sub-surface flow. The wetland at the Bourne site is a surface-flow system, designed to mimic natural wetlands. Surface-flow flow systems are able to support a combination of macrophytes; free-floating, submerged and emergent, whereas subsurface-flow systems which resemble wastewater treatment plants than wetlands, are limited to emergent macrophytes (Mitsch and Gosslink 2000).

Problems Associated with Urban Run-off

Rivers and streams are courses of water flowing along a bed of earth towards the sea (Haslam 1990). Anthropogenic activities such as land use i.e. agricultural and industrial have caused changes to the chemical and physical characteristics of the rivers and streams.

Urban run-off and highway drainage pose threats to receiving rivers and streams. The constituents of urban run-off are vary variable as it may contain dog faeces, heavy metals from vehicles suspended material, and at certain times of the year, rich in chloride from road-salting operations. The sources of this polluted effluent for, example, might be roof drainage, factories, sewage misconnections and highway drainage and the Bourne receives both roof and highway drainage.

The Bourne stream is set within an urban catchment. Urbanization leads to an increase in area of impermeable surfaces such as roads, driveways and a decrease in areas that are available for percolation and filtration of storm-water (Davies and Bavor 2000).

Urban run-off can carry quantities of nutrients such as nitrates and phosphates are macronutrients, which in small quantities are beneficial, as they are essential for the healthy growth of aquatic plants, such as the macrophytes, which grow in wetland habitats. However, in large quantities, they can cause eutrophication, which is the enrichment of waters due to the breakdown of organic material.

Organic compounds such as carbohydrates, proteins, fats and nucleic acids are broken down by bacteria into inorganic compounds, which include carbon dioxide, nitrates and phosphates.

One of the potential problems is, that the more organic pollution discharged into the watercourse the more oxygen is used by the bacteria during the decomposition process and the dissolved oxygen in the receiving water maybe used up at a greater rate than it can be replenished, causing oxygen depletion and a BOD. However, levels of depletion will depend on the rate of dilution, rate of aeration and the strength of the discharge, i.e. concentration of pollutants (Gray 1999).

Localised inputs may occur if there are livestock near the water. At the Bourne Stream upper catchment area, there are two horses, which live there permanently, but fences have been erected to prevent them from entering the wetland area. However, on one particular occasion they were seen within this area.

Effects of eutrophication on watercourses, like the Bourne stream are an increase in plant biomass, BOD and turbidity. A detrimental effect can be had on the amenity value of the watercourse too. The Bourne stream is in an area popular with walkers and at the lower and final stages of the stream, it is located in the popular Bournemouth gardens. The aesthetic quality of the water is just as important as the chemical and bacterial quality. In a resort such as Bournemouth, people do not expect to see waters which surfaces are covered in algal blooms or smell offensive odours from decaying algae. In November 2001, six of Bournemouth's green spaces were awarded with the Green Flag award including the towns Upper Central Gardens, through which the Bourne stream flows. The winning areas were recognised for environmental protection enhancement, high quality landscapes and safety, cleanliness and accessibility.

When a dry weather period is followed by a storm event a 'first flush' is the result. This can be highly polluting water much of which may come from catchpits of roadside drains, which have thick bacterial scums. High bacteria levels, was a problem in the Bourne and one of the primary reasons for building the wetland site. It might be thought that this increased level of pollutants might have an overwhelming effect on the wetlands performance, but one particular study conducted by the Environment Agency (Scholes *et al.* 1999) found that during storm events, removal efficiencies were actually higher, whereas during dry weather they varied greatly.

The use of constructed wetlands in this instance was primarily to treat urban run-off. Just like one of the Bourne Stream Partnerships goals, the Environment Agency saw this as an opportunity for enhancing the environment by creating a new habitat in urban areas.

The Use of Constructed Wetlands to Improve Water Quality

The use of constructed wetland systems to treat water is an emerging technology in the UK (Scholes *et al* 1999). Awareness of the effects of run-off on surrounding watercourses and the benefits of constructed wetlands as way of improving water quality has increased and there have been many initiatives adopted to attempt to control the amount of various pollutants entering watercourses.

Reduce Impacts of Road Run-off

The runoff from the high profile A34 Newbury bypass is one such example. A constructed wetland was built as one of a series of treatment stages and in 1999 a monitoring programme was initiated to evaluate the removal and 'behaviour' of pollutants (Pontier *et al.* 2001)

As there are no specific design and operating codes for this type of application, the runoff control systems were designed according to the best available guidance, such as Control of Pollution from Highway Discharges CIRIA Report No. 142 (Pontier *et al* 2001)

The wetlands at this site were effectively balancing ponds enhanced with wetland plants and this system was one of nine, which ran along the 13.5km bypass. Unlike the planting at the Bourne Stream site, a total of thirteen species were planted, the main one being the reed sweet grass, *Glyceria maxima*.

To allow establishment and development of wetland conditions which promote the treatment mechanisms, the ponds were planted a year before the road opened in November 1998. The wetlands at the Bourne site were not given any length of time to establish and were put into action as such, as soon as they were planted.

The results of the study, which assessed the effectiveness of the wetlands, showed that the most significant change in water quality was found in the total suspended solids (TSS), with a 40% reduction across the silt trap and a further 50% reduction across the wetland. The following shows the results for other parameters tested.

Fig. 4	BOD	TSS	Iron	Copper
	mg/l	mg/l	μg/l	μg/l
Wetland inlet	2.57	40.5	2997	17.8
Wetland outlet	3.52	19.1	2665	15.0

BOD levels entering the wetlands were lower than expected. Although variable, some removal of metals occurred as water passed through the pond. The study concluded that the levels of contamination of the runoff were lower than those reported in other runoff studies they had researched, but the wetlands effectively removed TSS and as the metals were mainly associated with particulates, the removal of TSS in the pond therefore promoted the removal of metals.

One particular study by Scholes *et al* (1999) showed how effective constructed wetlands are during wet weather when runoff is increased, focusing the removal of urban pollutants by constructed wetlands during wet weather with a view to improving the water quality of two tributaries to the River Thames.

The Environment Agency developed urban runoff wetlands in outer London. They found that during dry weather, removal efficiencies varied greatly but during storm events, removal efficiencies were higher. Pollutant loads and hydrological responses are highly variable. Just as the Bourne Stream Partnership has done, the Environment Agency also saw this as an opportunity for enhancing a new habitat in urban areas. The emergent macrophyte *Phragmites australis* was planted in the constructed wetland site.

This was a long-term study, which was carried out over two years. An increase in suspended solids was found and this was due to resuspension.

They performed a heavy metal analysis, which found that most metals could be removed from the water column and accumulate in the sediment. Metal analyses of total plant tissue of both *Typha latifolia* and *Phragmites australis* showed marked seasonal variations in metal concentrations, both containing highest concentrations in summer and with lowest concentrations in autumn. A suggested reason for this is that *Phragmites australis* has a longer growing season than *Typha latifolia*, which starts to die-back in autumn.

Apart from concluding that the constructed wetland was more than capable at removing a range of urban pollutants they highlighted the importance of having a maintenance and management plan. The Bourne Valley partnership has had a management plan since 1994 and has an updated and extensive plan for 2001. These plans set out the aims and objectives, information on work carried out and goals for the future.

The study concluded that constructed wetland systems are capable of removing a range of urban pollutants from the water column during both wet and dry weather.

To Comply with Bathing Water Directive 76/160/EEC

Bournemouth Borough Council are fully aware of the importance of complying with Bathing Water Directive 76/160/EEC and the consequences if it fails to do so. Coombes and Collett (1995) looked at the use of a constructed wetland to protect bathing water quality recognizing that the Bathing Water Directive 76/160/EEC imposes strict limits on the bacterial quality of the waters used by the public for bathing.

The site researched, an area in Thurlestone, which is on the south coast of the county Devon is also a site of special scientific interest (SSSI) into which treated sewage effluent is discharged.

The effluent has to be of both high bacteriological and chemical quality not only to comply with the directives standards but also to protect the SSSI. The popular reed, *phragmites australis* was planted as part of a horizontal flow system. Like Bournemouth, before the wetlands had been constructed, the bathing waters failed the quality standards required by the Directive.

Discharges are released into a small stream, which flows approximately 1.2km through a natural ley, which is the constructed wetland area and finally is discharged into the sea. The reed beds performed excellently with regards to improvement of bacterial quality. Removal efficiency of Total Coliforms was 99% and removal efficiency of E. coli was also 99%.

Overall the reed bed treatment systems proved to be very effective but total phosphate removal was disappointing but then phosphate removal is known to be unpredictable and not as effective. 3% of phosphate was removed whereas removal of total oxidized nitrogen was 24%.

Improve Wildlife and Biodiversity

The reed *Phragmites australis* was chosen to be planted at the Bourne site due to its fundamental properties, which make it (as well as other species of macrophytes) an essential component of a constructed wetland. Brix has investigated the functions of macrophytes in constructed wetlands and into the morphology of wetland plants such as *Phragmites australis*. For example, how they are adapted to growing in a water –saturated sediment, and environment typical of a wetland. They have large internal air spaces for transportation of oxygen to roots and rhizomes (Brix 1994).

Not only does he describe the functions that macrophytes perform in relation to water quality improvements but also he discusses the importance of wetland vegetation in relation to the habitats they provide for wildlife, including birds and reptiles.

The Bourne Valley is the habitat to sand lizards *Lacerta agilis* and smooth snake *Coronopus austrica* which are both endangered species and nationally protected.

Typical wetland birds such as the common moorhen *Gallina chloropus*, mallards *Anas platyrhynchos*, reed warblers *Acrocephalus scirpaceus* have been observed at the Bourne site. Various species of dragonflies have also been seen. Dragonflies inhabit freshwater and wetlands such as ponds, lakes, rivers, marshes, fens and bogs (Anon 2001). Over 20 different species of both damselflies and dragonflies have been recorded and they include the Small Red Damselfly *Ceriagrion tenellum*, Southern Hawker *Aeshna cyanea*, Emperor

Anax imperator which is Britain's largest dragonfly and the Keeled Skimmer *orthetrum coerulescens*.

Initiatives like the one adopted by the Bourne Stream Partnership are one of many worldwide. For example, substantial amounts of both time and money have been spent throughout the USA in an attempt to achieve clean and ecologically sound streams and rivers.

The Des Plaines River Wetlands Project (Kadlec and Hey 1994) successfully illustrates the potential of constructed wetlands for controlling non-point source pollution river water quality improvement. The Des Plaines River that runs through Wadsworth, Illinois, main water quality problem was turbidity but it also contained high levels of copper, iron and faecal coliforms.

When developing such a project, many other factors have to be taken into consideration. Those factors could include topography, hydrology, geology, soils, vegetation, aquatic invertebrates, terrestrial insects amphibians, reptiles, fish, birds, historic uses and public use. This is why a management and maintenance plan is essential for the continued and long-term success of constructed wetlands.

The improvements in the water quality of the river were very significant. Turbidity levels were dramatically decreased as the "experimental areas trapped about 88% of the sediments contained in the incoming river".

Methodology

Sampling Site Selection

To obtain accurate representation of the composition and nature of water, it is essential to ensure that the sample analysed is truly representative of the source (Tebbutt 1992).

When determining sampling site selection, several factors need to be considered. Firstly, the study's objectives. The main objective of this study was find out whether or not the wetlands made a significant improvement to the water quality of the Bourne Stream. Sampling sites should consist of one situated upstream, before the water passes through the wetlands and another, just after the water flows out from the wetlands.

Accessibility is another factor, which had to be taken into consideration. It was fortunate that access was available, ensuring appropriate sampling sites. For the biological sampling of the stream, access proved to be somewhat problematic and is discussed in further detail in the section headed 'Biological Sampling'.

The ideal sampling situation for a stream is a cross section that would yield the same concentrations of all constitutions from all points along the cross section, and a sample taken at any time would yield the same concentrations as one taken at any other time (Stednick 1991).

Sampling procedure

Water samples were taken from the upper catchment area where the stream emerges at Ringwood Road, once a month, over a five-month period from August to December 2001. The exact dates are as follows:

Thursday 2nd August, Wednesday 19th September, Monday 1st October, Thursday 8th November and Wednesday12th December.

University work placement and summer vacation employment commitments determined the first three sampling dates. However, despite these constraints, an attempt was made to achieve a systematic structure to the sampling schedule. Samples were taken over a five-month period in order to obtain as much quantitative data as possible in attempt to maximize both the validity and statistical power of the results.

Samples were taken from three points which are highlighted in the following diagram.

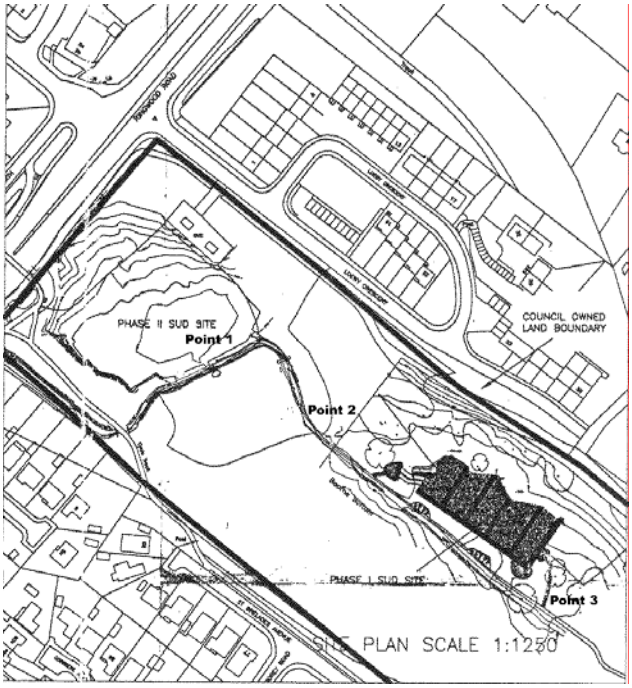

Fig. 5 Sampling points

Sample site 1.

The first was positioned near to where the stream emerges from an underground pipe and was chosen in an attempt to establish the immediate state of the water quality.

Sample site 2.

The second is a point just before the water enters the wetland area. This should be a good point to indicate the quality of the water prior to the treatment by the wetlands.

Sample site 3.

The third was the outflow point, after the water had passed through the wetlands. This point was chosen as it was considered a good point to assess the effectiveness of the plants at removing any contaminants.

Chemical and Physical Parameters

pH

The results for this test were obtained on site. A Camlab KS701 ISFET pH meter was used. Prior to use, it was calibrated using a 6.9 solution.

Temperature

The results for this test were obtained on site. A digital thermometer was used.

Dissolved Oxygen

A Camlab 46700-03 pocket colorimeter was used for this test and it was calibrated prior to use. Results were obtained on site. Instructed procedure was followed.

Conductivity

Conductivity is measured using a specific electrode and is expressed in micro-siemens per centimetre. A Hanna Instruments, DiST WP 3 meter was used which was calibrated prior to sampling. Results were determined on site.

Turbidity

Results were obtained on site. A Hanna Instruments, portable microprocessor, turbidity meter HI 93703 was used and was calibrated prior to use.

BOD_5

1 litre container bottles were filled with water sample and then kept in a dark environment for 5 days at 20°C. The Camlab 46700-03 pocket colorimeter was used to determine how much dissolved oxygen remained in the water. Dissolved oxygen measurements taken were used to calculate the amount of oxygen used over the 5 days.

Nitrates

10ml water samples were put into sterylene tubes, which were preserved in a freezer until they could be analysed. This test was measuring the amount of soluble nitrogen, in the form of nitrate (NO_3^-) in the water. Originally, results were to be obtained from the Ion Chromatography machine. Unfortunately it was out of service and unable to be used for this particular analysis (the same applied to the phosphate analysis). Alternatively, results were obtained by using the Hanna Instruments HI 93728 Ion Specific Meter and the corresponding nitrate reagent.

Phosphates

10ml water samples were also put into sterylene tubes, which were preserved in a freezer until they could be analysed. This test was measuring the amount of phosphorous, in the form of phosphate (PO^{4-}) in the water. Results were obtained by using the Hanna Instruments HI 93717 Ion Specific Meter and the corresponding phosphate reagent.

Microbiological Sampling

Total Coliforms and E-coli

100 ml water sample were collected. In the laboratory, a sachet of Colilert reagent was added to each of the samples and vigorously shaken. Each sample was then put into an IDEXX pack, which was sealed using a Quanti – Tray Sealer, model 2X, and then put into a Type 142 300 Incubator at 35°C for 24 hours. After the 24-hour period each pack was removed from the incubator. To determine total coliform levels the number of capsules on the pack which turned yellow were counted and converted into MPN counts using the Table MPN IDEXX, Quanti – Tray 200.

To determine E. coli levels, each pack was individually put under the Spectroline, Model – 10, Fluorescence Analysis Cabinet. The number of capsules which fluoresced were counted and converted into MPN counts using the same table as the one used for total coliforms.

Heavy Metal Analysis

The Unican 939 AA Spectrometer was used to determine levels present in the water.

Lead, Copper and Zinc standard solution were made up. These were used to calibrate the machine. Due to differing sensitivities of each element, concentration also differed:

Lead: 5,15, 10ppm Copper: 2, 4, 6ppm Zinc: 1, 2, 4ppm

Biological Sampling

The bio-diversity of the stream was investigated. To obtain a representative sample the three - minute kick and sweep method was used. This involved going into the stream and trying to make sure that all the major habitats were included.

The macro-invertebrate samples were separated from the substrate and the contents of the net were placed into a plastic tray half filled with stream water. The contents of the tray were poured into a 1-litre container bottle and taken back to the laboratory. Placing a sieve over the top of the container, the water was emptied away and replaced with methylated spirits. Alcohol was used to preserve the contents of the sample. The macro-invertebrates were identified and then an estimation of the water quality was determined by application of the widely used Biological Monitoring Working Party (BMWP) biotic index. A copy of the biotic score system can be found in the appendix (Fig. 6).

Results

Physical and Chemical parameters

pH

	Site 1	Site 2	Site 3
Date 1	8.0±	7.8±	8.0±
Date 2	7.9±	8.6±	8.2±
Date 3	7.4±	8.0±	7.8±
Date 4	7.4±	8±	8.0±
Date 5	7.8±	8.1±	8.2.±

Table 1

Table 1 displays the mean averages for all the sample dates at each sampling site. All standard errors are displayed in table 17 which can be found in the appendix. To find out if the wetlands had made a significant difference to the pH of the water, a 1 Way ANOVA test was used. 95% confidence limits were applied.

Results showed that Sig. (P) = 0.062 and F = 3.525. Due to $P > 0.05$, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not make a significant change to the pH of the water. Figure 7 displays the data above.

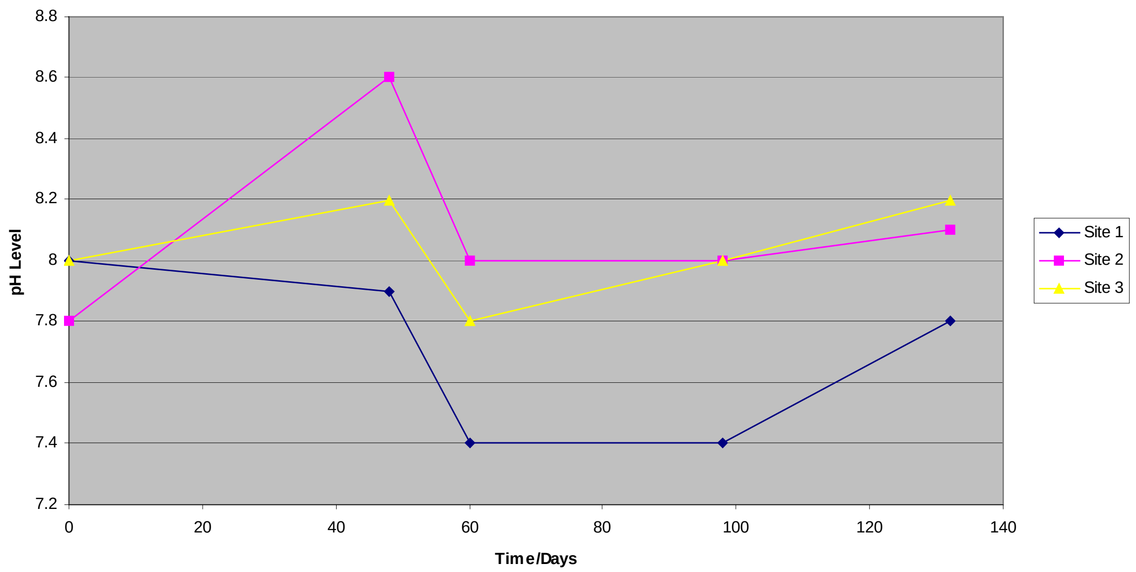

Fig. 7

On sample date 1, there was very little difference in pH levels between each site. Alternatively, both sample dates 2 and 3 show more of a difference between the sites. On date 2, there was a difference of 0.7 between site 1 and 2 (site 1 having a lower pH 7.9) and at site 3 the mean pH was 8.2 (a decrease of 0.4 between site 2 and 3). Results for date 3, show a similar trend, although the differences between the sites are less. Apart from date 1, the mean pH of site 1 was always lower than the means from sites 2 and 3, although the increase never exceeded 0.6. The mean pH of site 1 was 7.7, the mean pH of site 2 was 8.1 and for site 3, the mean pH was 8.0.

Temperature (°C)

	Site 1	Site 2	Site 3
Date 1	19±	19±	18.6±
Date 2	13.8±	13.7±	13.5±
Date 3	15.3±	15.5±	15.3±
Date 4	10.9±	10.9±	10.7±
Date 5	7±	7.7±	7±

Table 2

A correlation analysis was carried out to see if there was relationship between the temperature of the water and the amount of dissolved oxygen in the water. Due to data from all three sites being normally distributed, and having a linear relationship, the parametric Pearsons test was used. The results are as follows:

Site 1. correlation coefficient $r = 0.866$ Sig. $(P) = 0.000$

Site 2. correlation coefficient $r = 0.767$ Sig. $(P) = 0.001$

Site 3. correlation coefficient $r = 0.778$ Sig. $(P) = 0.001$

This analysis shows that there is a significant correlation between the temperature of the water and the amount of dissolved oxygen. As the temperature of the water decreases, the amount of dissolved oxygen increases.

Dissolved Oxygen (mg/l)

	Site 1	Site 2	Site 3
Date 1	8±	2.2±	4.3±
Date 2	9.4±	9.3±	4.7±
Date 3	9.7±	10.4±	6.2±
Date 4	10.6±	10.4±	6.4±
Date 5	11±	10.9±	10.3±

Table 3

Table 3 displays the mean averages for all the sample dates at each sampling site. To find out if the wetlands had made a significant reduction in the turbidity of the water a 1 Way ANOVA test was used. 95% confidence limits were applied.

Results showed that Sig. (P) = 0.157 and F = 2.168. Due to P > 0.05, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not make a significant change to the amount of dissolved oxygen in the water. Figure 8 displays the above data.

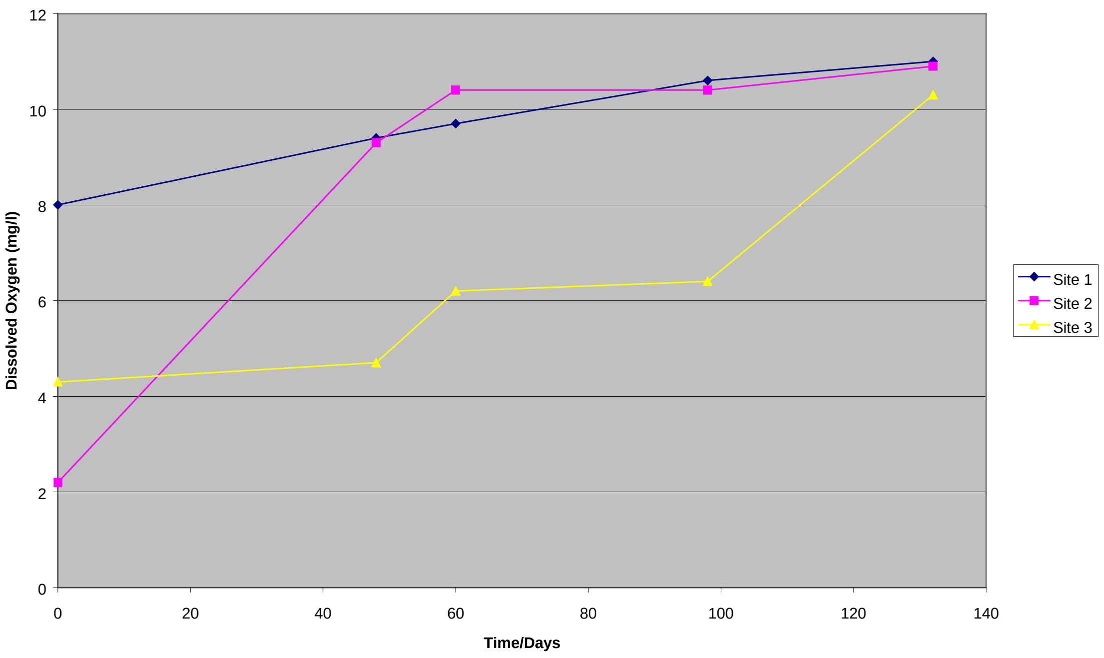

Fig. 8

Unexpectedly, site 3 had lower levels of dissolved oxygen than both site 1 and 2. and on sampling dates 2, 3 and 4, the levels were considerably less. Results from sampling dates 2, 4 and 5 show that there was a gradual decrease in dissolved oxygen. Over the five-month sampling schedule, each site displayed a general increase in dissolved oxygen Overall, the mean DO_2 measurements for each site are as follows: Site 1. 9.7, Site 2. 8.6 and Site 3. 6.4.

Conductivity (μScm^{-1})

	Site 1	Site 2	Site 3
Date 1	536.3±	526.7±	524.3±
Date 2	565±	556.8±	572±
Date 3	455±	525.3±	472±
Date 4	512±	524.3±	545.3±
Date 5	524±	541.3±	580.3±

Table 4

Table 4 displays the mean averages for all the sample dates at each sampling site. To find out if the wetlands had made a significant difference on the conductivity levels, a 1 Way ANOVA test was used. 95% confidence limits were applied.

Results showed that Sig. (P) = 0.637 and F = 0.468. Due to $P > 0.05$, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not make a significant change to the conductivity of the water. Figure 9 displays the above data.

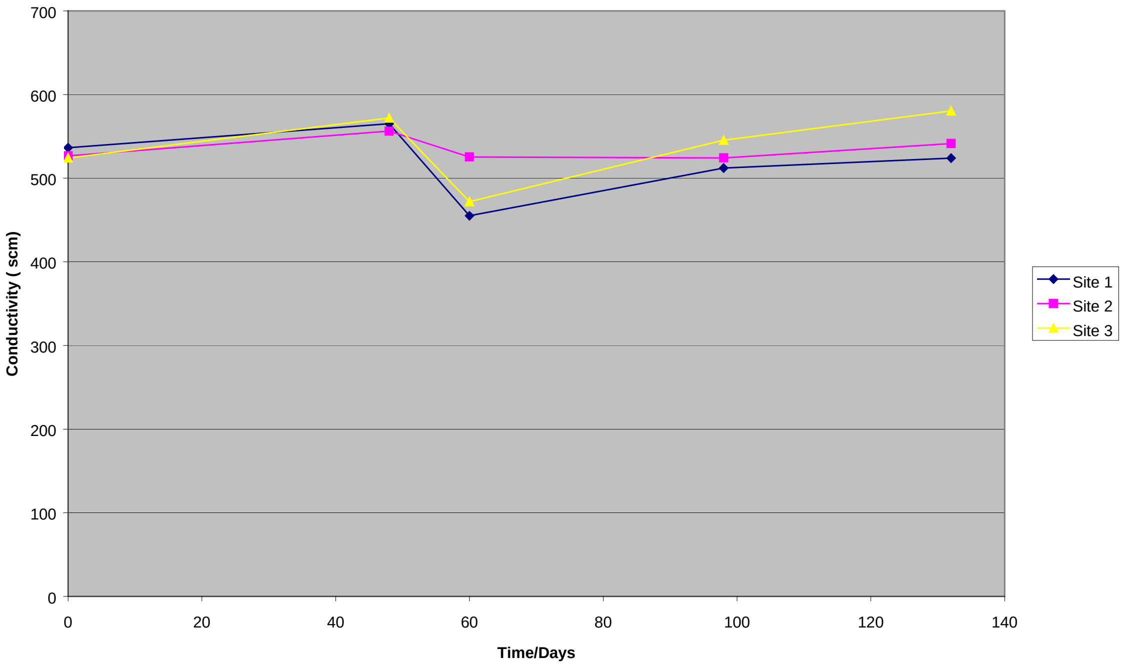

Fig. 9

It is easier to see from this chart that the measurements taken from each site over the five months are very close, in particular those taken on dates 1, 2, 3 and 4. The measurements were reasonably stable, keeping within the range of 455 and 580.3μScm^{-1}. Site 2, in particular gave the most consistent results overall, the highest mean being 556.8μScm^{-1} and the lowest mean being 524.3μScm^{-1}. Results showed that the highest mean was taken from site 3, which was 580.3μScm^{-1}.

Turbidity (NTU)

	Site 1	Site 2	Site 3
Date 1	2.1±	12.0.±	5.9±
Date 2	0.3±	5.7±	0.8±
Date 3	0±	0.6±	0.9±
Date 4	17.9±	18.9±	13.9±
Date 5	18.3±	18.5±	24.7±

Table 5

Table 5 displays the mean averages for all the sample dates at each sampling site. To find out if the wetlands had made a significant reduction in the turbidity of the water a 1 Way ANOVA test was used. 95% confidence limits were applied.

Results showed that Sig. (P) = 0.844 and F = 0.172. Due to P > 0.05, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not significantly reduce the turbidity of the water. Figure 10 displays the above data.

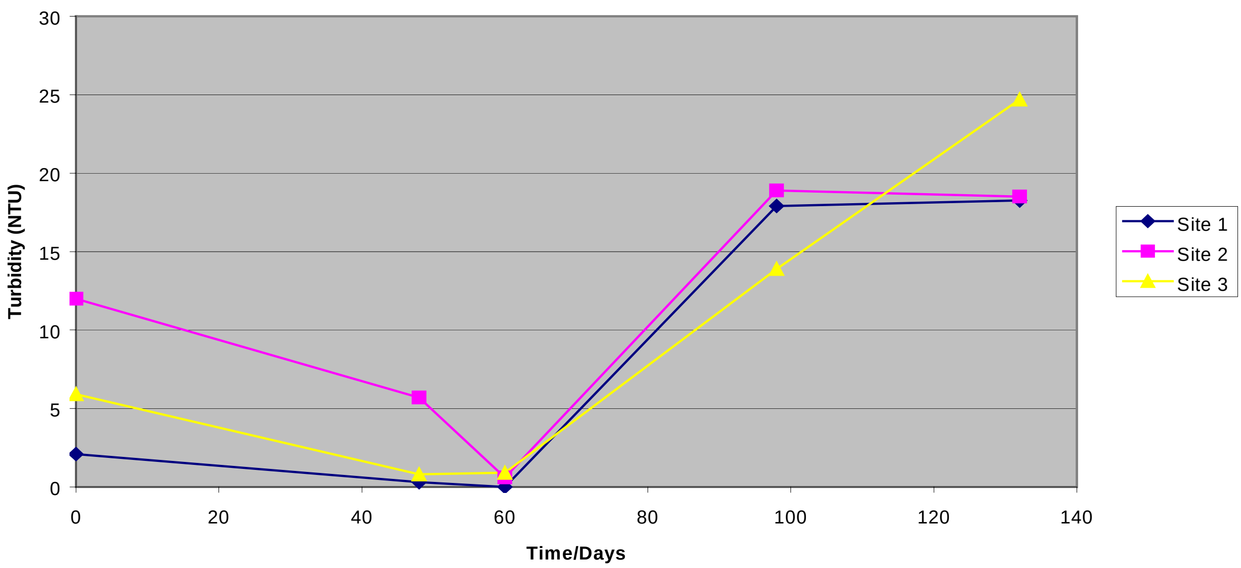

Fig. 10

Between sample dates 3 and 4 there is a sharp increase in the turbidity of the water at all sites. Date 3 displays a reduction in turbidity by the wetlands. A reduction in turbidity between sites 2 and 3 is also evident from results obtained from dates 1 and 2. Results from the final sampling date actually showed an increase in the mean turbidity measurement; sites 1 and 2 had very similar measurements (18.3 and 18.5 being the latter) but site 3 gave a higher result (an actual increase of 6.2 NTU). Despite the reductions that were made, they were not significant enough to make a considerable decrease of the turbidity of the water. A trend, which can be observed from site 2, is that the water samples taken from this site, always had a higher turbidity measurement.

BOD_5

	Site 1	Site 2	Site 3
Date 1	2.1±	3.1±	-3.3±
Date 2	1.1±	1.8±	-0.9±
Date 3	-0.0±	1.9±	-0.9±
Date 4	3±	3.8±	-0.6±
Date 5	0.8±	0.6±	1.6±

Table 6

The results from this test, i.e. the negative figures, indicate that there was an error in the methodology. Faults in some of the sampling bottles were discovered and the implications of this are mentioned in further detail in the discussion chapter. Due to these results being invalid and not giving a true indication of the BOD a statistical test was not carried out.

Nitrates (mg/l)

	Site 1	Site 2	Site 3
Date 1	1.8±	4.8±	4.4±
Date 2	3.8±	2.5±	4.8±
Date 3	4.5±	5.7±	4.5±
Date 4	4.5±	3.5±	2.3±
Date 5	4.6±	4.6±	5.0±

Table 7

Table 7 displays the mean averages for all five sample dates at each sampling site. To find out if the wetlands had made a significant reduction in the amount of nitrates in the water a 1 Way ANOVA test was used. 95% confidence limits were applied and data was tested for normality tests prior to proceeding with 1 Way ANOVA (normality tests were performed with data for each parameter).

Results showed that Sig. (P) = 0.849 and F = 0.166. Due to $P > 0.05$, the null hypothesis (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not significantly reduce the amount of nitrates in the water. Figure 11 displays the same data but in the format of a scatter graph, which helps to visualise the results.

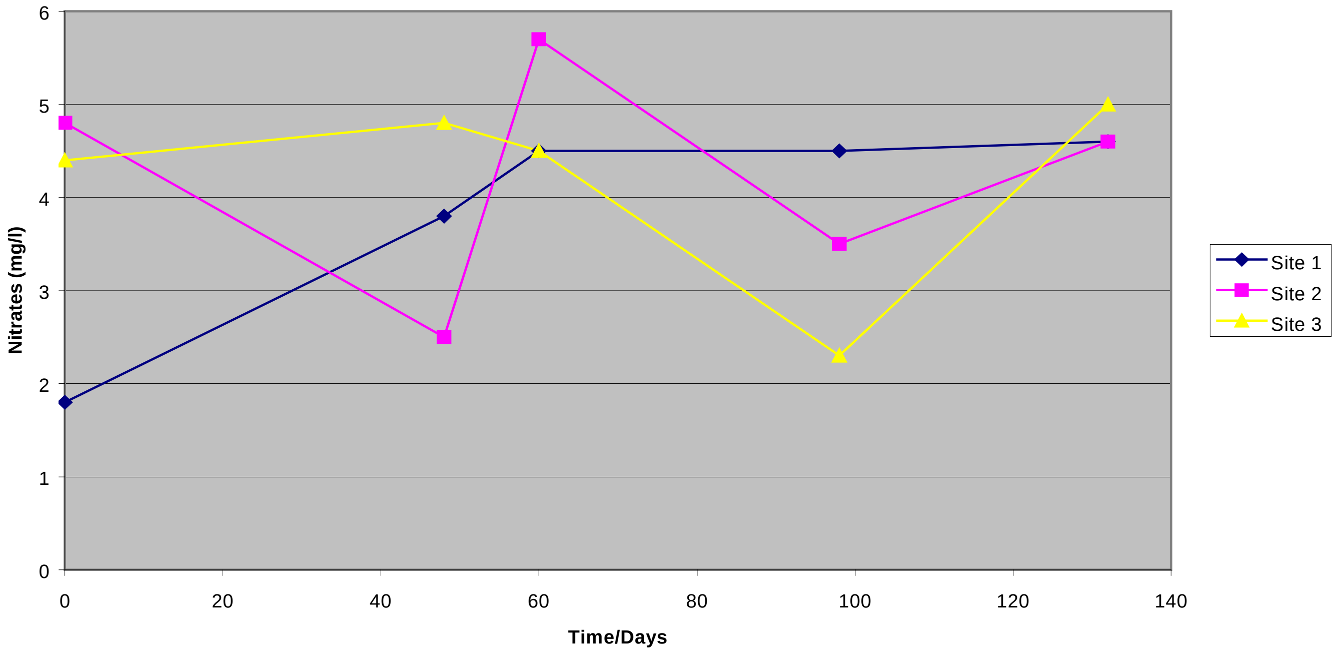

Fig. 11

On 3 of the sampling dates (1, 3 & 4) there were reductions in the amounts of nitrates in the water. However, the amount removed never exceeded 1.2mg/l. Quite unexpectedly, results from sample date 2 showed that the levels of nitrates between site 1 (before wetlands) and site 3 (after wetlands) had actually risen by 2.3mg/l. A rise had occurred on the final sampling date but this was just an increase of 0.4mg/l. However, it was still an increase.

Phosphates (mg/l)

	Site 1	Site 2	Site 3
Date 1	0.3±	2.0±	0.6±
Date 2	5.4±	3.0±	1.5±
Date 3	3.4±	1.2±	2.1±
Date 4	6.4±	3.3±	1.6±
Date 5	5±	2.6±	2.2±

Table 8

Table 8 displays the mean averages for all the sample dates at each sampling site. To find out if the wetlands had made a significant reduction in the amount of phosphates in the water, a non-parametric equivalent of the1 Way ANOVA test, which is known as Kruskall Wallis was used. This test was used as a result of the normality test showing that the data for this parameter was not normally distributed. 95% confidence limits were applied. Results showed that Sig. (P) = 0.121 and the test statistic = 4.220. Due to P > 0.05, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not significantly reduce the amount of phosphates in the water. Figure 12 displays the above data.

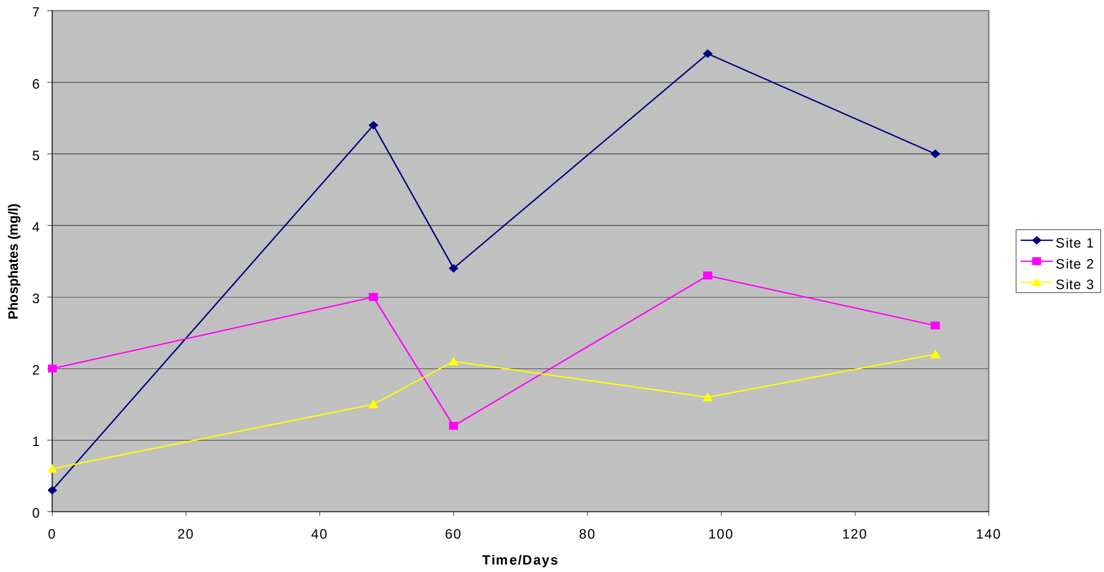

Fig. 12

Despite not achieving a significant reduction in the amount of nitrates in the water, there were decreases in the amounts between both sites 2 and 3 on four of the five sampling dates (1, 2, 4 & 5). The most substantial decrease occurred on date 4 when there was a reduction in phosphates by 1.7mg/l. On date 3, between sites 2 and 3 there had been an increase in the amount of phosphates in the water by 0.9mg/l. It is clear that there is a trend for the amount of phosphates at site 1 to be considerably higher and at site 2, the levels to be considerably lower.

Microbiological

Ecoli (MPN)

	Site 1	Site 2	Site 3
Date 1	121.5±	762.1±	2419.2±
Date 2	476.3±	370.2±	316.2±
Date 3	1337.7±	1806.0±	770.8±
Date 4	0±	0±	824.7±
Date 5	4.8±	19.6±	15.1±

Table 9

Table 9 displays the mean averages for all the sample dates at each sampling site. To find out if the wetlands had made a significant reduction in the amount of the bacterium E. coli in the water, a 1 Way ANOVA test was used. 95% confidence limits were applied. Results showed that Sig. (P) = 0.617 and F = 0.503. Due to P > 0.05, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not significantly reduce the amount of E. coli in the water. Figure 13 displays the above data.

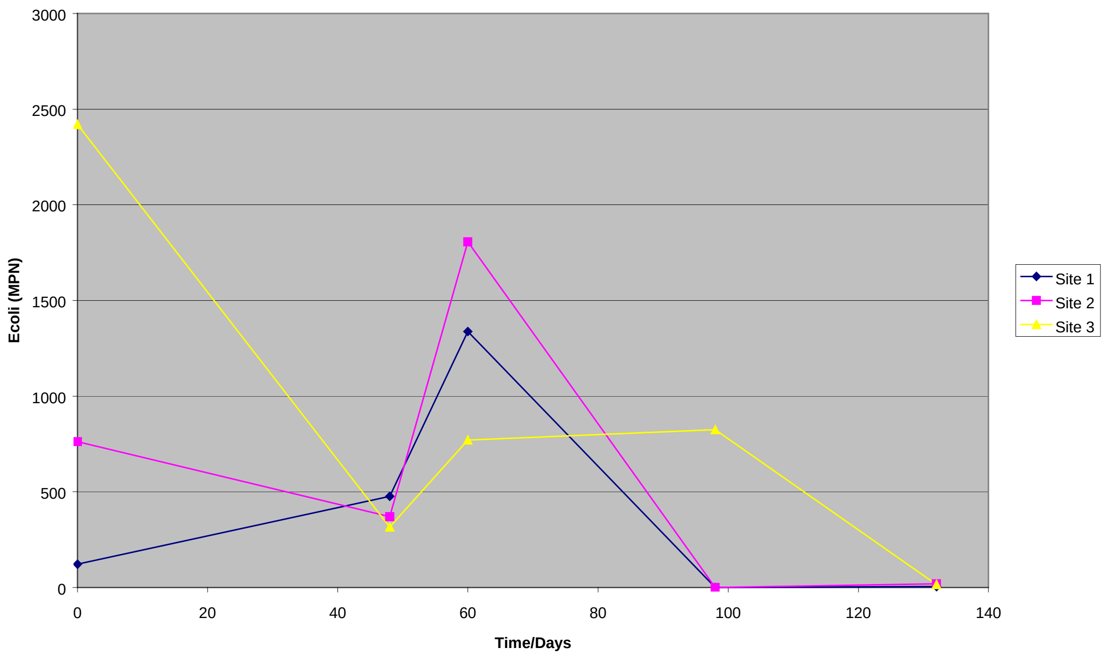

Fig. 13

On sampling date 1 there was a successive increase in bacteria levels between each of the three sites. Results from dates 2 and 3 show that there was a decrease in levels found between both sites 2 and 3, an indication that the wetlands are removing some of the bacteria present in the water. Not as predicted, on sampling date 4, there were no counts made at sites 1and 2 but there were counts at site 3. If there were no E. coli counts made at either sites 1 or 2, what is the source of these bacteria found in the samples taken from site 3?

Additionally, to find out if there was a relationship between rainfall and the levels of E. coli in the water, a correlation analysis was carried out. Was rainfall affecting the efficiency of the wetland system?

Total rainfall data from five days preceding each of the five sampling dates was correlated with the mean average measured from sampling site 1.

	Rainfall (mm)	Ecoli (MPN)
Date 1	0.0	121.5±
Date 2	3.4	476.3±
Date 3	29.8	1337.7±
Date 4	3.2	0±
Date 5	0.8	4.8±

Table 10

There was a definite linear relationship between this data and a parametric Pearsons test was used to determine whether there was a significant correlation between the data. Results showed that Sig. (P) = 0.013 and correlation coefficient R = 0.013. As Sig. (P) < 0.05, there is a significant correlation between rainfall and the levels of E-Coli in the water at site 1. As rainfall increases, so do the levels of E. coli. What is the source of these bacteria?

Total Coliforms (MPN)

	Site 1	Site 2	Site 3
Date 1	2419.2±	2419.2±	2419.2±
Date 2	2419.2±	2419.2±	2419.2±
Date 3	2419.2±	2419.2±	2419.2±
Date 4	0±	0±	1612.8±
Date 5	1612.8±	1612.8±	0±

Table 11

Table 11 displays the mean averages for all the sample dates at each sampling site. To find out if the wetlands had made a significant reduction in the amount of other bacteria such as those in the Total Coliform group, in the water, a 1 Way ANOVA test was used. 95% confidence limits were applied.

Results showed that Sig. (P) = 1.000 and F = 0.000 Due to P > 0.05, (Ho) was accepted which concluded that there was no significant difference between the data sets and that the wetlands do not significantly reduce the amount of Total Coliforms in the water. Figure 14 displays the above data.

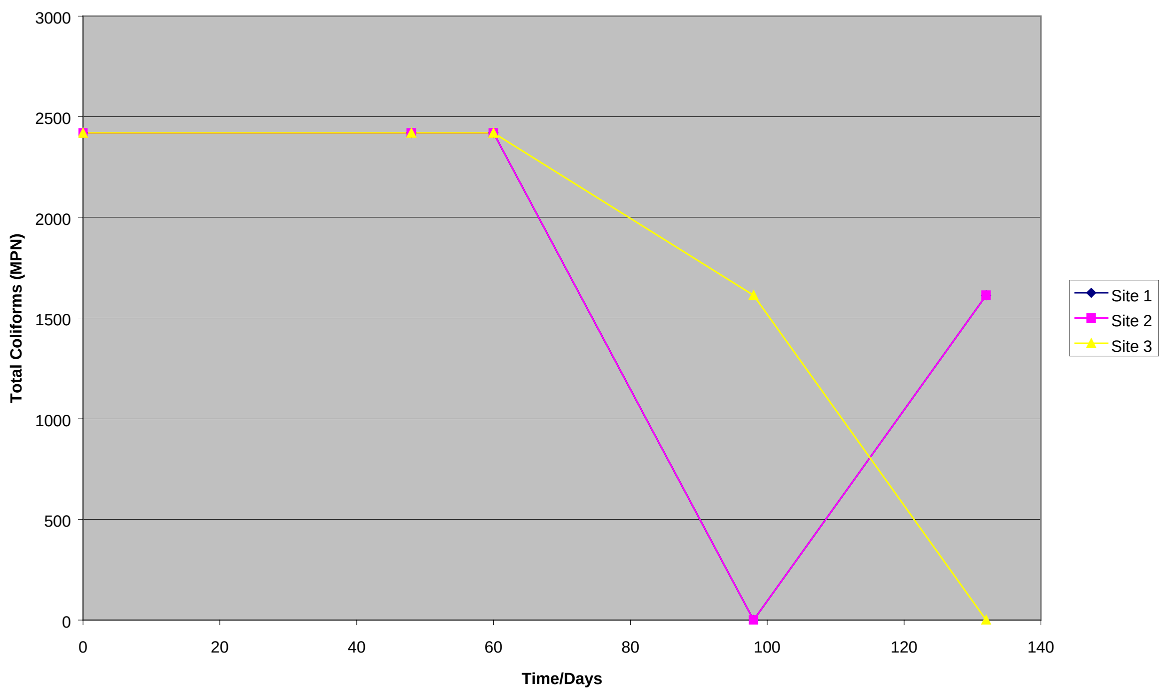

Fig. 14

Again, this graph displays more unexpected results. For the first three sampling dates, the levels of other bacteria from the Total Coliform group were not only very high (>2419.2 MPN) but these levels were consistent for each site. No bacteria were removed by the wetlands. Results for sampling date 4 show that there were no counts made from the samples taken from site 1 and 2 but there were high counts made from site 3 (mean MPN being 1612.8). Only on one the last day of sampling was any removal of bacteria by the wetlands evident. Both sites 1 and 2 having high counts but samples taken from site 3 did not have any counts.

A correlation analysis was also carried out between rainfall and the levels of Total Coliforms measured in the water. Total rainfall data from five days preceding each of the five sampling dates was correlated with the mean average measured from sampling site 1.

	Rainfall (mm)	Total Coliforms (MPN)
Date 1	0.0	2419.2±
Date 2	3.4	2419.2±
Date 3	29.8	2419.2±
Date 4	3.2	0±
Date 5	0.8	1612.8±

Table 12

Due to there being no linear relationship a non-parametric, Spearmans test was used. Results showed that Sig. (P) = 0.718 and correlation coefficient R = 0.224. As $P > 0.05$ there is no significant correlation between rainfall and the levels of other Total Coliforms in the water.

Heavy Metals

Lead (ppm)

	Site 1	**Site 2**	**Site 3**
Date 1	0.384	0.48	0.547
	0.414	0.495	0.568
	0.385	0.536	0.571
Date 2	0.119	0.201	0.352
	0.13	0.235	0.356
	0.175	0.266	0.382
Date 3	0.576	0.729	0.827
	0.601	0.728	0.865
	0.64	0.789	0.893
Date 4	0.181	0.248	0.426
	0.197	0.318	0.463
	0.244	0.354	0.486
Date 5	0.265	0.250	0.182
	0.257	0.243	0.185
	0.255	0.244	

Table 13

All the results obtained were below detection limits and it was decided to take this part of the investigation no further.

Cadmium (ppm)

	Site 1	**Site 2**	**Site 3**
Date 1	0.017	0.02	0.11
	0.031	0.025	0.01
	0.031	0.027	0.12
Date 2	0.118	0.02	0.252
	0.15	0.225	0.255
	0.165	0.233	0.262
Date 3	0.476	0.629	0.726
	0.501	0.628	0.766
	0.54	0.698	0.793
Date 4	0.17	0.24	0.311
	0.118	0.25	0.323
	0.23	0.255	0.325
Date 5	0.016	0.012	0.022
	0.025	0.012	0.018
	0.019	0.020	0.020

Table 14

Surprisingly, levels of heavy metals were below detection limits. Due to the low levels found for both lead and cadmium, further analysis was not taken any further. Again, all the results obtained were below detection limits and further analysis was not pursued.

Biological Sampling

Site 1.

Families Identified	**BMWP Score**
Asellidae (2)	3
Oligochaeta (3)	1
Chironomidae (10)	2
Sphaaeriidae (16)	3
Gammaridae (8)	6
	Total = 15

Table 15

Identification of the taxa is to the family level and abundance is not taken into account. Each family is given a score between 1 and 10 according to their tolerance to pollution. The final BMWP score is 15.
What was immediately noticed was the strong smell of diesel from the sample. This was an indicator of road run-off.

In order of abundance, the organisms observed are as follows:

The most abundant (16) organism found at this site, was the pea mussel *Pisidium* spp. from the Sphaaeriidae family. Pea mussels are abundant in all habitats, even occurring in isolated spring pools, water troughs or in gravel deposits (Fitter 1986).

The second most abundant (10) organism was from the family, Chironomidae. Chironomid larvae were observed. Due to the presence of haemoglobin-like respiratory pigment the larvae are able to exist in oxygen depleted sediments (Mason 1996).

Ten Freshwater Shrimps *Gammarus* spp. from the Gammaridae family were observed. This type of shrimp is probably the most widely distributed and familiar of all freshwater crustaceans. Typically they occur in almost any clean running waters. They are found, often in great abundance, in or under substratum that provided shelter from predators and a supply of organic debris, which is their main food source, under stones, in gravel and other coarse substrata, amongst living or dead vegetation.

Three Segmented worms from the subclass Oligochaeta, Family Tubificidae were observed in the sample. The majority of oligochaetes feed by swallowing large quantities of mud, soil or bottom debris, digesting the nutritious organic particles and discarding the remainder. Identification of the particular species was not successful. Identification below family level is notoriously difficult and even experienced biologists are reluctant to attempt it (Fitter & Manuel 1983). These worms are common and often abundant in muddy sediments where there are high levels of sewage contamination.

Site 4. Approximately 30m down from site 3.

Families Identified	**BMWP Score**
Asellidae (28)	3
Oligochaeta (100)	1
Chironomidae (5)	2
Sphaaeriidae (3)	3
Gammaridae (8)	6
Hydropsychidae (5)	5
	Total = 20

Table 16

The final BMWP score is 20.

All five families which were present at site 1, were also identified at site 4. However, the abundance of these organisms differed between sites. For example, at site 1, only three organisms from the Oligochaeta were observed whereas at site 4, there were approximately 100.

Members of the Asellidae family were more abundant. There were approximately 28 identified at site 4 whereas at site 1, there were only 2. Species from the Gammaridae family had the same abundance at both sites.

There were 3 pea mussels *Pisidium* spp. identified from the sample taken from site 4 and 16 from the sample taken from site 1.

At site 4 there were 5 organisms from the Chironomidae family and at site 1, there were 10. There were organisms identified from the sample taken from site 4 which were not identified from the sample taken from site 1. They were members from the Hydropsychidae family. Altogether 5 were observed. *Hydropsyche*, the commonest genus is usually found in fast – running water, in swift sections of streams and are generally found in unpolluted waters. This could be an indication that the water quality has improved as they were not present in the sample taken from site 1.

The Freshwater Shrimp *Gammarus Pulex* from the Gammaridae family, inhabits almost all types of water having abundant dissolved oxygen, high lime content and reasonable water quality. They can survive and grow in enriched conditions where the water is reasonably well oxygenated but never achieves the numbers it would in clean water. In Britain it has not been found in water with pH consistently below 5.7.

The Freshwater Hog House of Slater *Asellus* is quite pollution tolerant and maybe found in habitats ranging from clear running water to stagnant polluted water.

Those species belonging to the Sphaeidae family are tolerant of organic enrichment and can often found in the '*Asellus* Zone' downstream of sewage outfalls (Mason 1996).

Discussion

The results from the statistical tests, which were used to test the hypothesis, 'The Wetlands Significantly Improve the Water Quality', show that they have not made a significant improvement. However, some improvements; i.e., a reduction in turbidity and a reduction in phosphates were made.

pH

The pH was generally slightly lower at sample site 1. However, the difference was not significant and the lowest measurement, pH 7.4 indicates that the watercourse is not acidic. Goulet *et al* (2001) found that pH was on average, 0.3 units higher at the outlet. On two occasions an increase of 0.2 units was found between sites 2 and 3 at the Bourne site.

Extreme pH values are considered to be either below 5 and above 9 and levels such as these in water can be harmful to the freshwater organisms. From the measurements given from all the samples, the water is almost alkaline. Due to the nature of the construction of the wetland site, a large amount of concrete was used. The calcium bicarbonate in the concrete may be leaching into the water and having an effect on the pH of the water as the calcium bicarbonate content of freshwaters determines the pH or acidity/alkalinity balance.

Waters, which contain actively photosynthesising macrophytes, can have elevated pH levels ranging from 9 – 10 (Gray 1999). This is the result of the plants using CO_2 (which is closely linked with the chemical process that determine the acidity and alkalinity of water) and bicarbonate ions (HCO^-_3). This example might be another factor why the pH of site 3 may have been quite high (ranging from 7.8 – 8.2).

The pH of the water across all three sites was quite consistent, the lowest pH measured was 7.4 at site 1 and the highest was 8.6 at site 4.

Temperature

The differences between the five data sets of temperature measurements are due to seasonal changes. Samples were taken over a five-month period from August to December and weather conditions gradually became colder. Daily time scales should not have to be taken into consideration any further as all samples were taken between the two-hour period of 9am and 11am.

Temperature is one of three main factors apart from pressure and the concentration of dissolved minerals, which effect the solubility of oxygen. Results from the correlation analysis found that there was a linear relationship between temperature and the amount of dissolved oxygen in the water from the samples taken from all sites. As the temperature decreased, the levels of DO_2 increased. This is a result, which was expected, as lower water temperatures are known to have this effect on DO_2 levels. As temperature increases the saturation concentration decreases.

Not only is temperature important with regards to general water quality it is also important to the biota living in the water. Most organisms, which live in streams, are *ectothermic* and absorb heat from their surroundings. Growth rates, life cycles, respiration (as the solubility of oxygen in water decreases as temperature increases) and the productivity of the entire system are strongly under its influence (Allan 1995).

Dissolved Oxygen

There was an increase of dissolved oxygen between sites 2 and 3 on just two of the five sampling dates. Wetland species such as *Phragmites australis* and *Typha latifolia* are able to remove organic material, which exerts a biochemical oxygen demand, via physical processes which simply involve particles adsorbing to the plants them and biological processes such as nitrification for example. Removal of these materials from the watercourse should decrease the BOD and increase the amount of dissolved oxygen.

However, on three of the sampling dates there was actually a decrease in the levels of dissolved oxygen. The corresponding sampling dates were in the months of October, November and December when the plants are beginning to die-off and productivity is reduced. Bacteria levels were still high in these months and their continued oxygen requirement may be a reason for decreased levels in dissolved oxygen.

The breakdown of inorganic pollution such as nitrates and phosphates can greatly increase respiratory demand for oxygen but the levels of these nutrients in the Bourne were not high and the highest measurement of nitrate was only 5.7mg/l and of phosphate only 6.4mg/l.

Correlation analysis showed the positive relationship between temperature and dissolved oxygen levels. As temperature decreased, the levels of dissolved oxygen increased.

The following values below show this relationship; how dissolved oxygen saturation concentration varies with temperature at 1 atmospheric pressure. Source (Gray 1999).

Temp (°C)	Dissolved Oxygen (mg/l)
0	14.6
10	11.3
18	9.5
19	9.3
20	9.3
30	7.5

Dissolved oxygen levels were reasonably good. The average measurement for site 1 was 9.74mg/l, site 2 8.64mg/l and site 3 6.38mg/l, though it clear that there is a gradual decline.

Conductivity

Natural rivers have conductivities between 10 and 1000 μScm^{-1} (Gray 1999). Levels in excess of a 1000 μScm^{-1} are an indication of pollution. Strong correlations have been found between total dissolved salts and specific conductance (Allan 1995).
Given the levels, which were found in the water samples taken from the Bourne Stream never exceeded 651μScm^{-1}; pollution from dissolved solids such as mineral salts does not appear to be a posing threat to the quality of the water.

Turbidity

A trend that became apparent was that the water samples taken from site 2 had higher turbidity levels. Relating this to where site 2 is situated; it is located just after an area, which is densely covered with trees, much more than the other two sites. This part of the watercourse might be subject to receiving more plant litter or detritus from the above trees, which would increase the amount of suspended solids in the water and would consequently increase the turbidity of the water.
Those reductions which were made in the turbidity of the water, are likely to be a result of sedimentation of suspended solids which is promoted by the low flow velocity. This hydrological feature of wetlands results in suspended solids adsorbing to the aquatic vegetation. Plants also tend to dissipate or block wind and therefore help to maintain

quiescent conditions, which also promotes settling of solids. One of the key designs of the pond system at the Bourne site was to slow down the water and increase sedimentation

BOD_5

The results obtained from the BOD_5 test were unexpected. Some results were actually negative, for example on date 1, sampling date 3, the measurement given was -3.3mg/l. Results such as this are an indication of an error in the methodology. From examining some of the bottles used for this test afterwards, the observation that they were not completely airtight was made. This meant that oxygen would have been able to enter the bottles and so the results obtained would not be a true reflection on the oxygen demand of the micro-organisms present in the water.

From the samples taken, levels of inorganic material such as nitrates and phosphates were quite low so high BOD_5 were not to be expected.

Nitrates

Despite not being significant, from the five sets of samples taken, reductions of nitrates were made on sample dates 1,3 and 4 (see figure 10). The most considerable reduction made between site 2 and site 3 was 1.2 mg/l. Wetland plants such as *Phragmites australis* and *Typha latifolia* are able to reduce the amounts of nitrates in the water. The vegetation structure provided by these plants can act as a net, causing particles in suspension to settle in the sediment. The plant roots facilitate conversion of nitrates into gaseous components. As the nitrates diffuse deeper into the anaerobic regions of the soil, the nitrates can undergo *denitrification,* a biological process which involves the transformation of nitrate to nitrogen or nitrous oxide:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

In the oxidized rhizoshpere of the plants where aerobic conditions prevail, ammonium nitrogen can be converted to nitrate nitrogen by nitrifying bacteria, *Nitrosomonas* sp. This biological process is known as *nitrification*: Source: (Douglas 1998)

$$2NH_4 + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + \text{energy}$$

Unexpected increases in nitrates after the wetlands were found. This may be due to inputs of nutrients from other non-point sources otherwise known as diffuse pollution. The site is popular with dog walkers and animal waste is well known to be a source of both nutrients and bacteria.

Phosphates

Removal of phosphates was more successful in comparison to the removal of nitrates. Reductions were made by the wetlands on sampling dates1, 2, 4 and 5. However, whereas nitrates can be permanently lost from the system, phosphates cannot and can only be removed form the water by being absorbed by microflora or retained in plant litter and sediments (Douglas 1998*)*. This means that there is always the chance that the phosphate may be resuspended into the water column. Plant uptake and adsorption contribute to most shot-term phosphorus removal in wetlands and the only long-term sink is thought to occur in soil accumulation. In general, phosphate levels were considerably low, the lowest being 0.3 at site 1 and the highest 6.4 also at site 1. Levels such as these should not be detrimental to the water quality.

Microbiological

There was a positive correlation between rainfall and higher levels of E. coli. Rain causes run-off to enter the stream. The Bourne receives highway drainage, which passes through the gully pots, which are located on the side of the road before it reaches the stream. These gully pots are known harbourers of bacteria and maybe a contributing factor to the high levels of the bacteria found in the water, especially before the wetland system.

Very high counts of E. coli and other bacteria belonging to the Total Coliform group were frequently made. This might be so but it must be recognised that bacteria in streams can have large variations in population number (Stednick 1991). Populations of bacteria may actually alter during the day due to varying ultraviolet light intensity, resulting in the light killing the bacteria. Sampling times in this project were in the morning between the hours of 9am and 11am. A time bias has been highlighted in the sampling scheme and this might explain why such high counts were made. If samples had been taken in the afternoon for example, lower counts may have resulted.

However, this does not explain why significantly lower counts were not made after the wetlands, at sample site 3. Wetlands species such as *Phragmites australis* and *Typha Latifolia* which are both present at the Bourne Stream site are well known for their abilities to reduce bacteria from the receiving watercourse and results from the samples taken were expected to support this.

One possible explanation for this lack of removal of removal of bacteria by the wetlands might be that there is a non-point source of bacteria between site 2 and 3, which may be effecting the efficiency of the reedbed system. There are a number of sewer connections, which are within close proximity of the wetland site. Sewer misconnections have been recognised as a problem and a source of pollution to the Bourne and as a result Wessex Water set up "Operation Streamclean" which is a project involving the repairs of these misconnections. It might be possible that there are still misconnections, which are having an impact on the water quality and in particular, causing high bacterial levels. A map of the sewer connections surrounding the site can be found in the appendix (Fig 15).

Though this would not directly influence the results, a leak was observed just to the left and beyond of sampling site 3. Samples were taken and analysed for bacteria but only very low counts of E. coli were present. This was a leak that was visible and there could well be others, which are not and are situated within the wetland system.

Most bacteria prefer more or less neutral pH conditions (this is exactly what levels are present) although some species can exist in a highly acidic environment (Tebbutt 1992).

According to Spiral al, 1998 (Gopal 1999*)* macrophytes can actually promote growth of pathogens by providing substrate and contribute to their perpetuation in the system. Could this be another possibility for the high levels of bacteria that were found after the water had passed through the wetland system?

Studies by Roper and Marshall, Gerba; and Mcleod (1974 and 1976 cited Davies and Bavor 2000 p.358) show that the process of bacterial adsorption to particles can actually increase the bacterial persistence in aquatic environments by protecting them from environmental pressures that may otherwise be responsible for their mortality, e.g. solar radiation, starvation and attack by bacteriophages.

With regards to the Blue Flag award and meeting both the Mandatory and Guideline values of the relevant microbiological parameters it is difficult to say whether or not they are met as the levels measured are taken at the start of the stream and they may change, i.e., decrease as the water moves downstream and as it finally reaches the sea.

Parameter	**Guideline standard – no more than:**	**%age Compliance**	**mandatory– no more than:**	**%age compliance**
Total coliform	500 per 100ml	80%	10,000 per 200ml	95%
Faecal coliform	100 per 100ml	80%	2,000 per 100ml	95%
Feacal streptococci	100 per 100ml	90%	-	-

If the levels remained the same for Total coliforms for example, the guideline standards would not be met and as a result the Blue Flag would not be awarded to Bournemouth. However, mandatory standards would have been complied with.

Heavy Metals

The levels of copper and lead were surprisingly low. They were actually below detection limit. Higher levels were expected considering that the stream receives run-off from the roads. Hardness plays an important part in metal toxicity. For example, the higher concentration of calcium the lower the toxicity of Cu (Gray 1999). With pH levels ranging from 7 – 8 the metals are essentially unavailable biologically, minimising any toxicological effects for the biota in the water.

Biological

There was an increase in the biotic score by five points for the site sampled after the wetlands. This suggests that there is an improvement in water quality, although the significance of this improvement is unknown.

Site 1

Apart from the Gammaridae family, which scored a reasonable 5, the other four families obtained very low scores. This is a reflection of their tolerance to pollutants such as organic material. The most abundant species belong to the Chironomidae family and chironomids normally live in organic sediments and hence can easily tolerate an increase in organic load (Moss 1998). A total score of 15 suggests that water quality is poor.

However, it is important to highlight that high scoring stonefly, mayfly and caddisfly families may still have been present in the stream and just not caught in the net.

Unfortunately only one sample set was taken and ideally more should have been taken to increase the validity of the results.

Site 4

The same four low scoring families were identified from the site after the wetlands. The most abundant species belonged to the Oligochaeta family which received the lowest score is the most pollution tolerant.

Five species from the Hydropsychidae family were identified which increased the score by five points giving a total score of 20 points. Caddisflies belong to this family and their presence maybe an indication of an improvement to the water quality. As firstly they qualify for a score of 5 and Cairns and Dickson (1971 cited Welch 1980 p.247) categorise them as belonging to a group classed as intolerant to organic waste.

Overall, there was not a considerable difference between the sites with regards to the families identified but with site 4 obtaining a slightly higher score, this may indicate some improvement by the wetland.

The wetland area at the Bourne stream was not given any length of time to establish and this might be a contributing factor to why E. coli and total coliform removal rate was so low as well as other parameters not being significantly different after the wetland treatment.

The constructed wetlands which were built to deal with the run-off from the Newbury Bypass were planted a year before the road opened in November 1998 (Pontier *et al* 2001). This allowed the establishment and development of wetland conditions, which promote the treatment mechanisms.

There may have been error in the methodology and mistakes may have been made which will have affected the results. But care was taken for every step and any queries and doubts were always clarified with an available laboratory technician before. This has already been discussed with regards to the BOD test.

A reason for the results rejecting the alternative hypothesis is that results obtained from October (Date 3), November (Date 4) and December (Date 5) might be reflecting the lack of productivity of the wetlands as the plants *Phragmites australis* and *Typha latifolia* will be coming to the end of their life cycle, especially *Typha latifolia* which starts to die back in the autumn.

Odum (1974 cited Mitsch and Gosslink, 2001 p.730) described coastal ecosystems by their major forcing functions (e.g., seasonal programming of sunlight and temperature) and stresses (e.g., ice). If the major forcing functions are decreasing during these particular months; with shorter days and colder temperatures, this may be a contributing factor to why the wetlands at the Bourne have not made significant improvements to the quality of the water.

Finally, the sources that have been found during the course of this research project, all show positive results, that the wetlands significantly improve the water quality. Is it a possibility that results similar to the ones obtained from this project do not tend to get published? There may actually be other studies, which have found insignificant improvements, but these findings just have not been published.

Conclusion

There are still many results from the water samples, which cannot be fully explained. It is possible that there are other inputs of pollutants, some of which may have not been unidentified in this study, which could be affecting the efficiency of the wetland system. Pollutants from the surrounding industrial estate have been found to be infiltrating into the site some of which are not having a direct impact on the wetland system but on the receiving watercourse further downstream. These have been reported to the Environment Agency and are being dealt with.

There are no direct inputs of sewage into the stream but E. coli is known as an indicator organism and is a normal inhabitant of the human intestine. Its presence in water thus indicates human excretal contamination (Tebbutt 1992). Bacterial contamination has been a historical problem and it is evident that it is a present one too. With high levels of bacteria throughout the system, this is an area of concern, which needs to be addressed with perhaps even more stringency.

The Environment Agency has found significant improvements with regards to reductions in bacteria. Faecal coliform counts were measured before and after the wetlands. The graph shows that when counts were high, the wetlands were more effective in removing bacteria.

The wetlands performance overall with regards to improving water quality was not as well as expected. There are possible reasons for this and recommendations for future work are highlighted in the next section. Despite not being statistically significant, reductions were made in the amounts of nitrates, phosphates, turbidity and E.coli, which would have made some improvement. Additionally, the higher biotic which was obtained after the wetlands suggests some improvement too.

Recommendations

- Inputs of pollutant are not just located at the upper catchment of the Bourne Stream, they continue along its route through to Bournemouth. Consideration should be given to planting wetland species further downstream in order to reduce their impact on the water quality especially as it moves nearer to the sea. Bacteria reductions may be made upstream but levels might start to increase again further upstream and risk failure with the Bathing Water Directive 76/160/EEC.

- In comparison to water concentrations, sediment metal concentrations are indicators of long-term accumulation of metals for example in stagnant and running water bodies. This could possibly be an area for future research.

- The results obtained from this project span over five months but ultimately from only 5 days. Ideally a study of this kind should have had more sampling dates, gathering a maximum amount of data on the variables tested for. If time permitted, ideally, sampling frequency should be fortnightly.

- The sampling schedule ran into the winter months of October, November and December, which might explain why the plants performance was not as good as had been expected. A study of this kind from spring throughout the summer should give a better indication of the potential of these plants.

- The same methodology used by the Environment Agency to test for bacteria, i.e. the membrane filtration method should be adopted. This would make it easier to draw direct comparisons from the results obtained.

Acknowledgements

I would like to thank the following for their help and assistance:

David Hurst	Poole Borough Council
David Price	Poole Borough Council
Neil Turner	Environment Agency
Anita Shah	Bournemouth University
Iain Green	Bournemouth University
Alison Curtis	Bournemouth University
George Hood	Met Office

References

1. Bratli, J.L. et al., 1999, Self Purification of Nutrients and Suspended Matter through Natural Reed-Belts, *Water Science and Technology,* 40, 3, 325-332.

2. Chartered Institution of Water and Environmental Management, Minewater Treatment Using Wetlands, 1997, Edited by Younger. P. L, CIWEM.

3. Comin, F.A, et al, 2001, Restoration of Wetlands from Abandoned Rice Fields for Nutrient Removal and Biological Community and Landscape Diversity, *Restoration Ecology*, 9, 201-208.

4. Cooper, P.F. and Findlater, B.C., 1995, Constructed Wetlands in Water Pollution Control, Pergamon Press, Oxford.

5. Croft, P.S., A Key to the Major Groups of Freshwater Invertebrates, 1986, Field Studies Council.

6. Green, J.F.N, 1945, The History of The Bourne and its Valley, Presidential address to the Society of Bournemouth natural Science Society.

7. Harmancioglu, N.B., et al, 1999, Water Quality Monitoring Network Design, Kluwer Academic Publishers, Netherlands.

8. Kao, C.M, and Wu, M.J, 2001, Control of Non-Point Source Pollution by a Natural Wetland, *Water Science and Technology*, 43, 169-174.

9. Kent, D. M, 2001, Applied Wetland Science and Technology, 2nd Edition, Lewis Publishers, London.

10. Maltby, E., 1986, Waterlogged Wealth, Earthscan, Institute of Environment and Development, London.

11. Nemerow, N.L., 1991, Stream, Lake, Estuary and Ocean Pollution, 2nd Edition, Van Nostrand Reinhold, New York..

12. Perkins, J. and Hunter, C., 2000, Removal of Enteric Bacteria in a Surface Flow Constructed Wetland in Yorkshire, England, *Water Research*, 34, 1941-1947.

13. Petts, G. and Calow, P., 1996, River Biota, Diversity and Dynamics, Blackwell Science, London.

14. Reed, S. C., et al. 1995, Natural Systems for Waste Management and Treatment, 2nd Edition, McGraw-Hill, London. Severn Trent Water, Reed Beds & Constructed Wetlands For Wastewater Treatment, 1996, WRc, Swindon.

15. Shutes, R.B.E, 2001, Artificial Wetlands and Water Quality Improvement, *Environment International*, 26, 441-447.

16. Shutes, R.B.E and Sriyaraj, K., 2001, An Assessment of the Impact of Motorway Run-Off on a pond, Wetland and Stream, *Environment International*, 26, 433-439.

17. Spieles, D.J and Mitsch, W.J, 2000, Macroinverebrate Community Structure in High and Low Nutrient Constructed Wetlands, *Wetlands*, 20, 4, 716-729.