Constructed Wetlands on the Bourne Stream, Dorset: An Assessment of Water Quality and Highway Run-off.

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Abstract

Bournemouth Pier bathing beach has failed to comply with the "Guideline" standards, set in the Bathing Water Directive, in 10 out of the last 12 years, despite significant investment in reducing point source inputs. The main reason for this non-compliance is the Bourne Stream, which discharges close to the bathing water (www.bwhwater.co.uk/bsp).

The aim of this study was to investigate whether two constructed wetlands on the stream were significantly improving the water quality of the stream. The first of the two wetlands, the on-line system was installed in March 2000. The second off-line system was installed in March 2001. The objectives of this study were to analyse general water quality data of the stream from 2001, 2002 and 2003, and to assess whether the wetlands were reducing highway run-off in the stream. The general water quality data included pH, dissolved oxygen, biochemical oxygen demand (BOD), E.coli, Total coliforms, nitrates and temperature. To assess if the wetlands were reducing highway run-off, samples were analysed using gas chromatography and samples of total dissolved solids were also taken.

The general water quality data from 2001 only showed significant effects on dissolved oxygen levels in the stream. The data from 2002 showed that the constructed wetlands made a significant difference to pH, dissolved oxygen and nitrate levels. The 2003 data only showed significant differences in dissolved oxygen, BOD and total coliforms.

Results from the gas chromatography data for hydrocarbons (2003) showed reductions in total naphthalene and n-alkanes of 75%. Samples taken from the off-line wetland showed a 50% reduction in hydrocarbons after 24 hours retention.

In conclusion the wetlands are making some improvements to the water quality of the stream. However studies undertaken by the Urban Pollution Research Centre and the Water Research Council into the use of constructed wetlands show much greater improvements in water quality.

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Introduction

Background

Constructed Wetlands and reed beds are designed and man-made systems which are aimed at simulating the treatment that has been observed to take place when polluted water is let into naturally-occurring wetlands. These systems have been seen to purify water by removing organic matter (BOD) and oxidising ammonia, reducing nitrate, and removing phosphorous (Cooper et al 1996). The purification process in wetlands is complex and the most obvious biological component of the habitat, the emergent macrophytes, play an important, albeit minor role in the treatment of waste (Gray 1989).

Constructed wetlands were initially developed about 40 years ago in Europe and North America to exploit and improve biodegradation ability of plants. A range of large aquatic (macrophytes) assist in the breakdown of human and animal derived wastewater, removing disease-causing microorganisms and pollutants (Shutes 2001).

The major removal mechanisms are bacterial and fungal transformations and physico-chemical processes such as adsorption, precipitation, and sedimentation. The emergent plants have a number of important functions. The plant rhizomes provide a stable surface for heterotrophic growth as well as enhancing sedimentation of solids by ensuring flocculation and maintaining near quiescent conditions. Emergent macrophytes dominate wetlands due to the hostile root environment, which has restricted oxygen supply so that facultative and anaerobic bacteria flourish. The plants are able to translocate oxygen from their shoots to the roots making the rhizoshere (the root zone) an area where aerobic microorganisms can survive. Here heterotrophic and nitrifying bacteria flourish with nitrates diffusing to the oxygen-limited zones of the wetland where it is removed from the system by denitrification (Gray 1989).

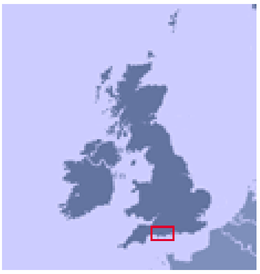
This study looks at the use of constructed wetlands as a treatment system for urban pollution. The Environment Agency and Government are actively promoting the use of sustainable urban drainage systems (SUDS) to deal with surface water run-off (www.bwhwater.co.uk/bsp). The study investigated two different wetlands (on-line and off-line), on the Bourne stream. The off-line wetland was constructed to deal with the 'first flush'. First flush is the initial runoff from a site/catchment following the start of a rainfall event. As runoff travels over a catchment it will pick up or dissolve pollutants and the "first flush" portion of the flow may be the most contaminated as a result. This is especially the case in small or more uniform catchments, however, in larger or more complex catchments pollution wash off may contaminate runoff throughout a rainfall event (www.ciria.org).

The Convention on Wetlands of International Importance Especially as Waterfowl Habitat (usually referred to as the Ramsar Convention after the place of its ratification in Iran in 1971) is one of the most important instruments for conserving wetlands. A distinguishing characteristic of the Ramsar Convention was the adoption of the concept of ‘wise use’ as a part of the idea of nature conservation. The wise use of wetlands is their sustainable utilisation for the benefit of mankind in a way compatible with the maintenance of the natural properties of the ecosystem (Nagle 2003).

The aims and objectives for this study come from research, which has been conducted by the Urban Pollution Research Centre and the Water Research Council. Research by the Urban Pollution Centre shows that for the removal of disease-causing microorganisms, an efficiency above 90% is normally achieved, for organic material and suspended solids 80% removal may be expected but nutrient removal efficiency is normally below 60% (Shutes 2001).

Studies of removal efficiencies by the Water Research Council show that constructed wetlands can remove up to 83% of hydrocarbons after 24 hours retention (Cooper et al 1996). Much of the information regarding the toxicity of hydrocarbons came from the National Park Service, U.S Department of the Interior’s website.

1.1 The Bourne Stream



The Bourne Stream (OS SZ0460094650) runs some 8kms through a shallow valley in Dorset from Poole through Bournemouth and onto the beach close to the pier (www.bwhwater.co.uk/bsp). The stream is prone to periods of poor water quality following severe rainfall, particularly after dry summer conditions. This can cause the

(Fig 1 UK location)

Bournemouth Pier bathing beach to fail the stricter guideline standards of the E.C Bathing Water Directive (www.greenlink.co.uk). As a result the beach at Bournemouth pier hugely popular with residents and visitors alike has failed the prestigious Blue Flag in ten of the last twelve years (www.bhwater.co.uk/bsp). The Foundation for Environmental Education in Europe (FEEE) launch the Blue Flag campaign in 1987 in cooperation with the European Commission as one of the projects within the European Year of the Environment. The Blue Flag Campaign is an eco-label exclusively awarded to beaches and marinas. The award is renewed very year to ensure the continuing compliance with the criteria, which includes water quality, environmental education and information, environmental management and facilities, and safety and service (www.un.org). An article from the Bournemouth Advertiser, Thursday August 21, 2003 claimed "Bournemouth's beaches could lose awards and fall below health and safety standards unless an extra £68,000 is spent on them next year. The warning comes as councillors examine the Town's leisure budget in a bid to keep down council tax". (Slade 2003).

In the upper reaches, the catchment boundaries are approximately defined by Ringwood Road to the west, Wallisdown Road to the north and Ashley Road/ Poole Road to the south. In the lower reaches, the catchment width gradually narrows towards the outfall in Poole Bay. The overall fall between the high levels in the upper catchment to the Poole Bay outfall is approximately 60m, giving an overall gradient of approximately 1:100 which is considered to be steep (www.bwhwater.co.uk/bsp).

1.2 Bourne Valley SSSI

The majority of the upper and middle catchment (Bourne Valley) was designated as a Site of Special Scientific Interest (SSSI) in 1985. The Bourne Valley SSSI is part of a complex of heathland sites which together comprise the Dorset Heathlands. This is one of the major lowland heathland areas in Britain, with the sites showing a high degree of ecological cohesion and clear ecological trends and patterns. The Heathlands are important in a European and International context for their plant and animal communities (Borough of Poole 1995).

1.3 The Bourne Stream Partnership

In 1999 Peter Brett Associates produced a study of best management practices for surface water run-off in the catchment. This report put forward possible in-stream structures, such as ponds and infiltration ditches to increase water retention time and provide treatment to improve water quality. Following the publication of this report, the ‘Bourne Stream Partnership’ was set up. The partnership brings together many organisations including Bournemouth Borough Council, Poole Borough Council, the Environment Agency, English Nature, Wessex Water, Bournemouth and West Hampshire Water, Bournemouth University, the Dorset Coastal Forum, the Dorset Wildlife Trust and Greenlink, who use their various skills and resources to limit pollution of the stream (www.greenlink.co.uk).

1.4 Phase 1 and 2 of the Constructed Wetlands

In March 2000 an on-line constructed wetland was installed by Borough of Poole Leisure Services and originally funded by English Nature. Between 60% and 80% of the stream should flow through the on-line wetland. The wetland is in the upper reaches of the watercourse downstream of Ringwood Road.

In March 2001 a second wetland was constructed upstream from the first. The second wetland is an off-line system to provide the initial treatment for the highway run-off from Ringwood Road, and is intended to deal with first flush waters containing a high level of pollutants (www.bwhwater.co.uk/bsp).

1.5 Highway Runoff

With increased environmental awareness, highway run-off has become regarded as more than simply displaced rainwater. Highway run-off from impermeable areas such as roads, storage areas, and car parks has been recognised to contain pollutants that can be toxic to the natural environment (www.esemag.com). Highway Runoff contains a mixture of suspended solids, oxygen demanding substances, heavy metals, hydrocarbons, and other potentially toxic compounds. Treatment of urban runoff is particularly challenging because factors such as intervals between storm events can influence the contaminants loading to the wetland, and the volume (size) of the rainfall event can control the hydraulic residence of contaminants in the treatment wetland (Kent 2001).

A major source of organic pollution in urban runoff is oil, which can be present in significant quantities, particularly during the initial stages of stormflow. The majority (70-75%) of the oil load is believed to be associated with suspended solids (Cooper et al 1996). Due to the different intrinsic physicochemical properties of organic contaminants, they tend to interact different extent with suspended particulate matter (SPM), bed sediments and biota, and are subject to various transformation processes including chemical transformation, biodegradation and photochemical degradation (Zhou et al 2003). Total hydrocarbons levels typically range between 1 and 25mg/l in urban water although concentrations as high as 400mg/l have been recorded during short intense storm events when suspended solids are high. Currently there are no water quality standards which define acceptable hydrocarbon contamination levels in surface waters, although maximum recommended values are normally the quantities which produce a visible surface film, a normal interpretation being 5-10mg/l. Hydrocarbon degradation is strongly temperature dependent. Plant litter and a soil substrate will provide thermal insulation in sub-surface flow wetlands.

In contrast, reduced water temperature in surface flow wetlands during winter months may lead to severe retardation of hydrocarbon degradation (Cooper et al 1996).

1.6 Hydrocarbons/Phenols/Immiscible Liquids

Organic contaminants such as polycyclic aromatic hydrocarbons (PAHs) are potentially hazardous, including highly mutagenic and carcinogenic four-to seven-ring compounds, and highly toxic two-or three-ring PAHs. PAHs are ubiquitous contaminants derived primarily from anthropogenic sources including both high and low temperature combustion of fossil fuels and the direct release of oil and its products (Zhou et al 2003).

Fluoranthene and Pyrene are both 4-ring PAHs, it is heavier (4-5-6 ring) PAHs such as these that are more persistent in the environment than the lighter (2-and 3-ring) PAHs. When released into water they rapidly become absorbed to sediments and particulate matter in the water column, and bioconcentrate in aquatic organisms. Pyrene has a lethal dose (LD50) of 4 micro-grams per litre for the water flea *(Daphnia Magna)* for a 1 hour exposure (www.nature.nps.gov).

Alkanes are a class of hydrocarbons (compounds of hydrogen and carbon) that make up the primary part of the saturate group of components in oil. They are characterised by branched or unbranched chains of carbon atoms with attached hydrogen atoms. At low concentrations, alkanes with low carbon numbers produce anesthesia and narcosis (stupor, slow activity) and at high concentrations can cause cell damage and death in a variety of organisms. Alkanes with a higher number of carbon atoms are not generally toxic but have been shown to interfere with normal metabolic processes and communication in some species (Fingas 2001).

Naphthalene is a low molecular weight 2-ring PAH. In the aquatic environment, naphthalenes are especially hazardous PAHs due to their particular combination of mobility, toxicity and general environmental hazard. In fact, some studies have concluded that the toxicity of oil appears to be a function of its di-aromatic hydrocarbons (that is, two ring hydrocarbons such as naphthalene). Naphthalene is an endocrine disrupter, when elevated in water to 10 ppm, naphthalene has caused crawfish ovaries to shrink, resulting in fewer eggs and smaller offspring. Low molecular weight PAHs are removed from the water column primary by evapouration, microbial oxidation, and sedimentation. The principal loss processes will depend on local conditions but half-lives can be expected to range from a couple of days to a few months. Biphenyl is also a low molecular weight 2 ring PAH. The biphenyl group is also a common component or base structure of for

PCBs and various other toxic organic compounds (www.nature.nps.gov). A study of the intrinsic bioremediation of a petroleum-impacted wetland by Mills et al shows that PAHs have an increased resistance to degradation with increasing number of aromatic rings.

Article 16 of the EC Water Framework Directive (2000/60/EC) sets out a "strategy against pollution of water". This strategy lists 32 priority dangerous substances including fluorathene and naphthalene (europa.eu.int/).

Phenols are a group of aromatic organic hydrocarbons which are highly toxic to living organisms (Porteous 1996). Releases of phenols may occur from processes in which they are used, from their application as pesticides, disinfectants and antiseptics and from waste incineration. Phenol is also emitted in vehicle exhaust and is found in cigarette smoke. Significant amounts of phenols are also released naturally, for example from forest fires. Some phenols (such as chlorophenols) persist and accumulate in the environment and may therefore have environmental effects at a global level. There is no UK (including Scottish) legislation controlling releases of phenols. They are however controlled from Europe and through international initiatives. European Directives controlling emissions of phenols include those concerned with improving the quality of bathing water (76/160/EEC); treatment of hazardous wastes (91/689/EEC); and they have been identified as "priority substances" for action to prevent harm to the environment and human health. Internationally, phenols are controlled through the OSPAR and Helsinki conventions which protect the marine environments of the north-east Atlantic and Baltic sea respectively; the Basel convention on transboundary movement and disposal of hazardous wastes; and the Rotterdam convention on the trade of certain hazardous chemicals and pesticides (www.sepa.org.uk). The Bathing Water Quality Directive (76/160/EEC) has mandatory levels for phenols at ≤0.05 mg/l and a guidance level of ≤0.005 mg/l (europa.eu.int/water/water-bathing/directiv.html).

Immiscible liquids may be present as oils, greases or tarry substances, often in the form of emulsions. (An emulsion is a colloidal suspension of one liquid in another). They may affect turbidity in the same way as suspended solids. However, emulsions are not likely to settle on the bed of the river. Oil is generally lighter than water and will spread over the surface to form an extremely thin film; a small quantity is therefore likely to pollute a large area. Even when the oxygen demand in the water is low and oil imposes little additional biological load, the presence of an oil film with the thickness of only one thousandth of a millimetre may reduce the rate at which oxygen is transferred from the air to water. The concentration of dissolved oxygen will continue to fall until the increased oxygen deficit is sufficient to overcome the oil barrier and the original transfer rate is restored (Anon 1992).

1.7 Aquatic Plants used in Constructed Wetlands

A wide range of aquatic plants have been claimed to have the ability to treat wastewaters. These include *Phragmites australis* (the Common Reed), *Schoenoplectus Lacustris* (the true Bulrush), the Rushes *Juncus effusus* and *conglomeratus,* the Sedge family *Carex, Iris pseudacorus* (Yellow Flag), the Reed Maces *Typha latifolia*, Glyceria maxima (Reedgrass), *Phalaris arundinacea* (Reed Canary Grass), *Acorus calamus* (sweet flag) and *Metha aquatica* (Water Mint).

Phragmites australis (the Common Reed) is the favoured plant in European systems and is one of the most productive, widespread species in the world. *Schoenoplectus Lacustris* (the true Bulrush) and *Typha latifolia* (Reed Mace), or a combination of the two, are the dominant species in most constructed wetlands in the United States (Cooper et al 1996).

A study by Coleman et al (1999) used three plant species to investigate their effectiveness in constructed wetlands. The three species were *Juncus effusis, Scirpus validus,*and *Typha latifolia.* The experimental design included five planting treatments (each species in monoculture, an equal mixture of the three species and controls without vegetation). When effluent water of all treatments was averaged and compared to influent wastewater, reductions of between 50 to 70% in total suspended solids (TSS), biochemical oxygen demand (BOD), total Kjeldahl nitrogen (TKN), ammonia, phosphate and fecal coliforms were realised.

The three species differed greatly in their abilities to facilitate the treatment processes. *Typha's* more aggressive growth and colonizing ability has been cited as a reason to avoid its use in constructed wetlands. However *typha* reduced BOD, TKN, ammonia, phosphate, and fecal coliform concentration in effluent compared to *Scirpus* and *Juncus.* The species mixture also had a consistently greater effect on effluent quality than did *Typha* in monoculture, although in no case was the difference between the two treatments significant.

1.8 Parameters

Comprehensive monitoring surveys for constructed wetlands from the Urban Pollution Research Centre include measurements of: pH, dissolved oxygen, total suspended solids, Biochemical oxygen demand, nitrates and phosphates, heavy metals and hydrocarbons (Shutes et al 1999).

Biochemical oxygen demand

Biochemical oxygen demand (BOD) is a standard water-treatment test for the presence of organic pollutants. This biochemical test depends on the activities of bacteria and other microscopic organisms, which in the presence of oxygen feed upon organic matter. The results of the test indicate the amount of dissolved oxygen in grams per cubic metre used by the sample when incubated in darkness at 20 degrees for five days. Below are some typical BOD five values.

Type of waste	BOD 5 days mg/L
Brewery	550
Domestic sewage	350
Pulpmill	25000
Petroleum refinery	850

(Porteous 1996)

The Royal Commission on Sewage on Sewage Disposal (1912) chose an incubation period of 5 days for the BOD test because that is the longest flow time of any British river to the open sea. An incubation temperature of 20 ºC was chosen because the long-term average summer temperature in Britain was 18.3 ºC. (Anon 1992).

Typical BOD concentrations ranges expected in rivers	
Natural background levels expected	BOD mg/L
Upland streams	0.5-2.0
Lowland streams	2.0-5.0
Large lowland rivers	3.0-7.0

(Gray 2002).

Suspended and Total Dissolved Solids

Suspended Solids are the dry weight of solids captured by filtering known volume of river water, usually expressed in mg/l (Porteous 1996). The Majority (70-75 %) of the oil load is believed to be associated with suspended solids because of the high partition coefficient of the non-polar hydrocarbons, adsorption, co-precipitation and sedimentation being responsible for the transfer of hydrocarbons from the aqueous to the sediment phase (Cooper et al 1996). Quantities are affected by seasonal changes and tend to be higher in winter because of increased storm run-off due to higher rainfall and melting snow (Anon 1992). Total dissolved solids are the solids residue after evaporating a sample of water or effluent expressed in mg/l (Porteous 1996).

Suspended solids can be classed as either inert or oxidizable (degradable). Inert solids can clog the feeding mechanisms of filter feeders and the gills of aquatic animals, which are both eliminated if the effect is prolonged. Inert particles can also increase the turbidity of the water, which reduces light penetration and depresses photosynthesis. When oxidizable solids settle out they blanket the substrate and undergo anaerobic decomposition releasing methane, sulphide, ammonia and toxic compounds (Gray 2002).

Temperature

All aquatic organisms have a fairly well defined temperature tolerance range and this determines their distribution. Temperature affects the saturation concentration of dissolved. An increase in water temperature will reduce the oxygen solubility as well as increase the metabolic rate of the organism. The combination of these two effects means that oxygen demand by organisms increases just when oxygen supply is being reduced (Anon 1992).

pH

pH is a measure of the acid balance of a solution and is defined as the negative of the logarithm to the base 10 of the hydrogen ion concentration. At a given temperature pH gives an indication of the acidic or alkaline nature of the water. The dissolved chemical compounds and biochemical processes in the water control it (Gray 1999).

Dissolved oxygen (DO)

The amount of oxygen dissolved in a stream, river or lake is an indication of the degree of health of the stream and it's ability to support a balanced aquatic ecosystem (Porteous 1996).

Total coliform and E.coli

Routine coliform testing comprises of two tests giving the total coliform and faecal coliform (E.coli) count. Coliforms do not only occur in faeces, they are normal inhabitants of water and soil. The presence of coliforms in a water sample does not necessarily indicate faecal contamination, although in practice it must be assumed that they are of faecal origin unless proved otherwise. The total coliform count measures all the coliforms present in the sample. However, only E.coli is exclusively faecal in origin. E.coli can survive for several weeks under ideal conditions and are far more easily detected than the other indicator bacteria (Gray 2002). The Bathing Water Directive sets mandatory levels at 10000 per 100ml for total coliforms, and a guidance level of 500 per 100ml. The standard for faecal coliforms is mandatory at 2000 per 100ml and the guidance level is 100 per 100ml.The standards from this Directive are also used in the Blue Flag Awards (europa.eu).

1.9 Aims and Objectives

The main aim of the study is to investigate whether the two constructed wetlands are reducing road run-off pollution in the Bourne stream. The study will also investigate whether the water quality of the stream has improved since the introduction of the wetlands.

These objectives will be achieved in a number of ways:

1. To assess using four different parameters the effectiveness of the constructed wetlands as a treatment system for highway run-off.
2. To investigate whether there is a significant difference across five samplings points (before, in, and after the wetlands)
3. To ascertain whether the off-line wetland reduces first flush pollution in 24 hours.
4. To investigate, using data from 2001, 2002 and 2003 if the water quality of the Bourne stream has improved since the introduction of the wetlands.

Methodology

Sample sites

Five sample points were chosen to give an overall picture of the water quality, before, in and after the two wetlands. Fig 2 shows the fourteen sampling points along the Bourne stream used by the Environment Agency/Bourne stream Partnership during the bathing season (May 15th to September 30th). As the purpose of this study is to investigate the use of constructed wetlands as a treatment system for highway run-off only sites one to three are relevant.

Fig 2 (www.bhwater.co.uk/bsp)

Sites one to three were also the same sampling points used by Bournemouth University students Kerry Fleet (2001), and Joanne Hutt (2002) for a studies of the wetlands. The 2002 study added two more sampling sites, one slightly downstream of sustainable urban drainage system (SUDS) phase II, and the other within the phase I SUD site. Fig 3 shows sampling sites 1,2 and 3 as used by the Environment Agency/Bourne Stream Partnership. These sites were also used for this study. However for this study they were sites 1, 3 and 5, site 2 was within the phase II SUDS site (the off-line system) and site 4 was within the phase I SUDS site (on-line system). Site 2 was added to this study because this wetland was built to take the first flush of highway run-off. None of the previous studies or the work the Bourne Stream Partnership/Environment have sampled for hydrocarbons or oils, however previous data will be used to assess whether the water quality of the stream has improved since the introduction of the wetlands. Parameters from the previous studies include: Dissolved oxygen, pH, temperature, nitrates, E.coli, total coliforms, and BOD.

Sampling Procedure

The Bourne stream Partnership/Environment Agency sampled on average every 9.2 days during the Bathing season (15th May-30th September) 2003. The 2002 study sampled fortnightly over a three-month period, and the 2001 study sampled monthly from August until December.

This study sampled oils, phenols, total dissolved solids and temperature on a fortnightly basis, and the analysis of hydrocarbons on a monthly basis. Hydrocarbons were sampled at sites one to five, and twenty-four after these samples were taken another sample was taken from site two. This is because studies such as that of Ellis and Revitt (1991) show that hydrocarbon can be reduced by between 54-70% after twenty-four hours retention (cooper et al 1996). A study by Shutes et al (1999) suggested that constructed wetlands should ideally have a minimum retention time of 30 minutes for the design storm event. An ideal design should retain the average annual storm volume for a minimum of 3-5 hours and preferably for 10-15 hours to achieve a good removal efficiency.

Site descriptions

Fig 4 shows site 1, this is the point there the stream emerges from a pipe close to Ringwood Road. This point is also site 1 for the other studies. Samples from this point show the quality of the water before it enters the wetlands. This site is very shaded.

Fig 5 shows site 2 this is the off-line wetland. Neither of the other studies sampled here, and this is not a sample point for the Bourne Stream Partnership. For health and safety reasons samples were taken near the edge of the wetland.

Fig 6 shows site 3, this was use to give an indication of water quality before the stream entered the on-line wetland. This point was also used to assess the improvements made to water quality by the off-line wetland. Samples are also taken from this point by the Bourne Stream partnership.

Fig 7 shows the stream flowing into the on-line wetland. Samples were taken from around the centre of the wetland. The 2002 study also sampled within the on-line wetland. This point was chosen to assess whether water quality fluctuates between the two wetlands.

Fig 8 is site 5, this point was chosen to give an overall picture of water quality improvements made by the wetlands. This point was used in previous studies and is used by the Bourne Stream Partnership as a sample point.

Chemical and Physical Parameters

Total dissolved solids and temperature were measured on site using a Hanna HI 98311 waterproof meter.The determination of oil was conducted on site using Macherey-Nagel oil test paper. Phenols were measured on site using a LaMotte Axial Reader Model P-52-R. Hydrocarbons were measured using gas chromatography, courtesy of Wessex Water in their laboratory in Bristol.

Table 1

Sample Dates	Parameters Tested
22/09/03	TDS/Temp/Oil
8/10/03	TDS/Temp/Oil/Hydrocarbons
29/10/03	TDS/Temp/Oil
14/11/03	TDS/Temp/Oil
3/12/03	TDS/Temp/Oil
11/12/03	TDS/Temp/Oil/Hydrocarbons

RESULTS

The physical and chemical parameters used from other studies for analysis were: pH, nitrates, dissolved oxygen, E.coli, total coliforms, temperature, and BOD.(due to equipment faults there was no BOD data from 2001 and 2002). As some of the data was non-parametric, the Mann-Whitney U Test was chosen. Only data from before and after the wetlands was used for statistical analysis. So from 2001 and 2003 only sites 1 and 3 were used, and from 2002 only sites 1 and 5.

2001 Data

Table 2

	pH			Dissolved Oxygen mg/l			Nitrates mg/l	
Date	Site 1	Site 3		Site 1	Site 3		Site 1	Site 3
1	7.4	7.8		8	4.3		1.8	4.4
2	7.4	8		9.4	4.7		3.8	4.8
3	7.8	8		9.7	6.2		4.5	4.5
4	7.9	8.2		10.6	6.4		4.5	2.3
5	8	8.2		11	10.3		4.6	5

	E.coli			Total Coliforms			Temperature	
Date	Site 1	Site 3		Site 1	Site 3		Site 1	Site 3
1	121.5	2419.2		2419.2	2419.2		19	18.6
2	476.3	316.2		2419.2	2419.2		13.8	13.5
3	1337.7	770.8		2419.2	2419.2		15.3	15.3
4	0	824.7		0	1612.8		10.9	10.7
5	4.8	15.1		1612.8	0		7	7

The pH data for 2001 was always higher at site 3 than at site 1 the Mann Whitney U Test was not applied and it was assumed that the wetlands were not reducing the pH of the water. The test was also not applied to the total coliform data from 2001 as the site 1 and site 3 data were the same. As on four of five sampling dates the nitrates were higher at site 1 than at site 3, the test was not applied to nitrates either.

The test showed that the wetlands were having a significant effect on the dissolved oxygen content of the stream, with a critical value of 4 at P = 0.05and an observed value of 3. With a critical value of 2 at P = 0.05 and an observed value of 13 the test showed that the wetlands were not having a significant effect on the E.coli in the stream. The wetlands were also not having a significant effect on the temperature of the stream with a critical value of 4 at P = 0.05 and an observed value of 21.5.

2002 Data

Table 3

	pH			Dissolved Oxygen mg/l			Nitrates mg/l	
Date	Site 1	Site 5		Site 1	Site 5		Site 1	Site 5
1	8.2	7.5		8.53	-		32.6	22.16
2	8.1	7.2		3.6	2.07		25.72	25.06
3	8.6	7.2		4.77	2.13		25.79	28.77
4	8.2	7.3		2.07	-		23.38	24.88
5	8.2	7.3		5.47	3.3		32.27	22.76
6	8.2	7.4		3.93	-		28.83	23.08
7	8.1	7.6		5.2	3.03		32.88	22.8

	E.coli			Total Coliforms			Temperature	
Date	Site 1	Site 5		Site 1	Site 5		Site 1	Site 5
1	419.97	474.13		398.0333	474.1333		16.23	16.37
2	106.2	214.97		1901.81	1859.575		16.9	18.9
3	1732.87	1413.6		2419.2	2419.2		19.17	-
4	290.9	204.6		2419.2	435.2		17.53	18.93
5	166.9	235.9		2419.2	2419.2		18.4	19.13
6	2419.2	2419.2		2419.2	2419.2		17.37	16.2
7	51.7	71		2419.2	2419.2		15.67	17.8

The pH data from 2002 showed that the wetlands were having a significant effect. The values from the Mann Whitney U Test were a critical value of 11at P = 0.05and an observed value of 0. For dissolved oxygen some of the data for site 5 was missing (dates 1, 4, and 6), so only data from dates 2,3,5, and 7 were used for the test. The test showed that the wetlands were continuing to lower dissolved oxygen levels with a critical value of 1at P= 0.05 and an observed value of 0. The nitrate data for 2002 also showed that the wetlands were having a significant effect with a critical value at of 11 at P = 0.05 and an observed value of 5. With a critical value of 11 at P = 0.05 and an observed value of 38.5 the test showed that the wetlands were still not having a significant effect on E.coli levels in the stream. As the E.coli levels at site 5 were only lower than site 1 on two of the dates (3 and 4) the non-significant result was not unexpected. With 4 sets of data for total coliforms being the same, the non-significant result was not unexpected with a critical value at of 11 at P = 0.05 and an observed value of 36. The test was not applied to the temperature data because the temperature was only lower at site 5 on one of the sampling dates (6).

2003 Data

Table 4

	pH			Dissolved Oxygen %			Nitrates mg/l	
Date	Site 1	Site 3		Site 1	Site 3		Site 1	Site 3
1	-	7.82		-	-		-	16.78
2	-	8		-	-		-	20.37
3	7.55	8.12		74.6	36.8		0.86	11.42
4	7.5	7.47		72.3	46.1		0.86	15.28
5	7.95	7.84		88.7	68.8		19.58	18.69
6	7.85	7.69		90.4	63.9		15.81	12.18
7	7.9	7.69		93.3	57.5		16.7	15.72
8	7.84	7.88		92.4	76.7		20.11	19.71
9	7.87	7.86		92.4	79.3		16.3	19
10	7.44	7.67		77.8	57.8		11.2	14.39
11	7.64	7.72		71.3	56.6		15.19	10.41
12	7.1	7.71		82.5	52.7		0.86	12.04
13	7.72	7.74		76.4	58.5		14.04	13.33
14	8.03	7.86		75	44.5		17.18	13.68

	BOD		Total coliforms		Temperature	
Date	Site 1	Site 3	Site 1	Site 3	Site 1	Site 3
1	-	1.76	-	3100	-	-
2	-	0.5	-	2600	-	-
3	7.95	2.52	100000	93000	15.1	15.4
4	17.2	3.86	2000000	100000	18	19.5
5	3.5	1.49	20000	3000	18.7	17.8
6	1.37	1	33000	18000	18.9	19.3
7	1.18	2.47	6000	5400	18.9	17.8
8	1.02	1.33	1000	4000	20.8	20.1
9	1	1	1000	1200	22	21.2
10	64.3	2	100000	5700	18.6	18.4
11	2.51	0.72	220000	5200	21.1	20.8
12	24.6	0.5	35000	300	18.9	16.9
13	6.77	1.37	100000	25000	19.4	18.2
14	0.67	0.78	37000	3800	17.6	16.5

Of the 12 sampling dates used for analysis of pH, only half were lower at site 3 than site 1. The Mann Whitney U Test was applied, but no significant difference was found. Critical value 42 at P = 0.05 and observed value 145. The results show that the wetlands are continuing to effect dissolved oxygen levels with a critical value of 42 at P = 0.05 and an observed value of 10. On each of the 12 sampling dates the dissolved oxygen level was always considerably lower at site 3 than site 1. The sampling data for nitrates showed that nitrates were only lower at site 3 than site 1 on 7 of the 12 sampling dates. The test showed that this was not significant with a critical value of 42 at P = 0.05 and an observed value of 73. The BOD data for 2003 (due to equipment fault there was no BOD data for 2001/2) showed that the wetlands were having a significant effect on BOD levels, with a critical value of 42 at P = 0.05 and an observed value of 41.5. As the samples from site 3 were lower than site 1 on 8 of the 12 sampling dates, the result was not unexpected. On 9 of the 12 sampling dates total coliforms levels were lower at site3 than at site1. The results of the test show this to be significant, with a critical value of 42 at P = 0.05 and an observed value of 36.5. Although 9 of the 12 dates for temperature are lower at site3 than site1 the Mann Whitney U Test showed that this was not significant, with a critical value of 42 at P = 0.05 and an observed value of 59.5.

Median Values

As some of the data was non-parametric median values instead of mean values were calculated.

Table 5

Median values for pH

2001	2001		2002	2002		2003	2003
Site1	Site 3		Site1	Site 5		Site1	Site 3
7.8	8		8.2	7.3		7.78	7.78

Table 6

Median values for Dissolved Oxygen mg/l

2001	2001		2002	2002		2003	2003
Site1	Site 3		Site1	Site 5		Site1	Site 3
9.7	6.2		4.77	3.03		8.01	5.76

Table 7

Median values for Nitrates mg/l

2001	2001		2002	2002		2003	2003
Site1	Site 3		Site1	Site 5		Site1	Site 3
4.5	4.5		28.83	23.08		15.5	14.83

Table 8

Median values for E.coli

2001	2001		2002	2002		2003	2003
Site1	Site 3		Site1	Site 5		Site1	Site 3
121.51	770.8		290.9	235.9		no data	no data

Table 9

Median values for Total coliforms

2001	**2001**		**2002**	**2002**		**2003**	**2003**
Site1	Site 3		Site1	Site 5		Site1	Site 3
2419.2	2419.2		2419.2	2419.2		3600	4600

Table 10

Median values for Temperature

2001	2001		2002	2002		2003	2003
Site1	Site 3		Site1	Site 5		Site1	Site 3
13.8	13.5		17.73	18.36		18.9	18.3

Table 11

Median values for BOD mg/l

2001	**2001**		**2002**	**2002**		**2003**	**2003**
Site1	Site 3		Site1	Site 5		Site1	Site 3
no data	no data		no data	no data		3.005	1.35

A comparison of online and off-line constructed wetlands

From the full sample data (see appendix) comparisons were made between the two wetlands. Using the median values.

Table 12

2001	Off-line		On-line
pH	+ 0.6		+ 0.2
Temperature	+ 0.2		- 0.2
Dissolved Oxygen	- 0.1		-4
Nitrates	0		-1.2
E.coli count	+ 15.4		-4.5
Total Coliform count	0		0

Table 13

2002	Off-line		On-line
pH	- 0.8		0
Temperature	+ 1.86		- 3.87
Dissolved Oxygen	- 0.75		- 2.73
Nitrates	- 1.42		- 2.14
E.coli count	+ 543.37		- 434.56
Total Coliform count	0		0

Table14

2003	Off-line		On-line
pH	+ 0.025		- 0.13
Temperature	- 0.2		- 0.6
Dissolved Oxygen	- 0.81		0
Nitrates	0		-1.285
BOD	+ 4.9		- 6.3
Total Coliform count	- 1000		- 5000

Total Dissolved Solids and Temperature Data from 22/09/03 to 11/12/03

Table 15

Date	Time	Weather	Site	Temp	TDS
22/09/03	3.00pm	Overcast	1	19	285
			2	17.6	249
			3	18.6	274
			4	18.6	275
			5	19	262

Date	Time	Weather	Site	Temp	TDS
8/10/03	4.00pm	Dry	1	17.7	312
			2	15.1	264
			3	14.9	312
			4	14.8	297
			5	14.7	301

Date	Time	Weather	Site	Temp	TDS	Water description
29/10/03	4.00pm	Dry, heavy rain earlier	1	12.4	235	cloudy
			2	10.2	185	smelly
			3	11.6	215	slightly cloudy
			4	11.3	162	cloudy
			5	10.9	155	clear

Date	Time	Weather	Site	Temp	TDS	Water description
14/11/03	3.00pm	Dry, rain earlier	1	12.2	205	cloudy
			2	9.8	214	clear
			3	11	259	clear
			4	10.6	224	clear
			5	10.7	220	clear

Date	Time	Weather	Site	Temp	TDS	Water description
3/12/03	3.00pm	Dry	1	11.7	240	cloudy
			2	9.3	120	clear
			3	10.2	220	clear

			4	9.8	214	cloudy
			5	9.6	212	clear

Date	Time	Weather	Site	Temp	TDS	Water description
11/12/03	8.30am	Raining	1	11.1	153	very cloudy
			2	8.5	195	clear
			3	9.7	156	cloudy
			4	9.5	247	cloudy
			5	9.8	235	cloudy

During the study both the Macherey-Nagel oil test paper and the LaMotte Axial Reader Model P-52-R (phenols) failed to give any readings. The Mann Whitney U Test was applied to the temperature and total dissolved solids data and no significant difference was found between site 1 and site 5 for neither. The total dissolved solids data had an observed value of 16.5 and a critical value of 7. The temperature data had an observed value of 9.5 and a critical value of 7.

Results of samples analysis by Wessex Water (October 2003)

GC-MS: Sample 1 (site 1)

The hydrocarbon profile showed weathered diesel/fuel oil, n-alkanes C14 – C25 (4.3 µg/L). There was a complex mixture of minor components, mainly associated with plastic. Results in µg/L:

Dimethyl naphthalenes	0.4
Trimethyl naphthalenes	0.4
Tri (chloroethyl) phosphate, fire retardant	0.4
Tri (chloropropyl) phosphate, fire retardant	1.9
Triphenyl phosphate	0.6
2-ethylhexyl diphenyl phosphate	0.9
Bisphenol A	0.4
Hexa (methoxymethyl) melamine, fireproofer?	1.7

Evidence of triethyl phosphate, alkyl phenol MW136, methyl naphthalenes, PAH, dichlorophenyl isocyanate, o-phenyl phenol (anti-microbial), and caffeine.

GC-MS: Sample 2 (site 2)

The hydrocarbon profile showed weathered diesel/fuel oil, n-alkanes C13 – C25 (2.0 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil. Results in µg/L:

Dimethyl naphthalenes	0.2
Trimethyl naphthalenes	0.2

Evidence of xylenol, alkyl phenol MW136, methyl naphthalenes, PAH.

GC-MS: Sample 3 (site 3)

The hydrocarbon profile showed weathered diesel/fuel oil, n-alkanes C13 – C25 (3.7 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil. Results in µg/L:

Dimethyl naphthalenes	0.3
Trimethyl naphthalenes	0.7
Triphenyl phosphate	0.1

Evidence of triethyl phosphate, alkyl phenol MW136, methyl naphthalenes, PAH, o-phenyl phenol (anti-microbial).

GC-MS: Sample 4 (site 4)

The hydrocarbon profile showed weathered diesel/fuel oil, n-alkanes C13 – C25 (4.9 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil. Results in µg/L:

Dimethyl naphthalenes	0.3
Trimethyl naphthalenes	0.4
Triphenyl phosphate	0.1

Evidence of triethyl phosphate, tri-(chloro propyl) phosphate, methyl naphthalenes, PAH.

GC-MS: Sample 5 (site 5)

The hydrocarbon profile showed weathered diesel/fuel oil, n-alkanes C14 – C25 (0.6 µg/L). There was a complex mixture of minor components, mainly associated with plastic. Results in µg/L:

Dimethyl naphthalenes	<0.1
Trimethyl naphthalenes	<0.1
Tri (chloroethyl) phosphate, fire retardant	0.2
Tri (chloropropyl) phosphate, fire retardant	0.1
Squalene	0.8

Evidence of 2-ethylhexyl diphenyl phosphate, palmitic acid, PAH, and caffeine.

GC-MS: Sample 6 (site 2 tested 24 hrs after first sample)

The hydrocarbon profile showed weathered diesel/fuel oil, n-alkanes C14 – C25 (1.0 µg/L). There was a complex mixture of minor components. Results in µg/L:

Dimethyl naphthalenes	<0.1
Trimethyl naphthalenes	<0.1
Tri (chloropropyl) phosphate, fire retardant	0.1

Evidence of tri (chloroethyl) phosphate, triphenyl phosphate, dichlorophenyl isocyanate, and o-phenyl phenol (anti-microbial).

Results of samples analysis by Wessex Water (December 2003)

GC-MS: sample 1 (site 1)

The hydrocarbon profile showed very weathered diesel/fuel oil, n-alkanes C14 – C22 (11 µg/L) and an unresolved hydrocarbon response (approximately 800 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil. Results in µg/L:

Alkylbenzenes MW120	1.5
Alkylbenzenes MW134	1.1
Methyl naphthalenes	0.8
Dimethyl naphthalenes	2.3
Trimethyl naphthalenes	2.7
Biphenyl	0.2
Fluoranthene	0.9
Pyrene	1.2
Coprostanol (faecal sterol)	22.0
Cholesterol	6.2

Evidence of benzonitrile, alkylbenzenes MW148 & 162, methyl substituted biphenyls, and other PAH.

GC-MS: sample 2 (site 2)

The major components remain unidentified but are possibly sterols (9.2 µg/L). Also present, in µg/L:

Chlorinated alkylphosphates	0.1
Sulphur	0.3
Squalene	1.0
Cholesterol	1.7

GC-MS: sample 3 (site 3)

The hydrocarbon profile showed very weathered diesel/fuel oil, n-alkanes C14 – C22 (4 µg/L) and an unresolved hydrocarbon response (approximately 370 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil. Results in µg/L:

Alkylbenzenes MW120	0.4
Alkylbenzenes MW134	0.8
Methyl naphthalenes	0.5
Dimethyl naphthalenes	1.7
Trimethyl naphthalenes	1.9
Biphenyl	0.1
Fluoranthene	0.4
Pyrene	0.6
Coprostanol (faecal sterol)	12.5
Cholesterol	4.6

Evidence of alkylbenzenes MW148 & 162, methyl substituted biphenyls, and other PAH.

GC-MS: sample 4 (site 4)

The hydrocarbon profile showed fresh diesel/fuel oil, n-alkanes C14 – C25 (2 µg/L) and an unresolved hydrocarbon response (approximately 200 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil and sewage. Results in µg/L:

Alkylbenzenes MW120	0.3
Alkylbenzenes MW134	1.3
Alkylbenzenes MW148	0.8
Alkyl tetralins MW160	1.0
Methyl naphthalenes	0.1
Dimethyl naphthalenes	1.3

Trimethyl naphthalenes	1.0
Fluoranthene	0.2
Pyrene	0.3
Coprostanol (faecal sterol)	1.8
Cholesterol	1.9
Equilenin? (horse steroid)	0.2
Tribromophenol (disinfectant)	0.1
Chlorinated alkylphosphates	0.8
Caffeine	0.2
Hexa (methoxymethyl) melamine	0.8

Evidence of Alkylbenzenes MW162, methyl substituted biphenyls, PAH, bisphenol A and triacetin.

GC-MS: sample 5 (site 5)

The hydrocarbon profile showed fresh diesel/fuel oil, n-alkanes C14 – C25 (3 µg/L) and an unresolved hydrocarbon response (approximately 130 µg/L). There was a complex mixture of minor components, mainly associated with diesel oil and sewage. Results in µg/L:

Alkylbenzenes MW120	0.3
Alkylbenzenes MW134	1.0
Alkylbenzenes MW148	0.5
Alkyl tetralins MW160	0.7
Methyl naphthalenes	0.1
Dimethyl naphthalenes	0.7
Trimethyl naphthalenes	0.4
Fluoranthene	0.1
Pyrene	0.1
Coprostanol (faecal sterol)	0.6
Cholesterol	1.9
Plant sterols	2.6

Equilenin? (horse steroid)	0.5
Chlorinated alkylphosphates	0.2
Caffeine	0.2
Hexa (methoxymethyl) melamine	1.0

evidence of Alkylbenzenes MW162, methyl substituted biphenyls, PAH, bisphenol A, tribromophenol and triacetin.

GC-MS: sample 6 (site 2 after 24 hours retention)

The major components were, in µg/L:

Chlorinated alkylphosphates	0.1
Sulphur	0.2
Hexa (methoxymethyl) melamine	0.2
Squalene	1.2
Cholesterol	1.3
Plant sterol	0.5

Until more complete information on the effects of all alkyl napthalenes is available, risk assessment experts suggest adding all alkyl napthalenes concentrations plus the parent compound concentration and comparing the sum to known toxicological effect benchmarks (www.nature.nps.gov).

The only substances common to all samples (except sites 2 and 6, for December 2003) for gas chromatography were dimethyl and trimethyl naphthalenes and n-alkanes C13-C25 or C14-C25.

Table 16

Total napthalene (trimethyl + dimethyl) & n-alkanes C13-C25 from October 2003						
	S 1	S 2	S 3	S 4	S 5	S 6
Total napthalene	0.8	0.4	1	0.7	0.2	0.2
n-alkanes	4.3	2	3.7	4.9	0.6	1

Total napthalene (trimethyl + dimethyl) & n-alkanes C13-C25 from December 2003						
	S 1	S 2	S 3	S 4	S 5	S 6
Total napthalene	5		2.2	1.4	1.1	
n-alkanes	11		4	2	3	

Conclusions

When drawing conclusions from the general water quality data, several confounding variables should be considered. These included:

- Sampling dates, 2001 (August –December) and 2002 and 2003 (May-September).
- Samples taken by different operators, and use of different equipment.
- Equipment failure, (BOD data 2001/2) and the maximum readable level of 2419.2 for E.coli and Total coliform data for 2001 and 2002.
- The high rainfall in 2002.

Dissolved oxygen levels have always been lower after the wetlands than before. In 2002 pH and nitrate levels were significantly lower after the wetlands. In 2003 total coliform and BOD levels were significantly lower after the wetlands than before them.

The significant decrease in total coliforms is particularly encouraging sign as high counts on microbiological parameters have caused the bathing beach at Bournemouth to fail its Blue Flag in the past. However the reductions fluctuate greatly across the sampling dates for 2003. These reductions vary from 99% to only 5%.

The wetlands are improving the water quality of the stream. However the reductions in pollution levels are not as good as those found by the Urban Pollution Centre and the Water Research Council. Highway run-off appears not to be a serious problem for the stream. Typical total hydrocarbon levels for urban waters vary from 1-25mg/L. The highest total hydrocarbon level entering the stream was 821.7µg/L. The off-line wetland showed significant reductions in hydrocarbons after 24 hours retention, and reductions of total naphthalene and n-alkanes were also significant.

Recommendations

The increase in E.coli, total coliforms and nitrates between the two wetlands maybe caused by a non-point source of pollution. An investigation of drains/sewers, which run through the area, may help identify any leaks or damage.

Fig 9 (sewer/drain covers)

From the left-hand side photo it can be seen that water appears to be flowing from the area around the sewer/drain cover.

As oil tends to be a film on top of the water a boom could to used to divert highway runoff into the off-line wetland, and another boom could be placed across the exit of the offline wetlands to retain the oil. A boom is a floating mechanical barrier designed to stop or divert the movement of oil on water. Booms resemble a vertical curtain with portions extending above and below the water line. Most commerical booms consist of four basic components: a means of flotation, a freeboard member (or section) to prevent oil from flowing over the top of the boom, a skirt to prevent oil from being swept underneath the boom, and one or more tension members to support the entire boom.

Sorbent booms are specialized containment and recovery devices made of porous sorbent materials such as woven or fabric polypropylene, which absorbs the oil while it is being contained. Sorbents are materials that recover oil through either absorption or adsorption. Sorbents can be natural or synthetic materials. Natural sorbents are divided into oranic materials such as peat, moss or wood products, and inorganic materials, such as vermiculite or clay. Sorbents are available in a loose form, which includes granules, powder, chunks, and cubes often contained in bags, nets, or “socks” (Fingas 2001). If the reeds were harvested in the winter, they could be bundled or tied together to make sorbent booms. These could also be placed across the on-line wetland as a secondary treatment. Where oil booms have been used, such a the Welsh Harp Reservoir, north-west London, research by Shutes 2001 showed a reduction in hydrocarbon concentrations immediately below the oil boom.

Water description data generally showed site 2 to be clear, when other sites were cloudy. This was particularly noticeable during heavy rain when the samples were collected for analysis by Wessex Water. The results of this analysis also showed much lower levels of pollutants at site 2. This may indicate that not enough water is being pushed into the offline wetland, for it to make a significant difference to the water quality of the stream. If adjustments were made so more of the water passed through the off-line wetland (such as the adjustments made to a wetland further downstream (summer of 2003) off Southpark road, fig 10) this would make a more effective use of this off-line wetland. If booms or sorbent booms were used the hydrocarbons from first flush would still be contained within the wetland.

The total hydrocarbons entering the stream proved to be less than average, although samples were only taken in October and December. Consideration should be given to sampling during the summer months, for a comparison with winter figures. Although hydrocarbon testing is expensive, it should continue to be conducted to assess whether highway run-off may be a problem in the future.

Fig 10