ENVIRONMENTAL QUALITY, STAKEHOLDER PERCEPTIONS AND SUSTAINABLE SOLUTIONS – THE CASE OF SEWAGE POLLUTION IN RUSCOMBE BROOK, STROUD

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DECLARATION

This Dissertation is a product of my own work and is not the result of anything done in collaboration.

I agree that this Dissertation may be available for reference and photocopying, at the discretion of the University.

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ABSTRACT

This study investigated sewage pollution in a local watercourse, Ruscombe Brook (in the Stroud District, Gloucestershire – UK). Major concerns of the incidences of raw sewage leaking into the watercourse were raised in 2004 by a group of the community – the Ruscombe Brook Action Group (RBAG). Apart from investigating the impacts of this problem on the overall water quality, this study identified two other major sources of pollution (specifically agricultural pollution and salt intrusion) as potential of negatively affecting the water quality. The study aims therefore were to critically evaluate the extent and nature of contamination in the brook (with reference to potential causes from agricultural and road runoffs as well as spatial and temporal variability in sewage leakage) on the basis of chemical, microbiological and ecological evidence; and to evaluate and propose a management strategy (with special reference to an existing proposal of implementing Sustainable Urban Drainage Schemes, SUDS) for improving the water quality.

The results of the study revealed that no major sewage pollution was encountered during the period of the study, but indications that the incidences had happened in the past were evident from biological assessments of water and sediment quality. The potential of farmlands (agricultural pollution) impacting on the water quality were also evident from biological assessments of water and sediment samples. The issue of salt pollution, however, was not completely evident from the results obtained and is therefore recommended that future studies on the brook investigate this.

It was also recommended that management schemes for improving the water quality should consider the implementation of SUDS (specifically reed beds and constructed wetlands or ponds) as long term solution; while at the same time taking into consideration management approaches that would reduce the impacts from the farmlands.

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ULTIMATE GLORY TO THE CREATOR OF MANKIND AND THE UNIVERSE

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Chapter 1

INTRODUCTION

1.1 The Problem Context

*What goes up must come down. But what goes down the sewer should not come up into our basements, streets, or streams (*Dorfman, 2004: p.1*).* The problem of sewage pollution in watercourses is highlighted in several studies (e.g. Crabill *et al*., 1998 and Mallin *et al*., 2007) and continues to remain an issue of national concern – even in industrialised nations. In the United Kingdom (UK), for example, despite the four progressive levels of treatment that aim to produce a final effluent that is clean enough to achieve water quality standards set by the European Bathing Water Directive, shellfish Waters Directive and Urban Waste Water Treatment Directive, there are problems of untreated (or partially treated) sewage bypassing the complete treatment system and escaping into nearby watercourses. This may occur (during wet weather) through overflows which may be caused by rainwater getting into the sewer through faults in pipes or illegal connections, exceeding the capacity of the system. Overflows may also occur in dry weather due to problems such as blocked pipe.

Much of the concerns of sewage pollution are not just about the public or human health implications but also the effect it may have on the aquatic ecosystems. Apart from the fact that raw or untreated sewage may contain pathogenic protozoa such as *Giardia* and *Cryptosporium* (Medema *et al*., 2003), that are a risk to human health, major sewage contaminants include nutrients that can cause algal blooms and encourage weeds to grow (euthrophication) and can kill native vegetation; chemicals such as detergents that may cause fish kills; and increased dissolved solids that may also be toxic to aquatic organisms (Crabill *et al*., 1998 and Mallin *et al*., 2007; Medema *et al*., 2003; Rueda *et al*., 2002; Pitt *et al*., 2000).

The impact that these contaminants may have on the watercourse and therefore on the aquatic ecosystems will, however, depend on the magnitude, frequency and duration of the sewage discharge as well as on the nature of the receiving watercourse. Thus for example, regular sewage discharges may have more severe impacts on the receiving watercourse and its inhabitants than for sporadic events. Similarly, where the volume of the receiving watercourse is low, the relative concentrations of contaminants in the water will be higher and consequently its impact will be greater.

Although a number of indicators (such as ammonia and faecal coliform counts) may be used to indicate sewage pollution in brooks and rivers, the choice of parameters and/or methodology devised for assessing sewage pollution may largely be influenced by the nature of the discharges (regular or sporadic) and other factors already mentioned above. Rueda *et al*., (2002), for example, have used several physical, chemical and biological parameters to investigate the effects of regular and episodic sewage inputs (domestic and industrial) on the water quality of a small Mediterranean stream (River Magro in eastern Spain). Their results showed that whereas chemical analyses were useful for monitoring water quality in areas where sewage discharges were regular, episodic and localised discharges were not detected by the chemical analyses. They also noted that macroinvertebrtates (bioindicators) were highly sensitive to (and therefore were able to serve as evidence of) episodic sewage discharges which were difficult to detect by classical and chemical monitoring.

In recent decades, the use of bioindicators (although the concept came into existence about a century ago; Iliopoulou-Georgudaki *et al*., 2003) has not only been widely employed in assessing problems of sewage pollution, but also in assessing water quality in natural rivers with respect to diverse contaminant inputs (e.g. Iliopoulou-Georgudaki *et al*., 2003; McCauley, *et al*., 2000; USGS, 1998; Hooda *et al*., 2000b). The implementation of the European Water Framework Directive (WFD) may also be said to have stimulated and encouraged the use of benthic organisms as indicators of water quality; as espoused in its objective of ensuring ‘good’ ecological quality status. Although this approach has been argued to be the most practical and providing all relevant information needed to assess water quality (Iliopoulou-Georgudaki *et al*., 2003; Hooda *et al*., 2000b), it is not without its limitations. Calow and Petts (1992), for example, note that it is difficult, if not impossible, to replicate observations or experiments in space and/or time. They also note that where and how often to sample also remain perennial problems. However, it may be argued that these limitations identified by Calow and Petts (1992) are also applicable when analysing for physiochemical parameters – and hence assessments of both physiochemical variables and macroinvertebrates may help eliminate some of these uncertainties.

This study sets out to investigate sewage pollution in a local watercourse, Ruscombe Brook (in the Stroud District, Gloucestershire – UK). For many years, Ruscombe Brook has not only served as a recreational watercourse for the community but also as a good source of water for watering livestock (Booth and Patrick; personal communication). In 2004, however, concerns about the health implications of children playing in the watercourse as well as the public health in general were raised following reports by some residents of the incidence of raw sewage leaking into the stream and onto nearby farmlands. As Health Canada (2006) explains, the most effective way of ensuring that local watercourses remain safe for use (in all kinds of human activities) is to become aware of the types of hazards (microbiological, chemical and physical) that can impact on its quality; so it was therefore not out of place when a group of the local residents formed an action group – the Ruscombe Brook Action Group (RBAG) to further raise concerns about the need to assess the environmental and public health impacts of this pollution, and on behalf of the local community, work in partnership to finding sustainable solutions. The incidence of this pollution, according to RBAG, has resulted in aesthetically very poor water quality, build up of silt, and low biodiversity in the brook. The plan is therefore to restore the water quality and biodiversity to a state that the community can enjoy as they used to.

The purpose of this study is to critically evaluate the extent and nature of contamination in Ruscombe Brook (with reference to potential causes from agricultural and road runoffs as well as spatial and temporal variability in sewage leakage) on the basis of chemical, microbiological and ecological evidence; and to evaluate and propose a management strategy (with special reference to an existing proposal of implementing Sustainable Urban

Drainage Schemes, SUDS) for improving the water quality. This will be accomplished through;

- extensive review of literature on the environmental and public health impacts of sewage and other organic pollution in small watercourses;
- water quality monitoring for a three – month - period including bacterial analyses of sediment , and macroinvertebrate survey of the brook;
- analyses of secondary / historical water quality data; and
- engaging with stakeholders and local residents to assess their perceptions on the scale of sewage pollution in the brook as well as on their views on implementing sustainable urban drainage schemes (SUDS) for improving the water quality.

The structure of the thesis will include a general introduction to the problem context and research needs, as ‘Chapter 1’. Extensive review of the literature (on sewage and other sources of pollution in watercourses, and the sustainability and suitability of SUDS for improving water quality with reference to case studies) to form ‘Chapter 2’. Brief description of the catchment characteristics, geology and environmental issues, as ‘Chapter 3’. Description and explanations to the choice of methodologies and parameters used for the assessments, as ‘Chapter 4’. Analyses of both primary (obtained from this study) and secondary data; discussion of the results (as well as the evaluation of sustainable management strategies) and a critical evaluation of the strengths and limitations of the methodologies employed in the study, as ‘Chapter 5’. And finally, concluding remarks and recommendations for future studies, as ‘Chapter 6’.

1.2 Aims and Objectives

1.2.1 Aims:

As part of the scoping exercise by the Ruscombe Brook Action Group (RBAG), this study aims to critically evaluate the overall water quality and of possible sources of pollution into the brook; and to establish what controls are/or may be required to reduce the pollution.

1.2.2 Objectives:

Specific objectives are to:

1. critically evaluate the extent and nature of contamination of the brook (with respect to potential causes from agricultural and road runoffs as well as spatial and temporal variability in sewage leakage) on the basis of chemical, microbiological and ecological evidence;

2. assess and critically evaluate (with respect to the literature, formal knowledge from stakeholders and informal knowledge from local residents) the possibility of implementing Sustainable Urban Drainage Schemes (SUDS) as a proposed solution for improving water quality in the brook; and

3. to critically reflect on the strengths and limitations of the methodologies employed in this study and make appropriate recommendations for any future research.

Chapter 2

LITERATURE REVIEW

2.1 Background Research

Several studies on the environmental and public health impacts of sewage pollution in watercourses have been carried out worldwide (e.g. in the UK and Jersey, by Kay *et al*., 2007; in Japan, by Nobukawa and Sanukida, 2002.; in Australia, by Schlacher *et al*., 2007; in Brazil, by Abessa *et al.,* 2005; and in Tanzania, by Senzia *et al*., 2003) and a principal challenge posed in such assessments is isolating the effect of the pollution from spatial and temporal variability of the contaminants. This uncertainty is gradually leading to a change from assessing water quality to assessing sediment (which serve as a reservoir of faecal bacteria) quality in response to major sewage spills. Whereas contaminants (particularly faecal bacteria) may remain in the water column for only a few days (after sewage discharge incident), they are able to survive in sediments for several weeks or months; and can easily be re-suspended into the water column once the sediment is disturbed (for example, by rainstorm or people or pets wading in the stream). Mallin *et al* (2007), for example, in assessing the impacts of raw sewage spill on the water and sediment quality in a multi-branched tidal creek estuary along the US East Coast observed that faecal coliform bacteria counts in water samples taken a day after the incident were elevated (15,000 – 21,000 CFU / ml), but drastically reduced to and remained below 100 CFU per 100ml after the second day of the incident. However, after fourteen (14) days of the spillage, about 4.5cm of rain fell, and faecal coliforms showed an increase again on the fifteenth (15^{th}) day to 2900 CFU per 100ml. From then on, faecal coliform counts decreased over the next few weeks to normal levels (approximately 100-400 CFU per 100 ml). The authors asserted that the loss of faecal coliforms from the water column could be due to mortality from sunlight (UV radiation), predation by protozoan and dilution by incoming tides. Sediment samples taken parallel to the water samples (following the same incident), however, continued to show elevated counts (though in a gradual decreasing order) of faecal bacteria even after three weeks of the spillage – demonstrating clearly that sediment are a viable medium for assessing past sewage pollution with respect to faecal coliform counts. In order to confirm whether the elevated faecal coliform counts in the water column following the rainfall were as a result of re-suspension from the sediment, they also conducted an on-site test, by collecting water sample at one location for faecal coliform counts and then proceeded to pass a boat motor over the site, stirring the water and sediments below. Counts taken from before the stirring were 21 CFU per 100 ml while counts taken after the stirring were nearly three times greater (60 CFU per 100 ml) – clearly demonstrating that sedimentation was a major cause of the elevated coliform bacteria counts in the water column. The authors therefore concluded that sampling water column for faecal bacteria is not sufficient for assessing the impacts of sewage pollution – particularly with regard to human health issues. In a similar study, Burkholder *et al* (1997) observed that significant quantities of faecal bacteria (following a large swine waste lagoon spill that entered the New River, North Carolina) remained in the sediments for nearly three months.

Other studies (e.g. Wear and Tanner, 2007 and Smith *et al.,* 1999) have employed the use of benthic macro fauna to investigate sewage pollution incidences and to demonstrate the temporal and spatial variation problems. These studies suggest that the disposal of untreated or partially treated sewage or human wastewater has a localised effect on the faunal assemblages surrounding the discharge point. The impact of the pollution though depends and varies from species to species. Wear and Tanner (2007), for example, in assessing the Spatio-temporal variability in faunal assemblages surrounding the discharge of secondary treated sewage (in Australia) identified that while the abundance of some species did not vary, the abundance of juvenile western king prawns (Melicertus latisulcatus) and blue crabs (Portunus pelagicus) progressively decreased with proximity to the outfall. They also noted that species richness and diversity also decreased towards the outfall.

Though not often recognized, another problem that may be associated with studies investigating sewage pollution incidences is the choice of parameters to analyse, and identifying the source of this pollution based on the concentration of parameters measured.

Whereas this might not be a difficult task for studies assessing the impact of pollution on water quality with respect to only sewage discharges, it poses a great challenge for studies investigating similar impacts with respect to other potential causes such as run-offs from arable and pasture lands. Both agricultural and sewage pollution are known to be of 'organic nature' (Zamora-Muñoz and Alba-Tercedor, 1996) and may therefore have similar impacts on water quality. In other words, the major indicators of sewage pollution [i.e. nutrients (nitrogen and phosphorus), dissolved oxygen, biochemical oxygen demand, and faecal coliform bacteria] are found in equally high concentrations or elevated levels in pollution resulting from agricultural practices. A review of water quality issues in livestock farming areas in the UK by Hooda *et al* (2000a), for example, indicates that several factors including livestock wastes may result in increased concentrations of phosphorous and ammonia and ultimately impair water quality. The ecological and human health impacts resulting from water pollution by livestock rearing has been highlighted in several studies (e.g. USGS, 1998; Hooda *et al*., 2000a) and are similar to those observed and attributed to sewage pollution (including increased mortality and decreased abundance or diversity of fish – e.g. Tsai, 1975 and Underwood *et al*., 1991). Other epidemiological studies have also shown that both direct human contact and external waterborne pollutants (from sewage and agricultural runoff) in recreational waters may result in gastrointestinal and upper respiratory illness (Health Canada, 2006).

Although more research on water quality are increasingly evolving, the impact of various forms of pollution to watercourses and their resulting impacts on human and ecological health continue to remain an issue of world-wide concern. The early detection or forecasting of human impacts on water quality will therefore not only enable effective management of riverine environments but also ensure the survival of aquatic ecosystems and associated activities, such as fisheries and recreation.

2.2 Water Quality and Factors affecting it

"*In view of the complexity of factors determining water quality, and the large choice of variables used to describe the status of water bodies in quantitative terms, it is difficult to provide a simple definition of water quality*" (Meybeck and Helmer, 1996; 6). Although some human activities have been known to cause specific problems to water quality, it is established that even without such anthropogenic impacts, pristine natural ecosystems will even undergo changes in response to natural variations and all ecosystems will gradually change over time. It can therefore be difficult to determine the exact point that changes in water quality parameters begin to cause degradation to the ecosystem. The concept of what constitutes "good" water quality is complex. The definition of acceptable water quality is based upon several interrelated parameters, including how the water will be used (e.g., drinking, swimming, fishing), concentrations of materials in the water above natural background levels that could have a deleterious effect on plants or animals (pollution), and the presence of compounds not usually found in the water (contamination). Parameters typically measured during routine water quality studies are salinity, dissolved oxygen, turbidity, biochemical oxygen demand (BOD_5), chlorophyll, faecal coliform, and nutrient concentrations, predominantly nitrogen and phosphorus (Table 1). Contaminants include heavy metals, pesticides, herbicides, and other chemicals.

What even constitutes the term 'pollution' has also changed overtime with European Union (EU) legislations. There is still debate on whether agricultural pollution should be classified as point or diffuse sources. It is also argued, for example, that it is the total amount of nutrients, including micro-nutrients, entering a waterbody that can result in overloading of the system, and not necessarily their concentration. It matters little whether nutrient addition comes from a single or a few concentrated sources of nutrients discharging into a water body or from many sources discharging lower concentrations of nutrients. The effect of the total loading to the receiving water body will be the same. This argument may further be illustrated with the fact that whereas deforestation may be said to increase sediment loading to a stream bed, sediment loading may also occur through agricultural run-off or through urban run-off via storm drains. Similarly, water temperature may be changed by forestry activities that reduce stream-bed shading or by high-temperature effluent from power plants.

Table 1. Parameters measured in routine water quality monitoring and examples of methods of analysis.

Water Quality Parameter	Examples of Methods of Analysis
Physicochemical parameters	
Temperature	thermistor or mercury thermometer
Conductivity/salinity	electrometer
Dissolved oxygen	Winkler titration or polarographic sensor
pH	electrometer
Light attenuation	PAR attenuation
Turbidity	Secchi disk or nephelometry/beam
Depth	measured line or pressure transducer
Nutrients	
Dissolved ammonia	indophenol
Dissolved nitrate and nitrate	diazo after Cd reduction
Dissolved nitrite	diazo
Total nitrogen	high temperature combustion nitrous oxide chemoluminiscence
Soluble reactive phosphorous	molybdate
Total phosphorous	high temperature digestion molybdate
Non-purgeable organic carbon	high temperature combustion/IR detection
Biological parameters	
Chlorophyll a	fluorometric
Alkaline phosphatase activity	fluorometric
Faecal coliform bacteria	incubation and plate count
Biochemical oxygen demand	incubation and oxygen analysis

It is also argued from the perspective of the aquatic community that, the source of an impact is usually irrelevant. If for example, the stream temperature is increased by the introduction of industrial effluent or from increased sunlight due to lost vegetation or deforestation; effects on the aquatic community will be relatively similar (Perry and Vanderklein, 1996). It should, however, be mentioned that the scale and persistence of the impact is very relevant as the effects of the contaminants on water quality are largely dependent on weather conditions (rainfall, wind direction and intensity), the volume of the pollutant discharged, its concentration, the rate of delivery, the nature of the receiving waters in terms of available dilution and mixing, the nature of the specific stressor, and, in marine areas, tidal conditions (BASIN, 2005; Perry and Vanderklein, 1996; GWRC, 2004).

The following sections discuss further some of the factors affecting water quality as they are of significance to this study.

2.2.1 Sewage and Stormwater pollution

Sewage or urban waste water is generally a mixture of domestic waste water from baths, sinks, washing machines and toilets, waste water from industry and rainwater run-off from roads and other surfaced areas. In the UK, DEFRA (2002) estimates that over 11 billion litres of waste water are collected daily and treated at about 9,000 sewage treatment works before the treated effluent is discharged in to the inland waters, estuaries and the sea. The purpose of this treatment is to remove organic substances (such as carbohydrates, fats, proteins, which together with bacteria and other chemicals can deplete dissolved oxygen levels in the water) in order to protect the riverine environment. However, the potential for this 'treated' effluent to also impair water quality and disturb the aquatic system cannot be underestimated. Surveys of pathogen occurrence in the sewage systems of urbanised areas show that pathogen presence in sewage and sewage effluents is the rule rather than the exception (see Table 2 - Medema *et al*., 2003). Treatment of sewage by sedimentation and activated sludge, for example, reduces the concentration of pathogens by 1-2 logs (90-99%

reduction), but effluent still contains high levels of pathogens and indicator organisms (Medema *et al*., 2003). Even in (chlorine) disinfected sewage with low or no coliforms detectable in the effluent, viruses and protozoa are still likely to be present. (Medema *et al*., 2003).

Table 2. Typical concentrations of enteric pathogens and index organisms in raw and treated domestic wastewater. Source: Medema *et al* (2003).

Micro-organism	**Raw sewage (numbers/litre)**	**Secondary effluent (numbers/litre)**
Pathogens		
Parasites	1 000 – 10 000	10 – 1 000
Cryptosporidium sp.	5 000 – 50 000	50 – 500
Giardia sp.		
Viruses		
Enteroviruses	10 – 100	1 – 100
Norwalk like viruses	10 – 1 000	1 – 100
(Norovirus)	10 – 100	1 – 10
Rotavirus		
Bacteria	100 – 10 000	10 – 10 000
Salmonella spp.		
Index parameters	$10^7 – 10^9$	$10^6 – 10^8$
Coliforms	$10^6 – 10^8$	$10^5 – 10^7$
Thermotolerant coliforms / *E.coli*	$10^6 – 10^7$	$10^4 – 10^6$
Enterococci	$10^5 – 10^6$	$10^4 – 10^5$
Clostridium perfringens	$10^6 – 10^7$	$10^5 – 10^6$
F-RNA phages	$10^6 – 10^7$	$10^5 – 10^6$
Somatic coliphages	$10^4 - 10^5$	$10^3 - 10^4$
Bacteroides phages		

Williams (1993) notes that although the effluent discharged from sewage works in the UK is usually within the limits or standards set by the Environment Agency, these standards may appear to be 'too lax' from river management and public health point of view. In other words, the effluent may still contain trace amounts of toxic substances that may be directly or indirectly detrimental to both aquatic organisms and human health when discharged into the watercourse. The current practice or approach of managing urban waste through the combined centralised sewerage system (where domestic and industrial wastewater and rain or storm water are all collected and conveyed through a single pipe) has been heavily criticised as adding to the problem of overall poor water quality and increased flash floods. For example, Parker and McIntyre (1988) indicate that this practice, although it can promote effective breakdown of the degradable components of human sewage, will often enhance the contamination of sewage by persistent or toxic materials (from industrial effluents). Williams (1993), in evaluating the sustainability of the concept and use of the combined centralised sewerage systems, argues that such method of disposal may worsen drought effects (see figure 1 – Williams, 1993). She also contends that although the sewage sludge resulting from the combined sewage treatments are applied on agricultural lands, its resource value is often compromised and subsequently limiting both the natural nitrogen and hydrological cycles.

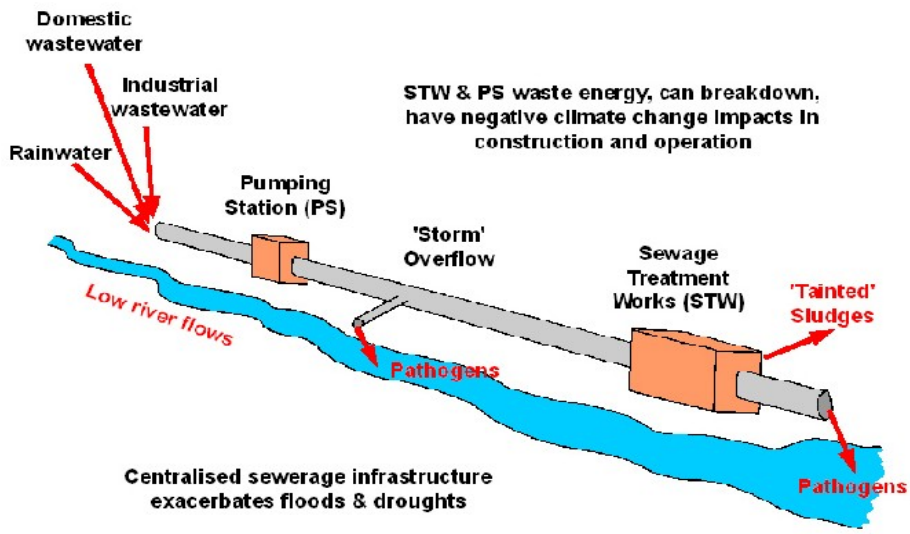


Figure 1. (Williams, 1993). Sustainability of sewers

At times ‘raw’ sewage (with extremely variable compositions) may even enter the environment before completing its journey through the treatment process. Some examples include:

- Broken or leaky pipes - usually as a result of ageing pipes, construction activities or road works.
- Overflows, during rainfall - the treatment facility may not be able to cope with the volumes of water and sewage entering the system, and raw or partially treated sewage is discharged directly into the environment (GWRC, 2004). This situation can be made worse where households have stormwater from roofs and other hard surfaces illegally connected to the sewerage system. In the case of combined sewerage systems, excess flows may be discharged directly to the water environment during heavy rainfall events. DEFRA (2007) asserts that it is normal for such overflows to be allowed in order to prevent flooding of properties, and sewage treatment works from becoming overloaded – although progress is being made in England and Wales to improve or reduce these overflows in order to comply with the Urban Waste Water Treatment Directive (91/271/EEC) which recognizes that despite the extent of dilution of sewage with significant amount of stormwater, their discharge can still be detrimental to the riverine environment – and hence requires that pollution from these overflows is limited (DEFRA, 2002).
- Emergency overflows - these can occur periodically during maintenance of sewerage systems (GWRC, 2004).
- Also potential, but often not regarded, is the potential for older properties, especially holiday homes, that may still be connected to septic tanks to leak contaminated water into the groundwater which, in turn, ends up in surface waters.

Sewage-polluted water has more serious health implications than just being disgusting or causing aesthetic offence. Although Fleisher and Kay (2006) have argued that epidemiologic studies of recreational associated illness are often invalid due to biases in the risk perceptions and self-reporting of illnesses, their report does not dispute the fact that exposure to sewage-polluted waters can result in measurable health effects. The most common symptoms identified include nausea, stomach-ache, vomiting and diarrhoea (Payment et al., 1994). Other symptoms include sore throat, cough, runny nose, earache and other respiratory problems (Fleisher et al., 1996). Contact with polluted water can also cause skin infections and rashes (Fleisher and Kay, 2006; ABAG, 2004). More serious water-borne diseases include infectious hepatitis, typhoid and cholera (ABAG, 2004).

Stormwater discharges are also a major cause of rapid deterioration in surface water quality. Storm events bring an elevation of turbidity, suspended solids, organic matter and faecal contamination into the drainage basin, caused by urban and agricultural run-off, discharges from stormwater sewers and re-suspension of sediments (Medema et al., 2003). The microbiological quality of stormwater varies widely and reflects human activities in the watershed. Geldreich (1990) found that stormwater in combined sewers (in the US) had more than 10-fold higher thermotolerant coliform levels (8.9×10^6 - 4.4×10^7/l) than separate stormwater sewers (1.0×10^5 - 3.5×10^6/l).

2.2.2 Rural run-off and livestock

Run-off from farms and other rural areas remain problematic diffuse source of pollution to watercourses. During rainfall, it can contribute significantly to faecal contamination of waterways as livestock are a well-known source of waterborne pathogens. Several outbreaks of cryptosporidiosis in the USA, Canada and UK have been associated with the contamination of water by run-off from livestock (Craun *et al.,* 1998). Impacts or major concerns regarding water quality degradation relating to agricultural activities include excessive amounts of plant nutrients, such as nitrogen and phosphorus (which will increase aquatic plant growth if they enter a surface watercourse), farm effluents (particularly livestock wastes), pesticides such as sheep-dipping chemicals, and other chemicals incorporated in fertilisers, bacterial and protozoan contamination of soil and water (Carpenter *et al.,* 1998; Chapman and Kimstach, 1996; Hooda et al., 2000a). Like all other diffuse or non-point sources of pollution, preventing or controlling agricultural-associated water pollution is very difficult, but may include, as a first step control, preventing off-site or uncontaminated runoff from flowing into livestock areas (particularly where they are confined). It may also be necessary to construct diversion ditches to direct clean water away from the area; or, if possible, run-off from the livestock pens should be channelled to a central collection or holding pond rather than directly discharging into the watercourse. Hooda *et al* (2000a) have outlined some Best Management Practices (BMPs) that may be followed to reduce the impacts of diffuse sources of water pollution. They include, inter alia;

- Determining the N and P content of manure, prior to any land application, in order to decide their rate of application;
- applying livestock waste to saturated or water-logged, snow-covered, frozen and steep sloping grounds as this may lead to high losses of N and P in surface runoff;
- Rationalising the use of fertilisers and livestock waste;
- Diluting spent-dip with three parts of slurry or water before spreading them on lands away from drains and farm streams.

2.2.3 Urban and road run-offs

In cities or urban areas where stormwater is not channelled into a main drain or sewer, runoffs (which may often contain derivatives of fossil fuel combustion, bacteria, metals, and industrial organic pollutants) may directly enter watercourses and subsequently deteriorate the water quality (Meybeck and Helmer, 1996). Even where urban run-off is collected in the sewerage system, excessive rainfall can lead to an overload of the sewers and overflow into nearby rivers, without reaching the sewage treatment plants. It may be quite difficult to establish or distinguish water pollution from urban run-off from municipal wastewater sources as they largely carry the same contaminants. Notwithstanding, water quality problems particularly associated with urban run-off are high levels of oil products and lead, as well as a variety of other metals and contaminants associated with local industrial activity (Chapman and Kimstach, 1996). Road run-offs may also contain high levels of chloride ions.

Examples of some other potential sources of pollution are given in the Table 3 below. The Table gives examples of sources of pollution and the potential pollutant discharges which could arise. It is important to note that whilst there are many potential hazards arising from the sources of pollution listed, the risks to the aquatic environment may be very small.

Table 3. Some sources of pollution and the potential pollutant discharges which could arise. Source: FWR (2007).

Examples of sources of pollution	**Point source or diffuse**	**Potential pollutant**
Effluent discharges from sewage treatment works	Point source	Nitrogen(N) and Phosphorous(P), persistent organic pollutants, pathogens, solids, litter
Industrial effluent discharges treatment	Point source	N, oxygen-depleting substances and a broad spectrum of chemicals
Industrial processes	Point source	Broad spectrum of chemicals released to air and water
Oil storage facilities	Point source	Hydrocarbons
Urban storm water discharges	Point source-arising from storm water runoff (from paved areas and roofs in towns and cities) entering the sewer network	N, P, Oxygen-depleting substances, heavy metals, hydrocarbons pathogens, persistent organic pollutants, suspended solids, settleable solids, litter
Landfill sites	Point source	N, ammonia, oxygen-depleting substances, broad spectrum of chemicals
Fish farming	Point source	N, P, oxygen-depleting substances, pathogens
Pesticide use	Diffuse	Broad spectrum of chemicals
Organic waste recycling to land	Diffuse	N, P, pathogens
Agricultural fertilisers	Diffuse	N, P
Soil cultivation	Diffuse	Soil, N, P
Power generation facilities	Diffuse	N, Sulphur
Farm wastes and silage	Diffuse	N, P, oxygen-depleting substances, pathogens
Contaminated land	Diffuse	Hydrocarbons, organic chemicals, heavy metals, oxygen-depleting substances
Mining	Point/Diffuse	Heavy metals, acid mine drainage
Leaking pipelines	Point/Diffuse	Oil, sewage

2.3 **Monitoring water quality**

Field monitoring activities, including the choice of sampling location and sampling frequency are highly dependent on the type of aquatic environment (Bartram and Balance, 1996). Although often misused and synonymously used, the terms 'monitoring' and 'assessment' means two different things. Meybeck and Helmer (1996; p.24) define water quality assessment as "*the overall process of evaluation of the physical, chemical and biological nature of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health and the health of the aquatic system itself";* and water quality monitoring as "*the actual collection of information at set locations and at regular intervals in order to provide the data which may be used to define current conditions, establish trends, etc.".* Thus water quality assessments will have to involve monitoring (of any kind) in order to inform or provide management decisions. For example, assessing the impact of sewage pollution in a river may involve monitoring background concentrations of selected parameters by measuring water quality at upstream reaches of the source of the pollution, and again at the actual source of pollution as well as some distance downstream. The results of the monitoring will then be evaluated or assessed to identify measures that may be used to reduce the pollution. Two commonly approaches of monitoring water quality are physicochemical and biomonitoring. These have been discussed further in the following sections.

2.3.1 **Physicochemical monitoring**

Unlike the biological assessment of water quality, where the incidence and intensity of pollution is based on the degree to which the chosen organism association deviates from its expected natural diversity, the physicochemical assessment is usually based on a comparison of the measurements made with water quality criteria or with standards derived from such criteria. Standards are normally set to meet specific water use purposes and therefore specific water quality assessments may be compared with the appropriate standard. For example, the Surface Water Abstraction Directive specifies microbiological standards for waters that are abstracted for potable water supply; whereas the Bathing Waters Directive specifies mandatory and guideline standards for identified bathing waters. There are, however, no microbial water quality standards in the UK that are applicable to all watercourses (Jones and Barr, undated), and although this may be subject to several health implications, the explanation is that the microbial quality of inland watercourses are highly variable due to rural and urban run-offs, as well as from the continuous discharges of effluent from sewage works (Morley, 2005 cited in Jones and Barr, undated). Thus a more practical, but highly expensive approach may be to develop such standards for each (classified) watercourse.

Physicochemical parameters may be selected for water quality assessments depending on the nature of pollution and the aim(s) of the assessment. For the assessment of organic pollution, for example, the more commonly measured parameters include Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Ammonia, Oxidised Nitrogen (Nitrites plus Nitrates) and Phosphates. Continuous records of concentration and flow would form the ideal basis for water quality assessment but in practice this is impossible for financial, technical and logistical reasons. Reliance may, therefore, be placed on discrete or batch samples and the results interpreted with care as such samples constitute only minute fractions of the whole body of water under investigation and are only representative of conditions at the particular time of sampling (Meybeck et al., 1996a; Radojević and Vladmir, 2006). The physicochemical variables selected for this study have further been briefly discussed in Appendix 1.

2.3.2 Biomonitoring

Aquatic environments can be influenced in many ways by both natural events and anthropogenic impacts. Most organisms living in a water body are also sensitive to these changes and therefore may respond in different ways. These changes may include migrating to other habitats, reduced reproductive capacity, and in extreme cases, death. This means that whereas some organisms can survive in heavily polluted waters, others can only live in unpolluted ones. The ability to identify the responses of particular aquatic organisms to any given changes may therefore, be used to determine the quality of water with respect to its suitability for aquatic life (Friedrich *et al*., 1996), and this forms the basis of monitoring water quality with biological material (biomonitoring).

Several indices could be used as indicators of water quality in such monitoring – a commonest one used being macroinvertebrates. The types of and numbers of macroinvertebrates (mostly insect larvae/nymphs) that form the benthic or biological community at a particular stream location are found to influenced by the composite environmental conditions flowing by the site during the recent past (Pallock, 2004; RSPB/NRA/RSNC, 1994). Many studies that have involved the use of macroinvertebrates have also argued that unlike fishes and other indices such as diatoms and aquatic and riparian vegetation, macroinvertebrates are very sensitive and generally react to various kinds of stream pollution; hence can be very good indicators and provide useful information on the water quality not only at the time of sampling but extendable over a period of time (e.g. Hooda *et al*., 2000b; Iliopoulou-Georgudaki *et al*., 2003). Nevertheless, the degree of precision or accurate prediction of water quality when using macroinvertebrates as indicators remains doubtful. As already mentioned, the biological community itself is significantly influenced not only by the water chemistry, but also geomorphology and hydrology of the riverine system (Friedrich *et al*., 1996; Byl and Smith, 1994). This means that any change to the river's morphology – for example, channel straightening and removing woody debris may result in loss of natural habitat and shelter for certain organisms – rather than responding to the effect of say introduction of a toxic substances from sewage discharges, agricultural run-off or other sources. Relating the effect of macroinvertebrate response to the contaminant source may therefore be misleading if not done with proper care and knowledge of the hydrological setting of the river under study. Calow and Petts (1992), for example, note that it is difficult, if not impossible to replicate observations or experiments in space and/or time. Thus, although it may not be significant, different results may be obtained for each sampling taking at different times of the day from the same sampling location. The ability to correctly identify and classify each organism to its species is a great challenge, which may further invalidate the assessment. In an approach to eliminate this factor, however, emerging indices (such as the Biological Monitoring Working Party, BMWP; and Average Score Per Taxon, ASPT) allow classification to the family level (Friedrich et al., 1996).

A clear example of the limitation of the biomonitoring technique to assessing water quality may be illustrated with Illiopolou-Georgudaki *et al*'s (2003) application of different bioindicators for assessing water quality on two rivers in Greece. Their results showed wide variations in the prediction of water quality among all the nine monitoring systems employed – hardly did all nine indices agreed on a common classification for any of the samples taken. For example, whereas some indices estimated the water quality at a particular point as 'moderate', others predicted 'poor' quality and yet others as 'very good' or 'good' for the same sample. It may, however, be argued that this does not necessarily render monitoring with any of the selected indices as ineffective, as the indices are usually derived based on a particular water body in a particular region or locality (Friedrich et al., 1996). So using the same system for other water bodies with dissimilar physical and chemical properties may result in anomalous interpretations, largely due to natural variations in species distribution. So the right monitoring system for a particular region or water body, if possible, should always be established and used for specific assessments.

The Biological Monitoring Working Party (BMWP)- score, which was derived in the UK for all water bodies (i.e. not specific to any single river catchment or geographical area), is the most acceptable and widely used system (Friedrich et al., 1996; Hooda et al., 2000b), and has been employed in this study. It mainly involves collecting macroinvertebrates and identifying them to the family level. Each family is then allocated a score between one (indicating least sensitivity to changes in water quality) and ten (indicating highest sensitivity) (see Appendix 2). The BMWP score is then calculated by summing the scores for each family represented in the sample (Armitage *et al*., 1983). Following a review, which identified the 'effect of sampling effort' (i.e. a prolonged sampling period can be expected, under most circumstances, to produce a higher final score than a sample taken quickly) as an inherent weakness of the BMWP system, the Average Score Per Taxa (ASPT) was developed by dividing the BMWP score by the number of taxa (Walley and Hawkes, 1996; 1997).

Due to the complexities that may be associated with all biotic indexes, and even though they can be used in isolation, it is always recommended that indices be used in conjunction with physiochemical monitoring to define water quality classifications (Friedrich et al., 1996), and to enable comprehensive water quality assessments. The advantages and shortcomings of biomonitoring in comparison with physicochemical monitoring has been summarised in Table 4 below. From the evaluations (of the table), it may be appreciated that both physicochemical and biological water quality assessment techniques have their own particular applications, advantages and disadvantages so that only by a combination of both may the limitations of each be overcome and a thorough understanding of the total situation be gained.

Table 4. Assessment of the Advantages and Shortcomings to biomonitoring and measuring physicochemical variables for assessing water quality.

Physicochemical measurements	**Biomonitoring**
Advantages: • Physicochemical techniques have the merit of being precise and quantitative (Meybeck et al., 1996a). • Essential if unpolluted waters are to be chemically typed or if pollutants in water are to be identified their concentrations quantified. • Thus results of physicochemical analyses may easily be related and used to identify the source(s) of pollution. • Could be used and applicable to all water bodies, including groundwaters.	Advantages: • benthic macroinvertebrate communities respond to a wide range of water quality characteristics and pollutants. • Because they can reflect the effects of mixed pollutants these changes occurring in the water body over a given time can be detected. • Good spatial and temporal integration (Friedrich et al., 1996).
Shortcomings: • Relatively highly costly – not just in terms of acquiring chemicals and equipment but also in the survey, e.g., whereas just two biological samples per annum (winter and summer) would normally provide a reasonably accurate assessment of average water quality. • A considerably greater number of physicochemical samples would normally be required to achieve such an assessment with the same degree of confidence. • Knowledge of the types of pollutants likely to be present is a prerequisite for effective chemical monitoring (Radojević and Bashkin, 2006; Meybeck et al., 1996a). With the increasing complexity of many industrial effluents this may prove difficult if not impossible in certain circumstances. • If a discharge is irregular or surreptitious there is a good chance that it will not be detected at all by routine chemical monitoring programmes.	Shortcomings: • The biological approach is that, although capable of detecting ecological change, indicative of water quality change, it does not identify the specific cause of a change. • Whilst water indicated to be of poor quality on biological grounds is suspect for most uses, water indicated to be of good quality on such grounds, although acceptable for most uses including fisheries, may not always be free from pathogens or harmful trace organics and may not therefore be acceptable as drinking water. • Assessment of this aspect may therefore, require specific microbiological and physicochemical tests. • Unlike physicochemical monitoring, Biomonitoring cannot be used to assess groundwater quality. • Also, in assessing water quality from data involving benthic communities, due recognition must be given to the influences of other ecological factors such as depth and flow rate, substratum type, the influence of shading and seasonal changes in life cycle (Friedrich et al., 1996) – a task that may be difficult to achieve.

2.4 Spatial and Temporal variation of water quality with discharge

In one way or another, the water quality of a particular water body or riverine system may vary for different samples taken from the same river (or even from a single source of the same river) but at different times of the year; or vary from one river to another in the same catchment or at different catchments taken at the same time of the year. This variation is often taken into account in many water quality monitoring studies. In most cases, continuous monitoring is established over a short term (from about six to twelve months; example, Sullivan and Drever, 2001) or long of up to about ten years or more (for example, Strasser and Mauser, 2001; Stewart and Skousen, undated) in order to account for this variation and to make comprehensive assessments and recommendations for effective management. In limited cases, and as is the case of this study (where only very short term; say, three months monitoring period is possible), attempts may be made to simulate or adopt sampling strategies that may also account for such variations. For example, where the assessment is carried out in only one particular season of the year, water samples may be taken at periods of relatively dry weather (say about two weeks of no rainfall) to represent and to replicate the conditions that may take place in the river during summer or hot weather where only base flows are expected; and again after heavy rains to replicate wet weather or high flows. This concept, however, remains questionable and may be misleading as false (i.e. not the actual) water quality conditions may be observed. For example, the observations made for water samples taken after downpours may not necessarily reflect the observations that may be recorded if the assessment took place during actual winter or wet seasons. The same is true for samples taken at dry weather conditions.

Several factors may affect the spatiotemporal variation of water quality. These include natural processes, such as the hydrological regime of the river (i.e. the water discharge variability), the number of floods per year and their importance, soil erosion; and anthropogenic influences through urban, industrial and agricultural activities and increasing exploitation of water resources (Armah et al., 2005; Carpenter et al., 1998; Krusche et al., 1997; Meybeck et al., 1996b; Singh et al., 2005; Stewart and Skousen, undated; Strasser and Mauser, 2001; Sullivan and Drever, 2001). Seasonal variations in precipitation, surface run-off, ground water flow and water interception and abstraction have strong effect on river discharge and subsequently on the concentration of pollutants in rivers (Vega et al., 1998). During flood periods, for example, water quality may vary markedly to reflect the inputs that were carried through surface run-off, which may also reflect landuse characteristics and hydrogeology of the catchment. Thus, there is no single established relation that may account for all spatiotemporal water quality variations for all water bodies. For example, whereas flooding may lead to increased concentrations of some physicochemical parameters in one river, the same flooding may rather dilute and result in lower concentrations of the same parameters in another river. It should, however, be mentioned that recent studies are now making use of statistical approaches and Geographic Information Systems (GIS) techniques to account for these variations and to assign spatiotemporal variations in water quality to their polluting sources (e.g. Vega et al., 1998) – but as to whether such results can be used to evaluate water quality for rivers other those on which the correlation was produced, is debatable.

Meybeck *et al* (1996b) have graphically demonstrated that changes in discharge, when compared to the simultaneous changes in concentrations of various substances, could provide useful information or indicator for tracing the sources of those substances (see figure 2). Curve (1) represents the case where a general increase in discharge results in decreased concentration of substances – an implication that the contaminants or substances present are diluted. Examples of such substances include major water-soluble cations (Na+, Ca2+, K+, etc.); and the situation is also characteristic of point source discharges such as municipal sewage (Meybeck *et al.,* 1996b). Curves (2) and (3) shows increases in concentration generally linked to the flushing of soil constituents (e.g. organic matter, nitrogen species) during run-off; except that in the case of (3) there is a decrease in concentration at very high discharges, indicating dilution of the soil run-off waters. Curve (4) shows the case where concentration increases exponentially with discharge, and it is associated with Total Suspended Solids (TSS) and all other substances (e.g. phosphorous, metals, pesticides) that bound to particulate matter. Curve (5) is the hysteresis loop that is observed when time is introduced as an additional parameter to the sediment discharge relationship shown in curve (4). This may also be associated with TSS and sometimes nitrates. 'X' and 'Z' represent the peaks in sediment concentration and discharges respectively, with X occurring before Z. Curve (6) represents a water source to the river where the concentration of substances remains relatively constant with discharge.

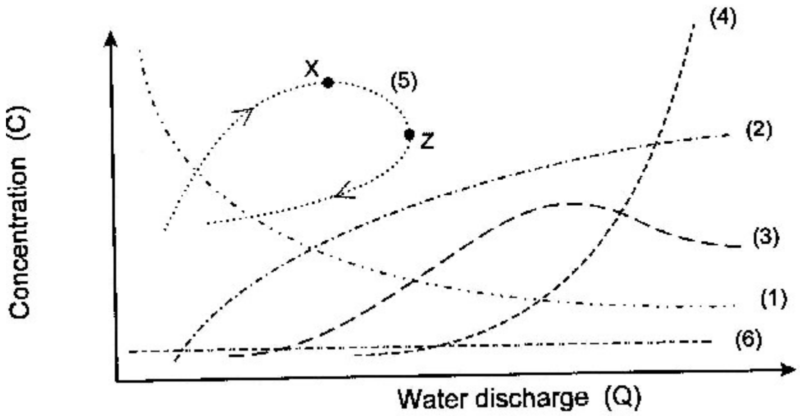


Figure 2. Patterns of concentration (C) with water discharge (Q) in rivers. Source: Meybeck *et al* (1996b).

2.5 Managing water quality – The Case of Sustainable Urban Drainage Systems (SUDS)

An integral part of this study is to identify controls or management measures to be implemented. Whereas the aim of this section (and therefore as part of the study) is to evaluate the option of implementing Sustainable Urban Drainage Schemes (SUDS - specifically reed beds and constructed wetlands), it should be noted that management measures, and therefore the best practicable or sustainable solution, may only be chosen when the mode of control is well suited to reduce such pollution. US-EPA (2007) identifies and classifies management measures into three modes of control: (1) source reduction, (2) delivery reduction, or (3) the reduction of direct impacts. For example, source-reduction measures may include nutrient management, pesticide management, and marine pump-out facilities. These measures all rely on the prevention of non-point source pollution; and may be achieved through 'Best Management Practices' (BMPs – e.g. Hooda *et al.,* 2000a) and through practices such as 'Catchment Sensitive Farming' as explained by DEFRA (2003). Delivery-reduction measures include those that rely on detention basins, filter strips, constructed wetlands, and similar practices for trapping or treatment prior to release or discharge to receiving waters. Measures that reduce direct impacts include wetland and riparian area protection, habitat protection, the preservation of natural stream channel characteristics, the provision of fish passage, and the provision of suitable dissolved oxygen levels below dams (US-EPA, 2007).

The concept of 'Sustainable Development' has found its way into many local and international policies, and indirectly promoted and proliferated the use of SUDS and the debate about its 'sustainability'. A key objective of the EU Water Framework Directive (WFD), for example, is to promote "sustainable water use"; and Article 7 (Drinking Water Protected Areas) of the same directive requires drinking water supplies to be identified as protected areas and measures taken so as to *"prevent deterioration in their quality in order to reduce the level of purification…"* (EUROPA, 2007). This Article requires Member States to introduce measures to protect raw water quality rather than introduce additional treatment at public water supplies – thus where drinking water sources, for example, are threatened by urban run-off, SUDS could be used to tackle the problem. The Government's Planning Policy Statement 25, Development and Flood Risk, promotes the use of SUDS *"to achieve wider benefits such as sustainable development, water quality, biodiversity and local amenity"* (Communities and Local Government, 2007; Annex F – Article F14). In an explanatory note to the revised draft of the Environment Agency's Policy on Sustainable Drainage Systems (Environment Agency, 2002), the Environment Agency states that it is its duty, under obligation of the Environment Act 1995, to promote sustainable development, and to promote the conservation and enhancement of inland waters, which when applied to surface water drainage requires the development and promotion of SUDS.

The Environment Agency (2002) defines sustainable drainage as *"the practice of controlling surface water runoff as close to its origin as possible, before it is discharged to a watercourse or to ground"* – thus moving away from the traditional piped drainage systems to softer engineering approaches that mimic natural patterns. This is the philosophy of SUDS. It is often recognised that traditional or urban drainage systems modify the natural drainage paths to such an extent that they can be a cause of flooding, as well as being very expensive and disruptive to construct (Mansell, 2003). Increased attention has therefore been focused on SUDS, which involve consideration of three aspects: water quantity, water quality and amenity, referred to as the "sustainable urban drainage triangle" (CIRIA, 2000). The objectives of SUDS are to provide inter alia (Communities and Local Government, 2007; CIRIA, 2000; Environment Agency, 2002; Mansell, 2003):

- attenuating peak flows by providing storage;
- protecting or enhancing water quality by minimising diffuse pollution arising from surface water runoff;
- achieving environmental enhancements, including improvement to wildlife habitats, amenity and landscape quality;
- maintaining recharge to groundwater subject to minimising the risk of pollution to groundwater;
- maintaining or restoring the natural flow regime of the receiving watercourse;

- minimising the amount of surface water runoff and infiltration entering foul and surface water sewerage systems.

Despite these advantages and in addition to being economically cheaper than conventional schemes, both in terms of construction and maintenance costs (CIRIA, 2000) the debate about its ‘sustainability’ continues. For example, there are concerns that contaminants will accumulate in SUDS and either leach from unlined systems to pollute groundwater or create polluted soil/sediment that requires disposal to landfill. A desktop analysis of the fate of heavy metals in different drainage configurations for the town of Sankt Gallen (population 75,000), Switzerland, showed that in conventional urban drainage systems the majority of contaminants accumulate either in sludge from wastewater treatment plants in combined sewer systems or are dispersed in the receiving surface watercourse in separately-sewered systems (Table 2.3, Boller, 1997). However, in SUDS, most contaminants accumulate in the structure itself, for example in the soil beneath an infiltration device or in the sediment in a detention pond.

Table 5. Estimated relative mass flow (%) of copper in the compartments of different urban drainage systems for Sankt Gallen, Switzerland (after Boller, 1997).

Compartment	**Urban drainage system**		
	Combined sewer	**Separate sewer**	**Separate sewer with infiltration of stormwater**
Wastewater treatment plant	5	2	2
Sludge from treatment plant	71	23	23
Soil below infiltration device	0	0	68
Surface water	24	75	7
Groundwater	0	0	?

Field measurements have found evidence of metal accumulation in soils beneath infiltration devices. Lind and Karro (1995), for example, measured higher loadings of copper, lead and zinc in soil of an infiltration device which had received runoff from a highway with a mean daily traffic flow of 11,400 vehicles for eight years, compared to soil from a reference site at the same distance from the road which had not been used for infiltration (Figure 3). It should be noted, however, that existing sediments in urban rivers are often contaminated. For example, a survey of sediment quality at 26 sites in nine urban rivers in Scotland found that at 23 sites at least one metal exceeded the level of contamination that can be tolerated by most organisms and at four sites the sediment would be classified as Special Waste if dredged, on account of its oil content (Wilson *et al.*, 2003).

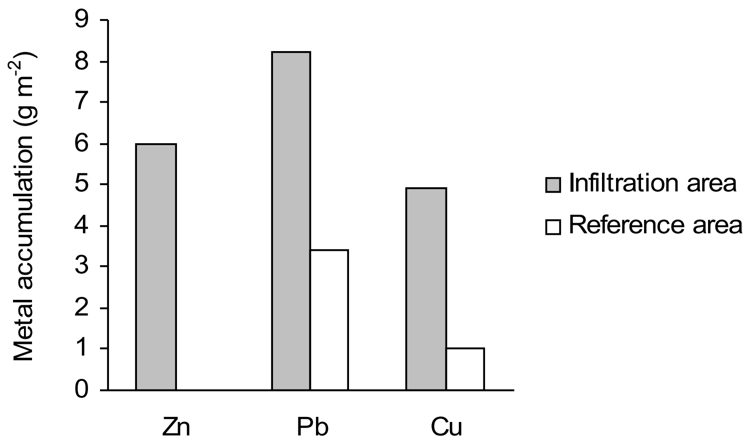


Figure 3. Anthropogenic metal accumulation over eight years in the top 5cm of soil at the Delsjövägen study site, Göteborg, Sweden. The infiltration device had a surface area of 1m^2 and received runoff from an area of 40m^2. (After Lind and Karro, 1995).

The sustainability of SUDS may also be questioned on the grounds that detention basins and wetlands have impoverished ecosystems compared to non-SUDS ponds in the same area. Plants and animals may be inadvertently introduced to SUDS during planting. Whereas this may be a strength in itself, as it may be argued to bring about or increase biodiversity, the question is what kind of species (alien or native) may be introduced and what impact or biological importance would they have on the existing ecosystem? Edwards and Lancaster (2003), for example, investigated for three years (1999-2002) the abundance of macroinvertebrates in three retention basins and a wetland at DEX, Dunfermline, Scotland, and observed that the benthic community in some SUDS was dominated by immature snails that were probably introduced by planting and whose numbers fluctuated dramatically from year-to-year, indicative of unstable, disturbed ecosystems.

It may be argued, however, that the questions about the sustainability of SUDS is probably not due to or a problem of the SUDS themselves but that practitioners have unrealistic expectations of SUDS or that SUDS are poorly implemented. All SUDS are designed to meet specific criteria and circumstances, and therefore may not be able or be expected to perform satisfactorily in all conditions. CIRIA (2000), for example, contains examples of SUDS designed to attenuate the 10-year, 60-minute storm or to treat runoff from 90% of annual storms at a site. A research on the performance of SUDS by CIRIA (2004) concludes that SUDS implementation in Scotland, for example, has been a great success in terms of achieving desired water quality and flow control objectives. Their report also reveals that the local acceptability of SUDS depends on its appearance – thus nicely designed SUDS may increase a communities feeling of ownership and eventually be involved in supporting the long term sustainability of SUDS. Jones (in a personal communication) asserts that some of the problems associated with SUDS may be characteristic of ‘large-scale’ SUDS rather than ‘small-scale’, which like small dams can perform very effectively and efficiently.

2.5.1 Case Studies – Suitability and Sustainability of SUDS for improving water quality

Effectiveness of SUDS can vary. One national study of pond type SUDS used in urban areas in the US found that about half of the phosphorus was removed from the runoff and roughly one-third of the nitrogen (Center for Watershed Protection, 1997). Senzia *et al* (2003) have also investigated the suitability of constructed wetlands for treating sewage effluent in Tanzania and found that the system was very effective in reducing biological oxygen demand (BOD_5), total nitrogen (organic and inorganic) and total suspended solids (TSS) concentrations at reasonably very high rates. There was, however, an increase of NH_3-N in downstream of the maturation pond – indicating that it was ineffective in reducing ammonia concentrations. Even under the best of circumstances, treatment of the runoff downstream raises several questions which may need to be considered when proposing SUDS. For example;

1. What are the water quality criteria or success criteria to be met?
2. What are the sources of pollutants?
3. How much land is available to install the scheme?
4. What types of SUDS will be most effective

Chapter 3

ENVIRONMENTAL SETTING

3.1 Location and Geology

The Ruscombe Brook flows north to south in the western part of Stroud. The geology of Stroud District is dominated by rocks of the Jurassic era. The relative porosity and hardness of these rocks have had a significant effect on the character of the landscape influencing land form, the formation of particular soil types and related vegetation cover and building materials (SDC, 2002). The influence of the geology is marked in the upland area of the Cotswolds which owes its existence to Oolitic Limestone (Witchell, 1882). This rock is yellowish to greyish, hard and porous (see figure 4). The strata of the limestone rock dip gently to the south-east resulting in a raised plateau landscape and dramatic scarp face. Underlying the limestones are beds of softer sandstone and siltstones with some clay. These rocks and sediments are exposed on the Cotswolds scarp face and valley sides and it is this interface of the limestone with the underlying clay which marks the transition to the lowland landscapes of the Severn Vale (SDC, 2002).

3.2 Catchment Features

The brook is fed by three major springs and drains an area of about 125 km^2 above Stroud, Gloucestershire in South Cotswolds region, UK. It flows first through farmland, then Puckshole and Hamwell Leaze before issuing into the Stroudwater canal below the Cainscross Lawns Pond (see figure 5). It travels through one of the most unspoilt valleys typical of the Cotswolds (RBAG, 2005-2007a), and one may therefore expect ‘good’ water quality status as long as it is not affected by any form of pollution downstream (SDC, 2002).

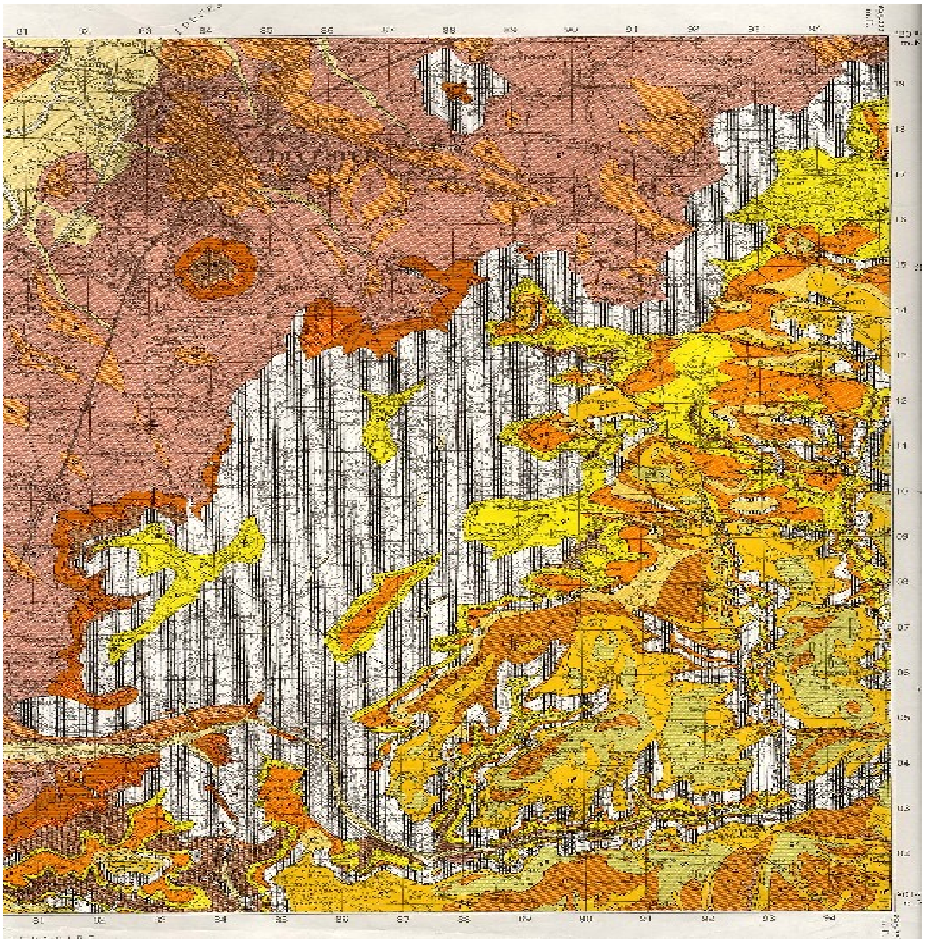
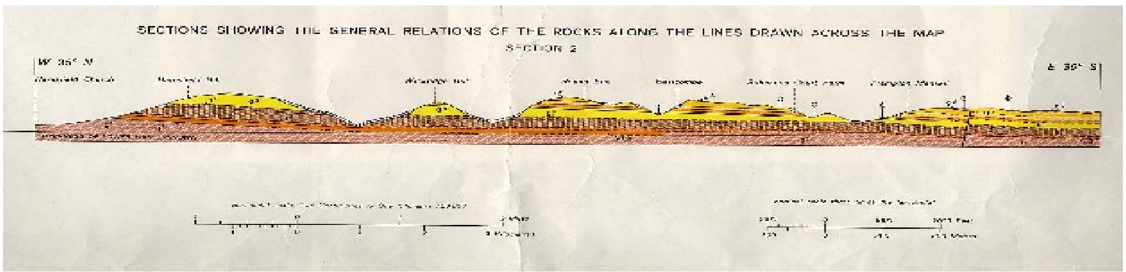
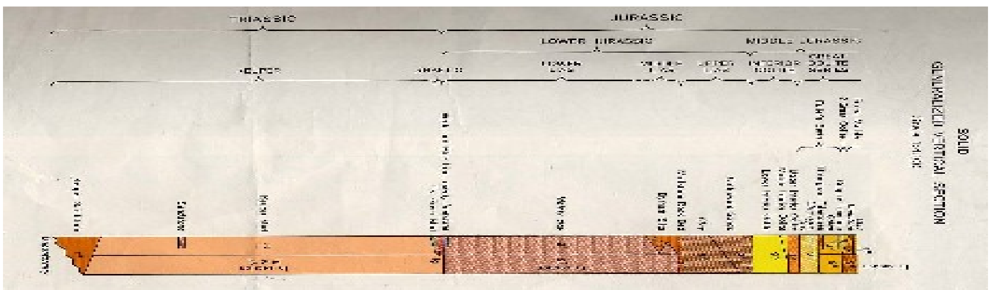


Figure 4. Geology map of the Stroud District. (Scale: 1: 50,000). Keys are shown on the two maps below:





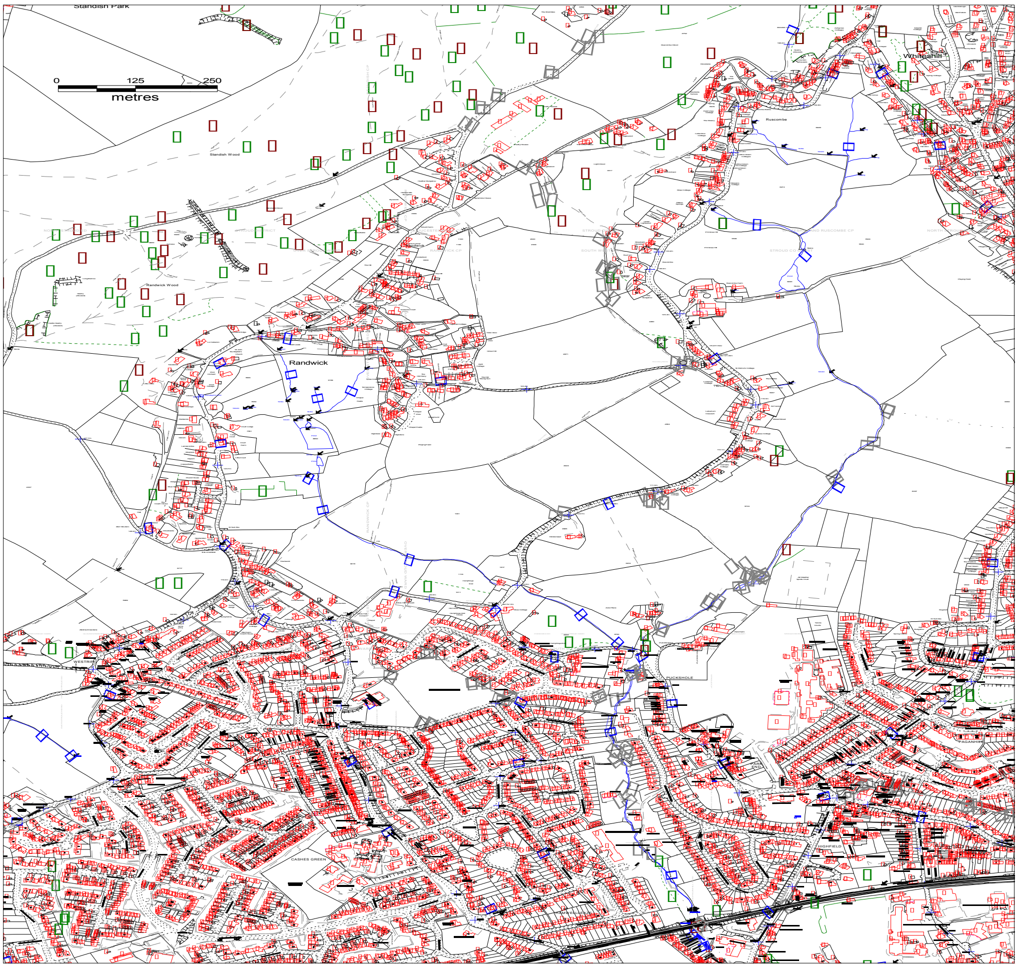


Figure 5 – Whole map of Ruscombe Brook (can be clearly seen in Appendix 3.1A).

…………… Road

………. Settlement

There is very limited information about the nature and historical use of the brook. Available information, however, suggests that in the 18th and 19th centuries there were at least five corn mills situated on the Ruscombe brook, which was also known variously as the Cuckold's, Woosley's, or Ozel brook (Pugh, 1976).The presence of these mills on the brook may have meant that some economic activity was derived from the brook for at least, a few of the communities around. However, by 1936 even the newest of the mills, Little Mill, had been demolished; and the building has now become the farm-house of Little Mill farm (Pugh, 1976). It is not certain if some or all of the mills were water-powered. If this is the case then it may be inferred that the brook had relatively high base flows compared to the present state, as large water supply may be required to run the mills (Beacham, 2005). Although weirs or impoundments are usually constructed on watercourses in order to produce an appreciable water head to effectively run the mills (Beacham, 2005), the absence/lack of evidence of such human alteration at the Little Mill site may support the argument that the water supply was enough to effectively run the mills throughout the seasons. In other words, the brook was able to provide a head of water for the mill without impoundment. According to Williams (1993) the streams in Stroud were noted (as part of their ability to power the mills) for their 'very constant high base flows' due to the porosity of the limestone rocks, which maximised infiltration. She contends that situation has presently been lost, although it could be remedied – with potential to restore all, or at least, some of the watermills.

In terms of quality, results of an 1896 water quality assessment was obtained from the Gloucestershire Records Office. The results of the assessment, which was also in response to similar sewage pollution incidents, proved dissenting (see Appendix 4). However, the results does not specify the sampling location (be it from the springs or the ponds or the stream itself), thus it may be difficult to conclude that the overall water quality (about 100 years ago) was fairly good. Besides the period between 1896 and presently is long enough to maintain or expect the same water quality.

3.3 Environmental Issues

As outlined previously, sewage pollution has been reported to be a major threat to the water quality of Ruscombe Brook. Between September 2005 and October 2006 alone, about 10 of such incidents had been recorded (RBAG, 2005-2007b). This may amount to between 1 million to 1.5 million gallons of untreated wastewater entering the brook in that single year. It must be noted that this only represent a fraction of the extent of actual pollution as several other incidents may have occurred but not reported. Although sewage discharges appear to be the obvious and hence the main problem perceived by the community, field reconnaissance and interaction with some members of the action group reveal that livestock rearing on two locations along the brook, as well as road drainage waters (which normally contain de-icing salt) could potentially affect the overall quality of the stream. Also potential, but beyond the scope of this study is the health implications of cattle and other livestock that may be grazing on sewage contaminated land around the stream during such sewer leakages and/or stormwater overflows.

Chapter 4

METHODOLOGY

PART A: Primary and Secondary Data Collection

4.1 Preliminary Investigation

The study began with a major aim of investigating raw or untreated sewage leaking into Ruscombe Brook. The study therefore started with informal interviewing of some key members of the Ruscombe Brook Action Group (RBAG), field visits for the author to identify point sources of pollution into the brook and to assess the magnitude of the said sewage pollution. It also included collection and examination of the area map of the catchment obtained from the Stroud District Council (Appendix 3.1), sewer record map obtained from Severn Trent Water Limited (Appendix 3.2) as well as sewer outfall map obtained from Water21 (Appendix 3.3). All these maps were very useful in identifying and selecting sampling locations on the brook. Secondary water quality data (monitored between May 1995 and April 1998 – see Appendix 4.1) was also obtained from the Environment Agency; whereas an 1896 water quality data (see Appendix 4.2) was also obtained from the Gloucestershire County Records Office. Finally, water quality data (analysed in October 2006) for samples taken from the Village Spring (the uppermost source of the brook – see figure 6) was also obtained from the Stroud District Council. All these secondary data were obtained in order to serve as background concentrations against which the present water quality status will be compared and assessed.

These preliminary investigations revealed that there were potential threats to the water quality from livestock farming and de-icing salt through road runoffs (in addition to the already reported incidences of sewage leakages). This subsequently influenced the choice of methodologies and parameters used as will be discussed later in the following sections and in Chapter 5.

4.2 Site selection, Reconnaissance and Sampling Strategy

The author acknowledges that the three (3) – month monitoring period was limited for investigating sporadic sewage pollution events. In order to take the temporal and spatial variation of physicochemical parameters into consideration therefore, the sampling strategy was devised to include sampling at different times (in space and in different flow conditions) and not necessarily at regular monitoring intervals. Three sampling batches were taken as follows;

- The first batch of water samples was taken on 15th June 2007 during relatively moderate flows of the stream;
- The 2nd batch of water samples was taken on 2nd July 2007 within 48 hours of heavy rainfall ; and
- The 3rd batch taken on 18th July after a relatively dry period (6 days of no precipitation).

These sampling regimes will henceforth be referred to as 1st, 2nd or 3rd batch respectively (with additional information as; taken during moderate flows, wet flows or dry flows respectively, where applicable).

With the help of the topographic map (on 1:8,768 scale) obtained from the Stroud District Council (see Appendix 3.1), two springs (Village Spring, S1 and Ruscombe Farm Spring, S2; see figure 6) were identified and sampled (during moderate flows of the brook) for water quality to serve as background data to assess the extent of pollution in the brook. Four other sites (Ruscombe Farm, #1; Puckshole Bridge, #2,; Little Mill Farm, #3; and Caincross, #4) were also selected for sampling (water and macroinvertebrates). Site #1 was selected on the basis that it is near to a livestock rearing farm and therefore it was expected that the concentration of any contaminants that may be carried through surface run-off from the pastureland would be highest at that particular location (assuming point source pollution). Thus, it was selected to ascertain if livestock rearing at Ruscombe Farm (along the brook) has any significant impact on the overall water quality. Similarly, sites #2 and #4 were identified as receiving possible sewage effluent discharges (through storm overflows) and urban road run-off (with potential salt contamination) respectively. In the case of site #2, however, the actual location (where the sewer pipe, which runs across the brook, was expected to overflow or leak into the brook) was inaccessible; and therefore two other locations (of approximately 100 metres each above and below #2) were selected and designated as 2A and 2B respectively. The choice and selection of site #3 is quite ambiguous, as although it was identified as being close to a farmland area, it was also apparent from observable sanitary materials floating in the brook, that the site may potentially receive sewage pollution as well. Thus the assessment of water quality at this site was meant to investigate evidence of sewage pollution or from agricultural run-off or both.

Following the results of the analyses of this first batch of samples, the field was visited again to survey if there were any other observable evidence of sewage or other sources of pollution into the brook. During this visit, a third spring (Double Spout Spring, S3) was identified and noted for subsequent water sampling and analyses. Also, two additional locations (one above and the other below each of the previously identified main sampling points; #1, #2, #3 and #4) were selected as additional sampling points. Samples taken from upstream or above the ‘original’ (or point source) sampling sites were assigned the suffix A; whereas those taken from downstream or below the ‘original’ sampling sites were assigned the suffix B. Thus three samples were taken from each identified pollution-potential point source, except in the case of #2 (Puckshole Bridge) where only two samples were taken due to lack of access to the ‘main’ site. For example, samples 1A, 1 and 1B were taken at site #1 to represent samples taken from about 100 metres above #1, at #1 and at 100 metres below #1 respectively.

It was, however, observed during this survey that site #1 was wrongly selected as the actual location that may directly receive surface run-off water from the farming area was the Ruscombe Farm Lake. Therefore the Ruscombe farm lake was rather noted (for subsequent sampling) and assigned ‘1’ whereas the initially identified ‘1’ was assigned ‘1B’ as it was just about 100 metres downstream of the lake.

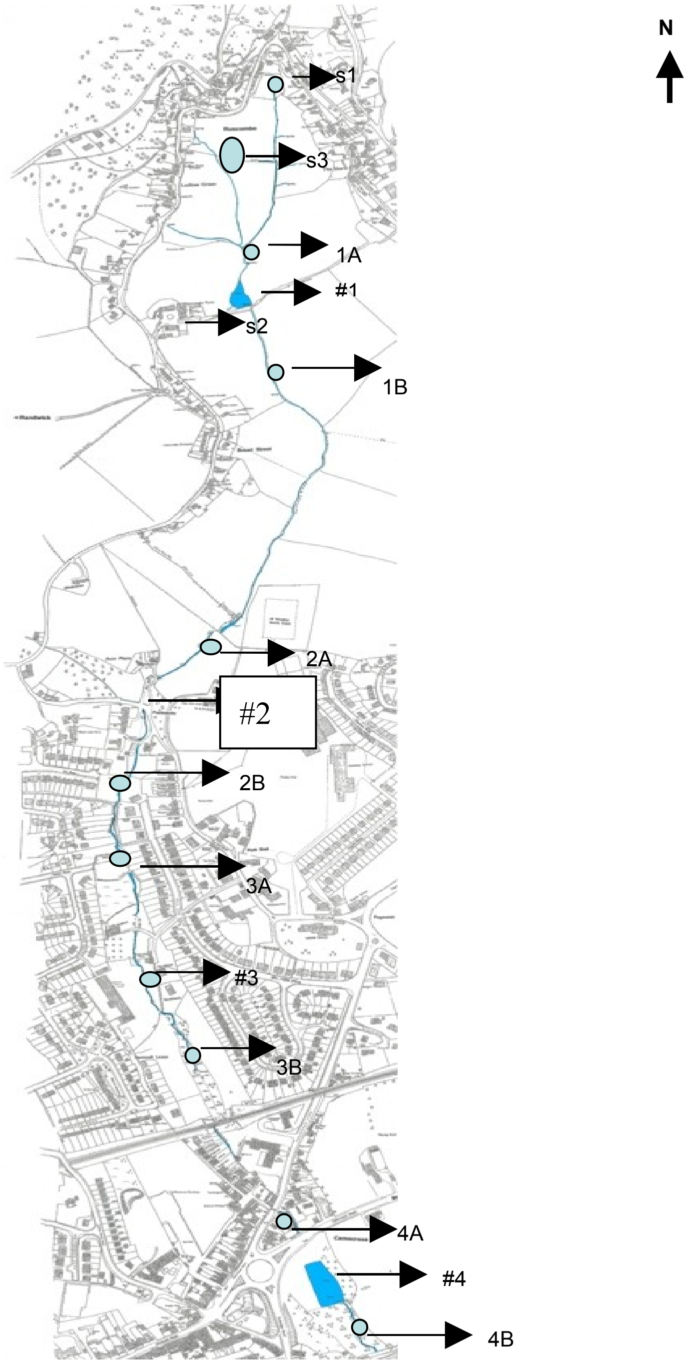


Figure 6. Map of Ruscombe Brook (not drawn to scale) showing the sampling locations.

S1 – Village Spring; S2 – Ruscombe Farm Spring; S3 – Spout Spring

#1 – Ruscombe Farm; #2 – Puckshole Bridge (not sampled due to inaccessibility)

#3 – Little Mill Farm; #4 – Caincross. ‘A’ and ‘B’ indicates upstream (above) and downstream (below) locations respectively to the corresponding main sites.

The inclusion of the additional downstream and upstream sites was influenced by recommendations from similar assessment of sewage and other organically polluted rivers (e.g. Hooda *et al*., 2000b; Zamora-Muñoz and Alba-Tercedor, 1996) and to enable an evaluation of the impact each identified pollution source may have on the overall water quality. It was also meant to confirm if the primary observations made (that apart from the obvious sewage contamination, there were potential threats to the water quality from two farmlands along the brook as well as salt contamination from urban road run-off towards the end of the brook) were true. The 100 metre spacing was also selected with a consideration of the accessibility to sampling sites. Ash (1999), for example, in monitoring the water quality of Sausal Creek, Oakland, California, observed the recovery distance of water quality from sewage leakage sites and recommended that monitoring sites for investigating sewage and other organic pollution should be selected at 1 kilometre or less spacing to ensure that the point sources of pollution are identified or detected.

Sediment samples were also collected (later in August) for bacterial analyses to further serve as evidence for any past sewage pollution in the brook. Analyses of sediment quality in this way has been established to be an effective method of assessing past sewage pollutions due to the ability of bacteria to bound to sediment for over a long period. Mallin *et al* (2007), for example, have asserted that the impacts of sewage pollution on water quality may only be traced after a few hours of the discharge; whereas evidence could be sourced from sediment samples even after several weeks of any raw sewage discharge incident. Crabill *et al* (1999) have also established that water quality can become severely impaired (in the absence of any major new sewage contamination) or even in the absence of recreational users, possibly due to the re-suspension of bacteria (as a result of some sewage pollution incidents) that have remained bound to sediments (see section 2.1 under Literature Review).

4.3 Fieldwork and Laboratory Analyses

4.3.1 Physicochemical parameters

The physicochemical parameters selected for this study were those generally used in assessing organically –polluted waters (including sewage and runoffs from agricultural lands). These include faecal coliform bacteria, biochemical oxygen demand (BOD_5), dissolved oxygen, ammonia, nitrates, nitrites, phosphates and potassium (see Table 3). Temperature, pH, conductivity, alkalinity and sulphate were measured as general indicators of water quality (see Tables 1 & 3). Chloride (although it also occurs in very high concentrations in sewage effluents; Meybeck and Helmer, 1996) was measured primarily to investigate the impact of de-icing salt on the water quality at site 4 (Caincross Lawns Pond) where salt intrusion (through road runoffs) was likely. Turbidity was also measured to indicate the concentration of suspended solids (that may arise as a result of increased sedimentation) in the brook. It should be noted that although sediments are a natural part of streams and other waterbodies, excessive fine sediment can fill the small spaces between the river bed gravel and reduce suitable habitat for many benthic invertebrates (e.g., mayflies, stoneflies, and clams) and spawning fish – a condition referred to as embeddedness (MRBDC, 2007). Measurement of turbidity may therefore be useful in assessing or explaining water quality results obtained from sampling macroinvertebrates.

Temperature, electrical conductivity (EC), dissolved oxygen (DO), pH and water depth were measured on-site. Temperature, pH and conductivity were measured by means of a combined pH/temperature/conductivity meter (HI-991003); whereas a portable HI-9142 Rugged waterproof Dissolved Oxygen meter was used for measuring the dissolved oxygen. The depth of the water was determined from a reference point with 1 metre rule. Water samples from the three springs (S1, S2 and S3) as well as the 11 selected sites (1A, 1, 1B, 2A, 2B, 3A, 3, 3B, 4A, 4 and 4B) along the stretch of the brook were taken with thoroughly rinsed 250ml plastic bottles, kept away from direct sunlight as much as possible, and transported to the laboratory where they were refrigerated at 4°C. Separate samples (for

BOD analyses) were collected in clean 250ml glass bottles and ensured that no air bubbles were trapped. These were also stored at 4°C in the laboratory.

As a standard recommendation (Radojević and Vladmir, 2006), ammonia, nitrite, nitrate, phosphate and 5-day biochemical oxygen demand (BOD_5) levels were analysed within 24 hours of collection. The other parameters, alkalinity, chloride, potassium, sulphate and turbidly were determined within one week of collection. BOD was analysed using the ISCO Manometric 5 day method (see Appendix 2). Turbidity was measured in the laboratory using the LP2000 Dual range turbidity bench meter. The Palintest® test methods were utilised for measuring alkalinity, chloride, potassium and sulphate. Detailed procedure can be found in Palintest Ltd (undated).

4.3.2 Macroinvertebrate Survey

Biomonitoring was employed in this study to substantiate the results of the physicochemical analyses and to help account for any peculiarities that may have arisen as a result of the sampling strategy adopted. Benthic macroinvertebrates were therefore sampled from each selected site (but not the springs), except the two lakes; Ruscombe Farm Lake, #1; and the Caincross Lawns pond, #4, which were too deep and boggy to allow kick sampling during all three sampling times). Benthic macroinvertebrates were selected in preference to other biomonitors such as fishes and diatoms because they are known to be comparatively more sensitive to organic pollution (Friedrich *et al*., 1996; Iliopoulou-Georgudaki *et al.,* 2003) and have been proved very useful for investigating episodic sewage pollution impacts on water quality (e.g. Rueda *et al.,* 2002; Wear and Tanner, 2007 and Smith *et al.,* 1999).

The macroinvertebrates were collected by means of a hand net using the 3-minute 'kick sample' technique (RSPB/NRA/RSNC, 1994; Armitage *et al*., 1983). The contents of the netting were gently emptied into a white tray where large stones and debris were carefully removed. The remaining contents were then transferred into labelled plastic containers and transported to the laboratory where they were sorted and preserved in absolute ethanol for later detailed identification.

The macroinvertebrates were later identified (with the help of a microscope) to the family level and the sites were then scored using the Biological Monitoring Working Party (BMWP) score system. The Biological Monitoring Working Party (BMWP) technique which was developed in the late 1970s (Hooda *et al*., 2000b) was employed in this study as being the standard developed for the United Kingdom and also as the technique utilised by the Environment Agency in interpreting macroinvertebrate surveys. The BMWP system assigns points to particular taxa or family according to their known sensitivity or tolerance to organic pollution. The most pollution sensitive, such as stoneflies, score ten, while the most pollution insensitive oligochaete worms score one. Further information and the standard BMWP scoring table is presented in Appendix 5.1. The BMWP score for a site is the sum of all the scores of the taxa, with each taxon only being counted once, irrespective of abundance ((Armitage *et al*., 1983; Friedrich *et al*., 1996; Hooda *et al*., 2000b; RSPB/NRA/RSNC, 1994; Walley and Hawkes, 1996, 1997; Zamora-Muñoz and Alba-Tercedor, 1996). Therefore, although the organisms collected on the field were quantitatively transferred and transported to the laboratory (i.e. by ensuring that each and every organism sampled did not escape regardless of the abundance of that particular specie collected), no attempt was made to estimate the abundance levels of the macroinvertebrates. Invertebrate identification to the family level was based on identification sheets for the diversity of freshwater habitat (see Appendix 10), and a guide to freshwater invertebrates (Covich and Thorpe, 1991).

4.3.3 **Bacterial Analysis**

Bacterial analysis, mainly to determine the presence and abundance of faecal coliforms and Escherichia Coli (E. *coli*) was also performed on the water samples collected to further confirm the possibility of faecal contamination of the brook. For the first batch of water samples, a qualitative determination of total coliform bacteria and E. *coli* was performed within two days of collecting and storing the samples in the fridge at 4°C. 100ml each of the water samples was analysed (for E. *coli* and total coliforms) in the laboratory according to the Colitag™ method (see Appendix 6 for the detailed stepwise procedure). This method takes advantage of the characteristic that coliforms and *E. coli* possess the enzyme β-D-galactosidase and will degrade *ortho*-nitrophenyl-β-D galactopyranoside to produce a yellow product. *E. coli* also cleaves methylunbelliferyl-β-glucurinide and produces a fluorescent product which can be seen under UV light (CPI, 2005).

As this method is only qualitative (i.e. does not estimate the abundance levels of bacteria and therefore unable to indicate the level of faecal contamination), it was not utilised for the second and third batch of water samples collected. Rather, the samples were kept in the fridge at 4°C for three weeks after which a more quantitative determination of bacterial populations was carried out using the standard plate counts (SPC) method (Protocol 406; APHA / AWWA / WPCF, 1971) for colony forming units (CFU).

Sediment samples were also taken (from the river bed) with the help of a sterilised spatula into sterilised glass tubes filled with 10ml of phosphate buffer solution. About 1g of the sediment was gently scoped and transferred into the tube and then thoroughly shaken to ensure uniform suspension. Since the viable coliform bacteria, introduced by settling, should be present largely or exclusively in a thin surface layer (Rittenberg *et al*., 1958), samples were taken within the first 2cm surface layer. Although a somewhat variable depth of the sediment column was sampled from the different sites, it was ensured that at each site the surface area, which represents the most significant portion, was captured. Sampling this way was possible because the sampling coincided with relatively very dry weather and therefore very little base flows in the brook.

The samples were then transported to the laboratory where they were stored in the fridge at 4°C and analysed within 48 hours. Prior to the analyses, each sample was shaken again in order to reduce faecal coliform burial and homogenise the bacterial suspension. From the mixture of sterile phosphate-buffer and sediment, 100ul (0.1ml) each of the sample was taken (with a piston-driven air displacement pipette) and put on previously prepared sterile agar plates. With the help of a sterile glass rod (bent into an L-shape), the drop of sample was uniformly spread over the surface of the agar. All plates were incubated in an incubator for 24 hours at 37°C. After the 24-hour incubation period, each plate was inspected for growth or colonies of bacteria. It must be noted that two different nutrient agar plates were prepared for the analysis – one to analyse separately, the presence of E. *coli* and faecal coliforms; whereas the other was to examine the growth of total coliforms in general. Bacterial colonies satisfying the respective criteria for each method were counted after incubation by visual inspection, and were expressed as the Colony Forming Units (CFU) per 100ml of sample. Serial dilutions were also prepared and the procedure repeated for samples which gave colonies of over 300 – a standard recommendation for analyses employing the standard plate count method (APHA / AWWA / WPCF, 1971). No effort was made to distinguish critically between the various species of coliforms present on the nutrient agar (meant to estimate total coliforms although *Actinomycetes spp.* were identified and counted as separate colonies.

PART B: Social Survey

4.4 Questionnaire Design and Survey

In order to source accurate information about the perception of sewage pollution in the Ruscombe Brook and also to canvass opinions on the possibility of implementing sustainable urban drainage systems for maintaining and improving water quality of the brook, two set of questionnaires were designed. A 'resident' questionnaire (see Appendix 7.2) was administered to 5 households located at each of the sampling sites. The objective of this was to allow the residents (irrespective of their involvement in the community action group) present their own personal views of the problem. It was also meant to validate the hypotheses made in selecting and sampling at those locations. This is because a resident at a particular area of the catchment is more likely to be abreast with and updated with any physical or recognisable changes to the water quality.

Thus questions included in the questionnaire (Appendix 7.2) include:

- How long they have lived in their residences;
- Whether they are aware of any past or recent incidences of raw sewage leaking into the brook; what they reckon was the cause; and whether they continue to experience this problem;
- Whether they are aware of any other pollution threats (including their own landuse changes) to the water quality and;
- Their perception on the need to employ SUDS in improving the water and/or suggesting alternative management strategies.

It must be indicated that in order not to influence their decision on the perception of implementing sustainable urban drainage systems (SUDS), no information, whatsoever was provided as part of the questionnaire. Thus the respondents were allowed to present their own unbiased views on SUDS and where necessary make their own investigations before answering the question. An option was therefore given for respondents to indicate if they have no ideas about SUDS or unsure about its implications. To each respondent contacted, an introductory note (see Appendix 7.1) explaining the importance and ethical considerations of the study was attached. The questionnaires were presented to the respondents in pre-paid self addressed envelopes to allow them ample time to complete and return by post.

Four stakeholders were also identified for the questionnaire survey. These are the:

- Environment Agency as the organisation responsible for ensuring water quality and protecting all waterbodies in England and Wales;
- Severn Trent Water Limited as the sewerage undertaker of the Ruscombe area;
- Stroud District Council as the overseer of the district with responsibilities such as improving or maintaining water quality and general sanitation.
- Water21 as the a non-profit organisation with strong advocacies in the concepts and sustainability of sustainable urban drainage schemes, and also a collaborator of RBAG in finding sustainable measures to improving water quality in the Ruscombe Brook.

Each organisation was contacted through a key contact and the 'stakeholder questionnaire' (see Appendix 7.3) was sent by e-mail via these contacts. With the various responsibilities and partnerships with RBAG, engaging with organisations or stakeholders was to help provide further useful information (formal knowledge) about the perception of the reported sewage discharges and their implications on the water quality of the brook; and also to help evaluate the effective management schemes with reference to the concepts (policy considerations, engagement with key people, etc.) of implementing SUDS for improving water quality in Ruscombe brook.

Specific questions asked the organisations therefore include;

- Whether the organisation has any interest or is responsible for monitoring water quality in the brook;
- Whether they are aware of any past or recent sewage discharges into the brook and if so on what scale they perceive the problem;
- Whether they could specifically indicate any sewer outfalls on the brook (where the problem is due to combined sewer or sanitary sewer overflows);
- How they view implementing SUDS for improving the water quality and;
- Where possible, provide an alternative management strategy for improving water quality in the brook.

Chapter 5

RESULTS AND DISCUSSION

5.1 ANALYSES OF RESULTS

PART A: ANALYSES OF PRIMARY DATA

5.1.1 Physiochemical analyses of water quality

The results of the indicators measured on-site and in the laboratory are shown in Table 6 below. Results are presented as measured concentrations of parameters for each sampling date and the average concentrations for the three samplings. Dissolved oxygen levels were very high at all sampling times and locations (ranging from 9.05 mg/l at Little Mill Drive to 11.00 mg/L at the Caincross Lawns pond). The high dissolved oxygen levels correspond with no measurable levels of biochemical oxygen demand (i.e. BOD_5 levels of 0 mg/l) except at Little Mill Farm (3A, about 1.71 kilometres downstream of the Village Spring – see figure 6) where 9mg/l and 3mg/l BOD_5 levels were respectively measured for the 2nd batch of samples (taken during relatively high river flows) and for the 3rd batch of samples (taken during relatively low flow rates) – given an average of 6mg/l BOD_5 at site 3A (upstream of the Little Mill Farm, #3). This results suggests that the site 3A (although selected to confirm if there were any major pollution occurring at the Little Mill Farm, #3; and therefore what impact that may have on the water quality downstream) may well be receiving contaminant inputs (see section 5.2.1 – Discussion of Results).

Average pH, potassium and nitrite levels were relatively stable (did not show any marked variation) at the different sampling points along the brook; whereas nitrate concentrations varied markedly with distance (see figure 7) from the Village spring, which is the upstream-most source of the brook (see figure 6). Very low levels of ammonia (ranging from 0.02-0.18 compared to the maximum allowable concentration of 0.5mg/l; Private Water Supply

Regulations, 1991) were also recorded at all sampling locations except at the Ruscombe Farm Lake (1; 0.46km from the Village Spring) and at the Little Mill Farm site (3B; 1.92km from the Village Spring) where ammonia concentrations exceeded 1mg/l for samples taken at wet weather flows. There were no marked variations in concentrations of ammonia between the various sampling locations. The relatively very high concentrations of ammonia recorded at the two farmlands, however, may be an indication of surface runoff (of muck) from the farmlands into the brook – suggesting that ammonia is a good indicator of agricultural pollution. Further explanation can be found in section 5.2.1 (Discussion of Results).

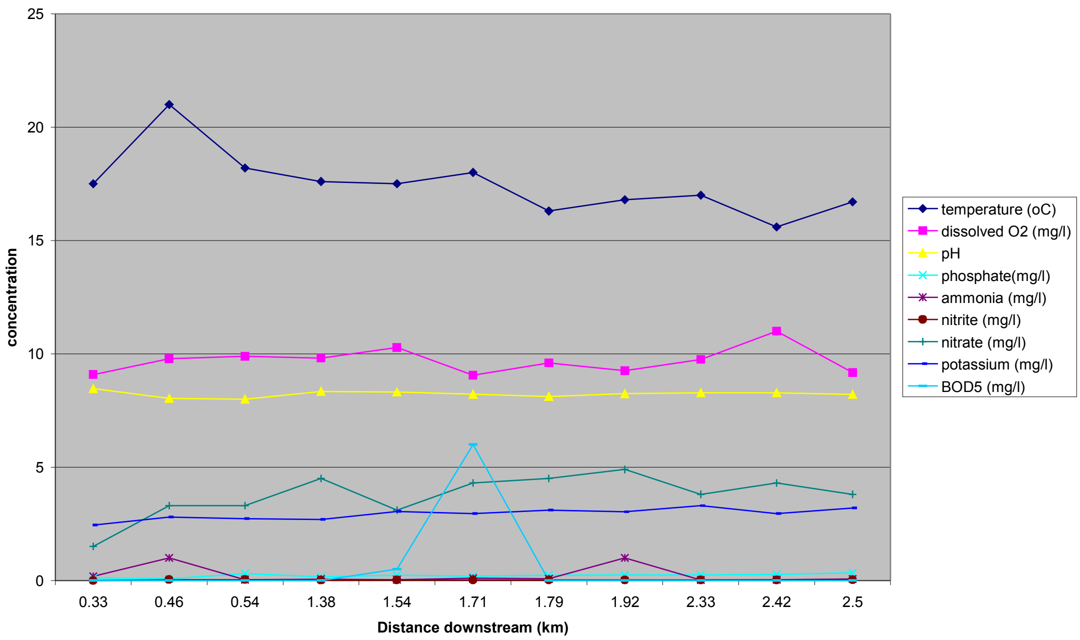


Figure 7. Variation of parameter concentrations with downstream distance downstream.

Distances were measured (using 1:8,768 map; see Appendix 3.1) from the Village Spring (which is the uppermost source of the brook). Each distance (in kilometres, km) shown (to two decimal places) on the graph corresponds to the different sampling locations.

i.e. 0.33 ≡ 1A; 0.45 ≡ 1; 0.54 ≡ 1B; 1.38 ≡ 2A; 1.54 ≡ 2B; 1.71 ≡ 3A; 1.79 ≡ 3; 1.92 ≡ 3B; 2.33 ≡ 4A; 2.42 ≡ 4; and 2.5 ≡ 4B.

Where: 1 is Ruscombe Farm; 2 – Puckshole Bridge (not sampled due to inaccessibility) 3 – Little Mill Farm; and 4 – Caincross Lawns Pond. ‘A’ and ‘B’ indicates upstream (above) and downstream (below) locations respectively to the corresponding main sites.

Figure 8 also shows the variation of the parameters; conductivity, turbidity, sulphate, alkalinity and chloride concentrations with distance from the Village Spring. Chloride, which was measured as an indicator of salt intrusion from road run-off (although it may also be found at high levels in sewage polluted rivers) did not show any marked variation between the various sampling sites; whereas conductivity (a measure of the dissolved solid content) increased markedly but unsteadily with distance downstream from the reference point (Village Spring).

All three springs were not much different in terms of the concentrations of parameters measured. Nitrate levels, however, were relatively higher in all three springs than any other site measured along the stretch of the brook (see figure 9). This, however, does not imply that the springs are polluted (in terms of nitrate levels). Sources of nitrates are variegated – including both natural (e.g. in groundwater depending on the soil types) and anthropogenic (e.g. through sewage and agricultural pollution). DEFRA (2003) estimates that in relatively unpolluted or pristine catchments, higher concentrations of nitrates are expected in springs and groundwaters than in rivers or streams – suggesting that the relatively high nitrates in the springs (compared to those measured in the brook) are normal. It should also be noted that these concentrations (ranging from 6.0 – 8.6; see Table 6) are within the allowable nitrate levels in drinking water (i.e. 50 mg/l according to the Private Water Supply Regulations of 1991) and may therefore imply that the springs (with respect to nitrate levels) are suitable for drinking and other domestic uses.

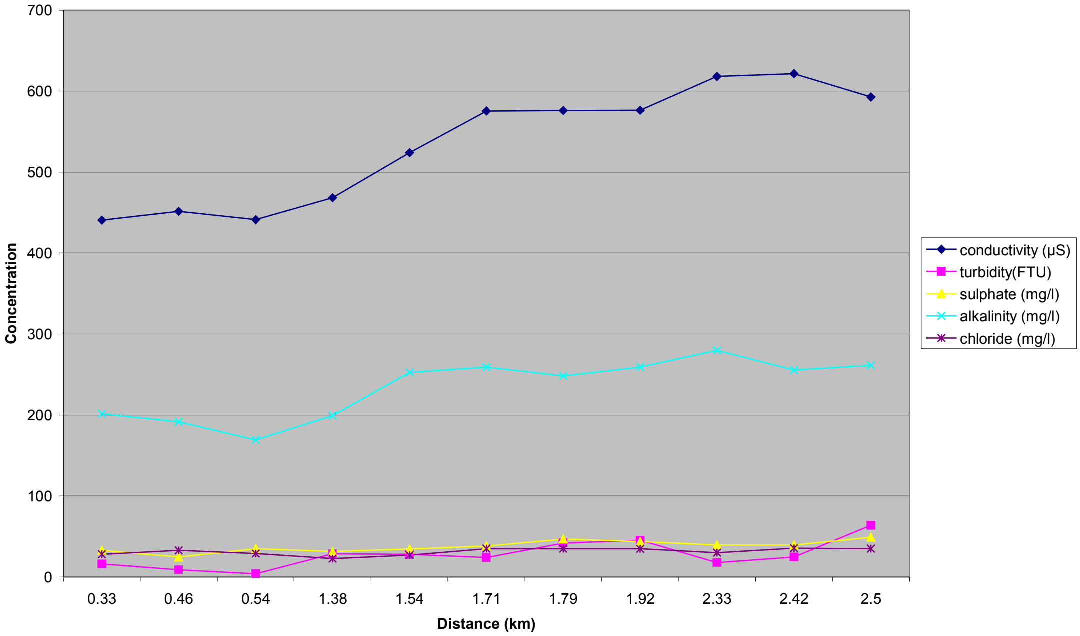


Figure 8. Variation of (average) concentrations of parameters with downstream distance downstream

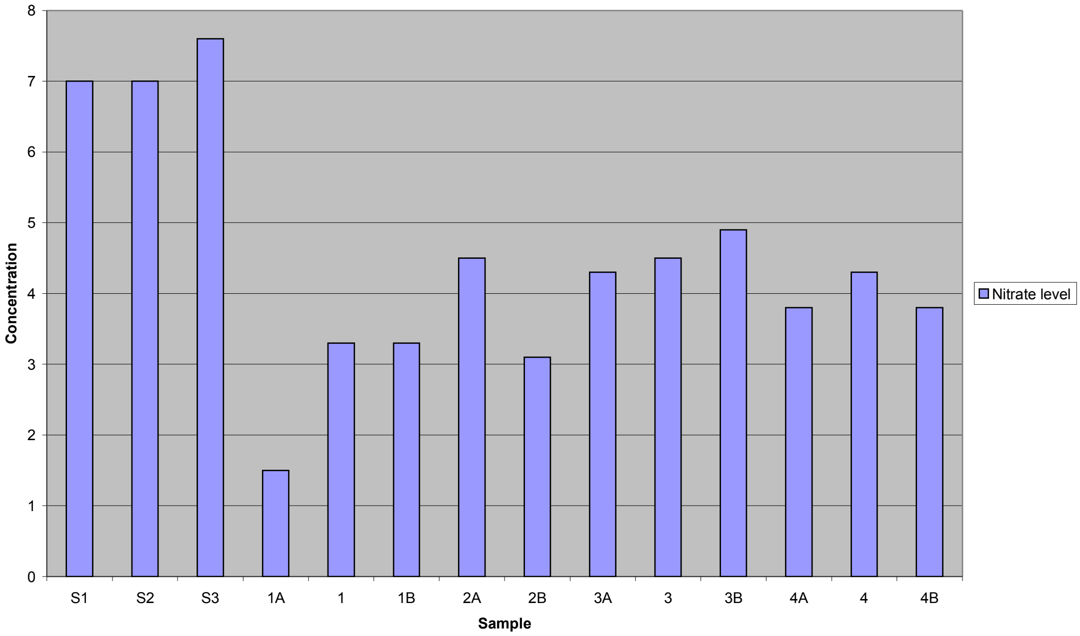


Figure 9: Comparison of (average) concentration of nitrates recorded at the different sampling sites.

S1, S2 and S3 represents the Village, Ruscombe Farm and Double Spout springs respectively.

Table 6. Results of physicochemical analysis on water samples for the three sampling times

Parameter	Sampling Date	Spring samples			Ruscombe Farm Lake (#1)			Puckshole bridge (#2)		Little Mill Drive (#3)			Caincross (#4)		
		S1	S2	S3	1A	1	1B	2A	2B	3A	3	3B	4A	4	4B
Temperature (°C)	15/6/07	13.6	13.1	*	*	*	15.5	15.7	*	*	15.9	17.9	*	*	18.7
	02/7/07	13.2	14.0	13.0	16.0	20.0	20.0	17.0	17.0	16.0	16.0	15.0	15.0	14.8	15.4
	18/7/07	13.0	13.6	13.5	19.0	22.0	19.0	20.0	18.0	20	17	17.5	19	16.5	16.0
	Average	**13.3**	**13.6**	**13.3**	**17.5**	**21**	**18.2**	**17.6**	**17.5**	**18**	**16.3**	**16.8**	17	**15.6**	**16.7**
DO_2 (mg/l)	15/6/07	10.8	10.56	*	*	*	9.38	8.87	*	*	8.78	8.80	*	*	8.45
	02/7/07	10.06	10.4	11.00	9.24	10.42	8.41	9.24	9.23	9.30	10.84	10.16	10.07	9.92	9.7
	18/7/07	10.73	9.93	9.36	8.91	9.13	11.87	11.32	11.33	8.80	9.17	8.78	9.43	12.07	9.36
	Average	**10.53**	**10.48**	**10.18**	**9.08**	**9.78**	**9.89**	**9.81**	**10.28**	**9.05**	**9.60**	**9.25**	**9.75**	**11.00**	**9.17**
pH	15/6/07	7.40	7.58	*	*	*	7.87	8.10	*	*	7.99	8.07	*	*	8.09
	02/7/07	7.84	7.62	7.64	8.43	8.00	8.12	8.41	8.33	8.24	8.24	8.32	8.3	8.25	8.24
	18/7/07	7.81	7.67	7.94	8.52	8.06	8.01	8.5	8.29	8.2	8.20	8.34	8.25	8.31	8.31
	Average	**7.68**	**7.62**	**7.79**	**8.46**	**8.03**	**8.00**	**8.34**	**8.31**	**8.22**	**8.12**	**8.24**	**8.28**	**8.28**	**8.21**
Conductivity (µS)	15/6/07	445	506	*	*	*	410	432	*	*	538	528	*	*	516
	02/7/07	150	256	467	466	483	468	518	516	600	608	615	633	636	632
	18/7/07	120	570	456	415	420	446	455	532	551	582	586	603	607	630
	Average	**388.3**	**444**	**461.5**	**440.5**	**451.5**	**441.3**	**468.3**	**524**	**575.5**	**576**	**576.3**	**618**	**621.5**	**592.7**
Turbidity (FTU)	15/6/07	2.28	0.75	*	*	*	3.66	36.41	*	*	56.50	55.0	*	*	160
	02/7/07	1.76	0.88	1.82	11.01	8.84	5.28	22.47	29.98	25.68	31.82	42.83	17.35	22.41	14.95
	18/7/07	1.48	0.75	2.64	21.18	9.07	3.25	26.70	25.84	21.80	37.41	38.27	18.40	26.93	16.28
	Average	**1.844**	**0.79**	**2.23**	**16.10**	**8.96**	**4.06**	**28.53**	**27.91**	**23.74**	**41.91**	**45.37**	**17.89**	**24.67**	**63.74**

PO_4 – P (mg/l)	15/6/07	0.07	0.58	*	*	*	0.08	0.20	*	*	0.24	0.26	*	*	0.64
	02/7/07	0.04	0.56	0.03	0.16	0.10	0.16	0.20	0.22	0.18	0.28	0.26	0.24	0.24	0.18
	18/7/07	0.04	0.64	0.06	0.07	0.06	0.07	0.12	0.26	0.18	0.20	0.22	0.26	0.30	0.20
	Average	**0.05**	**0.59**	**0.05**	**0.12**	**0.08**	**0.31**	**0.17**	**0.24**	**0.18**	**0.24**	**0.25**	**0.25**	**0.27**	**0.34**
NH_3 - N (mg/l)	15/6/07	-	-	*	*	*	0.07	0.02	*	*	0.07	0.04	*	*	0.04
	02/7/07	0.05	-	0.00	0.06	>1	0.04	0.12	0.03	0.15	0.10	>1	0.04	0.07	0.10
	18/7/07	-	0.00	-	0.47	0.02	0.00	0.03	0.04	0.05	0.06	-	-	-	-
	Average	**0.02**	**0.00**	**0.00**	**0.18**	**~1**	**0.04**	**0.06**	**0.04**	**0.10**	**0.08**	**~1**	**0.02**	**0.04**	**0.07**
NO_2 – N (mg/l)	15/6/07	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	02/7/07	0.000	0.007	0.000	0.006	0.034	0.040	0.016	0.014	0.014	0.023	0.019	0.012	0.019	0.023
	18/7/07	0.000	0.000	0.000	0.003	0.042	0.034	0.011	0.028	0.025	0.027	0.028	0.027	0.027	0.040
	Average	**0.000**	**0.004**	**0.000**	**0.003**	**0.038**	**0.037**	**0.014**	**0.021**	**0.020**	**0.025**	**0.024**	**0.020**	**0.023**	**0.032**
NO_3 – N (mg/l)	15/6/07	7.4	6.0	*	*	*	3.6	4.2	*	*	4.4	5.0	*	*	2.8
	02/7/07	7.4	8.4	8.6	2.8	3.0	3.4	6.0	3.0	3.8	4.4	4.4	4.0	4.0	3.8
	18/7/07	6.2	6.6	6.6	0.12	3.6	3.0	3.2	3.2	4.8	4.8	5.4	3.6	4.6	4.8
	Average	**7.0**	**7.0**	**7.6**	**1.5**	**3.3**	**3.3**	**4.5**	**3.1**	**4.3**	**4.5**	**4.9**	**3.8**	**4.3**	**3.8**
SO_4 (mg/l)	15/6/07	40	43	*	*	*	46	48	*	*	60	59	*	*	67
	02/7/07	30	35	33	35	18	28	14	35	36	40	34	39	39	40
	18/7/07	27	32	31	31	31	31	32	34	40	40	38	40	40	40
	Average	**32.33**	**36.67**	**32**	**33**	**24.5**	**35**	**31.33**	**34.5**	**38**	**46.67**	**43.67**	**39.5**	**39.5**	**49**
K (mg/l)	15/6/07	1.3	6.4	*	*	*	2.4	2.5	*	*	3.2	3.1	*	*	3.5
	02/7/07	2.2	5.9	1.3	2.7	3.1	3.4	3.1	3.4	3.2	3.4	3.3	3.9	3.2	3.3
	18/7/07	2.2	5.2	1.3	2.2	2.5	2.4	2.5	2.7	2.7	2.7	2.7	2.7	2.7	2.8
	Average	**1.9**	**5.83**	**1.3**	**2.45**	**2.8**	**2.73**	**2.7**	**3.05**	**2.95**	**3.1**	**3.03**	**3.3**	**2.95**	**3.2**
Cl^- (mg/l)	15/6/07	36	40	*	*	*	0	0	*	*	34	32	*	*	34
	02/7/07	27	23	22	20	20	14	22	18	22	23	27	14	23	23
	18/7/07	30	36	36	36	46	44	46	36	48	48	45	46	48	48
	Average	**31**	**33**	**29**	**28**	**33**	**29**	**22.67**	**27**	**35**	**35**	**34.67**	**30**	**35.5**	**35**

Alkalinity (mg/l)	15/6/07	112	158	*	*	*	130	143	*	*	205	223	*	*	250
	02/7/07	140	228	148	215	210	215	255	255	285	300	305	320	278	273
	18/7/07	130	233	130	188	173	163	200	250	233	240	250	240	233	250
	Average	**127.3**	**206.3**	**139**	**201.5**	**191.5**	**169.3**	**199.3**	**252.5**	**259**	**248.3**	**259.3**	**280**	**255.5**	**261.5**
BOD$_5$ (mg/l)	15/6/07	0	0	*	*	*	0	0	*	*	0	0	*	*	0
	02/7/07	0	0	0	0	0	0	0	1	9	0	0	0	0	0
	18/7/07	0	0	0	0	0	0	0	0	3	0	0	0	0	0
	Average	**0**	**0**	**0**	**0**	**0**	**0**	0	**0.5**	**6**	**0**	**0**	**0**	**0**	**0**
Depth (cm)	15/6/07	-	-	-	*	*	*	10.2	*	*	14.0	8.0	*	*	14.0
	02/7/07	-	-	-	7.0	57.0	13.0	19.0	22.0	25.5	19.0	13.5	17.0	15.0	18.5
	18/7/07	-	-	-	3.9	31.2	5.8	10.5	10.4		10.2	6.2	8.1	7.5	10.0
	Average				**5.45**	**44.1**	**9.4**	**13.2**	**16.2**	**18.8**	**14.4**	**9.2**	**12.6**	**11.3**	**14.2**

'*' indicate that no sample was taken (due to reasons already discussed in the methodology) and therefore no data/results is available.

'-' indicates that the measured concentration is negligible or less than 0; or in the case of the spring samples, determination not applicable.

Average concentrations of the different parameters (for the three samplings) are shown in **bold face**.

5.1.2 Macroinvertebrates Survey

The macroinvertebrates survey did not show high biodiversity levels (or produce wide variations of different organisms) at all of the sampling points. The most common families identified were the *Glossiphoniidae* (or leeches), *Gammaridae* (commonly known as the fresh water shrimp), *Limnephilidae* (cased caddisfly larvae), and the *Tipulidae* and *Simulidae* (collectively referred to as the True flies). *Gammaridae* or the fresh water shrimp was the most abundant macroinvertebrate occurring at all the sampling locations. Tables 7, 8 and 9 present the BMWP/ASPT scores for samples taken during each sampling period.

Table 7. Invertebrate scores for 1st batch samples (taken at moderate flows).

	1B	2A	3	3B	4B
BMWP	18	12	7	68	41
No. of Families	3	3	2	10	8
ASPT	6	4	3.5	6.8	5.1
LQI	4.5 (Good)	3 (Moderate)	2 (Poor)	5.5(Excellent)	5 (Excellent)

Table 8. Invertebrate scores for 2nd batch samples (taken at relatively high flows).

	1A	1B	2A	2B	3A	3B	4A
BMWP	48	43	11	37	11	31	31
No. of Families	9	9	2	8	2	6	6
ASPT	5.3	4.8	5.5	4.6	5.5	5.2	7.8
LQI	5 (Excellent)	4.5 (Good)	4.5 (Good)	4.5 (Good)	4.5 (Good)	5 (Excellent)	5 (Excellent)

Table 9. Invertebrate scores for 3rd batch samples (taken relatively low flows).

	1A	1B	2A	2B	3	3B	4A	4B
BMWP	18	21	21	26	26	18	18	9
No. of Families	3	4	5	6	5	4	4	2
ASPT	6	5.3	4.2	4.3	5.2	4.5	4.5	4.5
LQI	4.5 (Good)	4.5 (Good)	3.5 (Moderate)	4 (Good)	5 (Excellent)	4 (Good)	4 (Good)	3.5 (Moderate)

The weightings in the BMWP score specifically reflect the impact of organic pollutants such as readily biodegradable organic compounds, ammoniacal nitrogen and suspended solids which are associated with effluents like sewage and farm slurry (National Rivers Authority, 1994). Therefore, one can generalise by stating that the higher the BMWP score the lower the level of organic pollution. The ASPT Score, however, tends to reduce the impact of occasional finds of high scoring taxa (where the use of BMWP scores for interpreting results may be misleading). The Lincoln Quality Index (LQI) (Mason, 1991) has been determined to provide a basic, qualitative interpretation of the BMWP and ASPT Scores and the index descriptions are included in the table of results above. Standard tables and the calculation of the LQI for each site are presented in Appendix 5.2.

It would be observed that not all sampling sites were sampled for invertebrates due to either the substrate type being too stony or boggy during the sampling time to allow kick sampling.

The Average Score Per Taxon (ASPT) was calculated as follows:

ASPT = BMWP / Number of Taxa (or families) present.

The ASPT scores showed quite wide variation of change between upstream and downstream sites. This trend is consistent for the 2nd batch samples (taken during wet weather flows on 2nd July 2007) where there is a general decrease in ASPT values from upstream to downstream reaches (figure 10). This upstream and downstream trend of decreasing ASPT values and therefore decreasing biodiversity level suggests pollution sources that gradually deteriorate the water quality downstream at those sites measured.

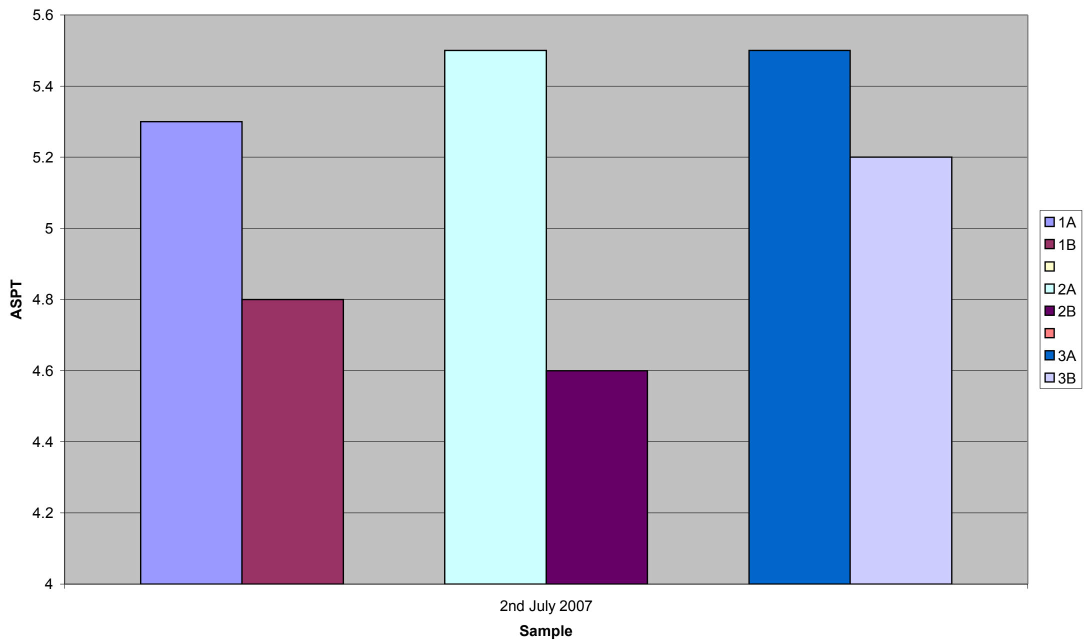


Figure 10. Impacts of pollution inputs on the invertebrate score, ASPT, between the upstream (suffix A) and downstream (suffix B) reaches of the sampling locations.

Note the wide variation between the sites 2A and 2B (upstream and downstream reaches respectively of the Puckshole Bridge, site #2 – see figure 6). Site #2 is the location where the sewer pipes runs across the brook. Sewage pollution was therefore the major concern for the selection of this site. The wide variations in ASPT scores observed between the upstream, 2A and downstream, 2B sites may therefore be indications of past sewage pollution that has depleted the aquatic life downstream.

Sites '1A' and '1B' represent upstream and downstream locations, respectively of the Ruscombe Farm Lake (site #1 – see figure 6). This site was selected on the basis of potentially receiving runoffs from the farmland. Similarly, '3A' and '3B' represent upstream and downstream locations, respectively of the Little Mill Farm (site #3 – see figure 6) also selected on the basis of receiving contaminants from sewage and agricultural pollution.

The invertebrate scores for the 3rd batch samples (taken during dry weather flows on 18th July 2007), however did not show marked variation or observable trend of pollution impact between upstream and downstream points of sampling locations (figure 11). This results, is however, not reliable (and will not be discussed further) as many of the invertebrates collected decayed (such that they could no more be recognised) prior to their identification. This is due to a problem of water shortage that resulted in a closure of the laboratory just on the day the organisms were collected. Thus they were not properly sorted and preserved.

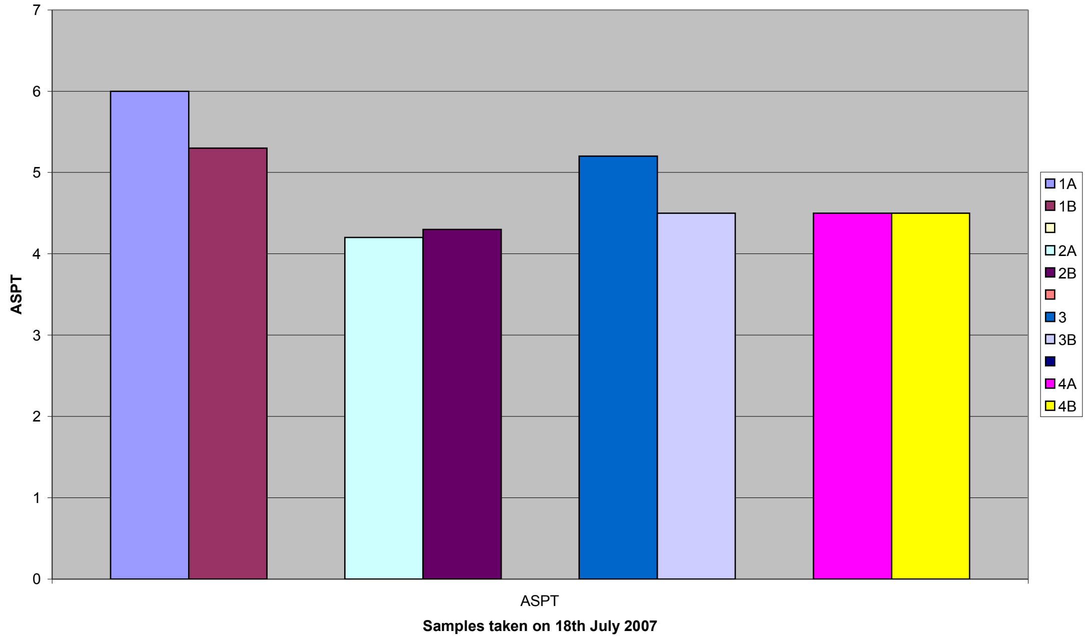


Figure 11. Impacts of pollution inputs on the invertebrate score, ASPT, between the upstream (suffix A) and downstream (suffix B) reaches of the sampling locations.

Sites ‘1A’, ‘1B’, ‘2A’, ‘2B’, ‘3A’, and ‘3B’ remain the same locations as in figure 10.
‘4A’ and ‘4B’ represent upstream and downstream locations, respectively of the Caincross Lawns Pond (site #4 – see figure 6). This site was selected on the basis of potentially receiving de-icing salt through road runoffs.

5.1.3 **Microbiological Analysis**

The qualitative bacterial analyses (Colitag^{TM} method - see Appendix 6) carried out on the 1st batch of water samples (taken during relatively moderate flows) showed that all samples (except that of the Village Spring samples, which contained faecal coliforms but not E. c*oli*) contained both E. *coli* and faecal coliforms (Table 10) – an indication of some level of faecal pollution. These results were based on the production of yellow colouration (to indicate the presence of faecal coliforms) and fluorescent product under UV light (indicating the presence of E. coli) after 24 hours of incubating the samples according to the method.

Table 10. Results of Bacterial analyses on 1st batch of water samples (taken during moderate flows, on 18th June 2007)

.

Sample	E. *coli*	Faecal coliform
S1 (Village Spring)	Absent	Present
S2 (Ruscombe Farm Spring)	Present	Present
1B (Below Ruscombe Farm Lake)	Present	Present
2A (Acre place,/ Above Puckhshole bridge)	Present	Present
3 (Little Mill Drive)	Present	Present
3B (Below Little Mill Drive)	Present	Present
4B (Below Caincross Lawns Pond)	Present	Present

The 2nd (high flows) and 3rd (low flows) batches of samples, however, did not show any indication of faecal contamination as there was no growth of both E. *coli* or faecal coliforms after 24 hours of incubation. Unlike the Colitag™ test method, the standard method utilised for the analyses of these samples relies on the formation of bacterial colonies on the appropriate substrates or culture media, and estimates quantitatively the number present. The presence of both E. *coli* and faecal coliforms in the first batch of water samples but not the 2nd and 3rd batches, however, may be subject to several interpretations and these are discussed further under section 5.2.1 (Discussion of Results).

Faecal coliforms as well as general (total) coliforms were enumerated in the sediment samples (from the respective agar plates) and expressed as colony forming units (CFU) per 100ml of sample (Table 11), using the following equation:

CFU (per 100ml) = [(number of colonies counted * dilution factor * 100) / 0.1ml]

Where dilution factor is the reciprocal of the dilution; and 0.1ml is the actual volume or aliquot of sample used for spreading. It should be noted that the dilution factor for undiluted samples is 1; hence for such samples the equation reduces to;

CFU (per 100ml) = [(number of colonies counted * 100) / 0.1ml

Table 11. Results of bacterial analysis on sediment samples

sample	Faecal coliforms count (CFU/100ml)	Total coliforms count (CFU/100ml)	Actinomycetes (CFU/100ml)
1A - (Above Ruscombe Farm Lake)	0	34000	31000
1B - (Below Ruscombe Farm Lake)	8000	48000	40000
2A - (Above Puckshole Bridge)	2000	100000	19000
2B - (Below Puckshole Bridge)	6000	700000	6000
3 - (Little Mill Farm)	15000	88000	6000
3B - (Below Little Mill Farm)	13000	84000	22000
4A - (Above Caincross Lawns Pond)	22000	170000	56000
4B - (Below Caincross Lawns Pond)	30000	200000	52000

The faecal coliform counts include E. *coli* counts. It must, however, be noted that although efforts were made to identify and count colonies indicative of E. *coli* separately (based on the distinctive purple colour of their colonies), it was only in the sample '3B' that 2 CFU per 0.1 ml (equivalent to 2000 CFU of E. *coli* per 100ml of the sample) were identified and counted. This sample (3B) corresponds to the location below the Little Mill Farm where threats to water quality of the brook were expected from either sewage outfalls and from livestock waste and therefore the presence of E. *coli* there may be due to either of these sources. However, as livestock farming is a regular practice at this reach of the brook, it may be argued that any faecal pollution resulting from farmland manure (if any) or from the animal dung may easily be detected from bacterial analyses of water samples, especially through surface run-off following the heavy rains (i.e. in the 2nd batch water samples). The fact that no faecal coliforms were detected in water samples taken during both wet and dry flows therefore, is an indication that such microbial pollution might have occurred in the past and may therefore likely be attributable to past sewage pollution as already reported and confirmed from the resident through the questionnaire survey (see Table 12 under section 5.1.4) rather than from livestock rearing.

The relatively high elevated levels of total coliforms recorded in sediment samples taken from site ‘2B’ (which is just 100 metres downstream of where the sewer pipe runs across the brook at Puckshole Bridge) as compared to the rest of the sampling sites (figure 12) may also be a strong evidence of past sewage pollution. The fact that no E. *coli* was detected at this location may therefore support the recent argument that E. *coli* are not reliable for assessing long term pollution of faecal origin as they are not environmentally long-lived like many pathogens (Fujioka and Yoneyama, 2001).

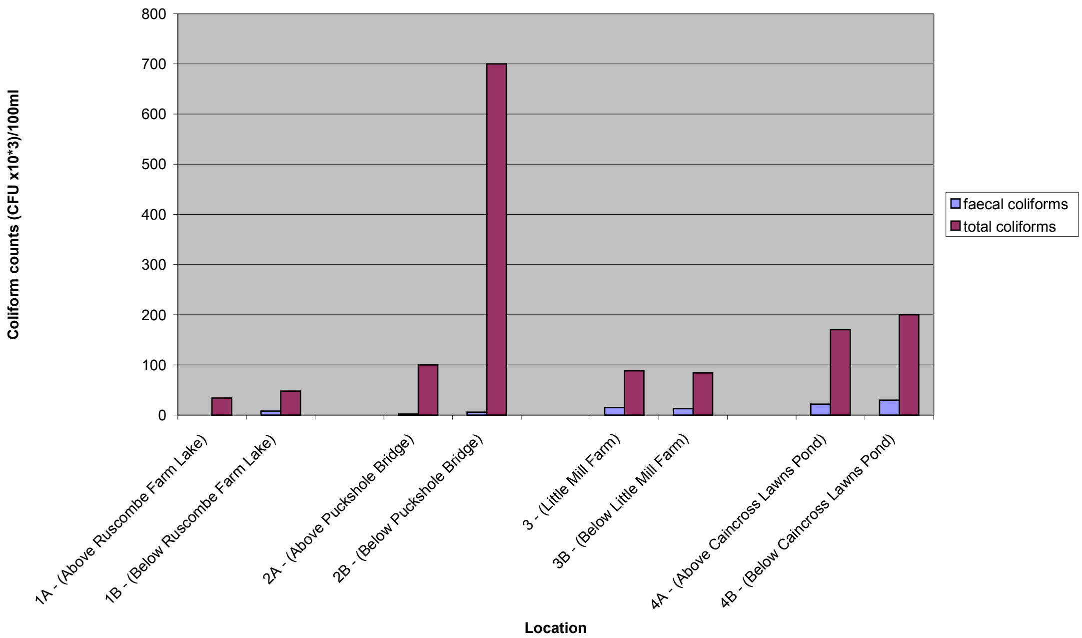


Figure 12. Comparison of faecal and total coliform counts at the various locations of sampling along the brook.

The situation becomes somewhat complicated when direct comparison are made between the faecal coliform counts for all the sampling locations. Although total coliform counts were highest at the already mentioned site ‘2B’ (downstream of the Puckshole Bridge and therefore the sewer pipe), its faecal coliform counts (which are the actual indicators of faecal pollution) were comparatively lower than at other sites (such as the upstream, 4A and downstream, 4B reaches of the Caincross Lawns Pond, #4 – see figure 12) which were expected to receive less faecal pollution. However, when compared to its upstream control site (i.e. '2A', above the Puckshole bridge), both faecal and total coliform counts at 2B strongly suggests that the water quality at there (below Puckshole Bridge) is at severe risk of faecal pollution. This pollution may only be attributable to sewer leakages as may be deduced form field reconnaissance and results of the 'resident questionnaire' survey. Similarly, direct comparison of upstream (A) and downstream (B) sites of the various sampling locations indicate the presence of some pollution source at the selected site that has resulted in elevated coliform (both faecal and total) counts downstream. It must, however, be noted that occurrence of high concentration of indicator bacteria does not necessarily indicate public health risk, and low concentration of these do not necessarily indicate low public health risk (Glasner and McKee, 2002).

5.1.4 **Resident and Stakeholder Assessments**

Resident Questionnaires:

All five residents identified responded to the questionnaire survey. The actual number of years they had lived in their residences were 1, 1.5, 3, 28 and 33 years. All respondents (four females and one male) confirmed the problem of sewage leaking into the brook and gave similar explanations as to the cause of the problem (Table 12 – item 1). However, only one categorically stated that the problem had occurred about fifteen (15) years ago.

When asked if Ruscombe Brook still continues to experience the problem, three respondents answered in the affirmative; whereas the other two indicated that due to the replacement and repairing of the sewer pipes (by Severn Trent Water Limited) identified to be leaking or causing the problem, they no more experience the problem in their area. The three who responded affirmatively were asked to provide in their views on what measures could be taken to stop the problem. Their responses are summarised in Table 12 (item 2).

Table 12. Summary of some responses obtained from the questionnaire survey

Item	**Question**	**Answers**
1	In your view what do you think was the cause of the sewage leakage?	• "*overflow of sewage system due to blockage and low capacity; surface water overflowing sewers*" • *"overload of the system"* • *"breaks and fractures in the sewer from Ruscombe overflowing into the brook"* • *"Overflowing manhole covers in flash floods/heavy rains also roots blocking pipes"* • *"manhole covers coming off and sewage overflowing"*
2	If the brook continues to experience this problem, could you please briefly state, in your perception, what measures could be taken to stop the problem?	• Increasing the sewer pipes capacities. • Providing alternative drainage systems for surface water – such as the use of Sustainable Urban Drainage Systems (SUDS) to prevent the system from reaching capacity. • Employing the use of holding tanks or soak-aways to recycle or clean the wastewater. • Replacing the old sewer pipes. • Planting reed beds along the brook to clean up the water. • Regularly checking and preventing tree roots from entering the sewer pipes.
3	In your view, do you think the sort of farming you are practising directly or indirectly introduce some contaminants into the stream which may impact on the water quality?	• *"No, Sheep are stock-fenced away from stream".* • *"Yes, there is always the possibility of cattle dung entering the stream, but they don't have anywhere to stand in the stream, rather just coming to it to drink"*
4	What other sources of pollution have you personally identified to likely impact on the water quality?	• *"tipped over salt and grit bins; Brook passes next to a small garage along car repairs – possible depositing of waste oil in the brook"* • *"cattle poaching from adjacent fields – Acre Place"*
5	In your own view do you think implementing SUDS schemes could be the best or sustainable solution for restoring the water quality; and why?	• *"Yes; not adding to limited capacity and independent of brook"* • *"Yes, it would filter overflowing sewage outlets and road drainage – especially where people wash cars out on above roads"* • *"Yes, I think this is a part of a long-term sustainable improvement in water quality but also in the livelihood of flooding. More immediate actions required also"* • *Yes, the water needs to go back into the land – a more environmental solution – it would help prevent flooding, slow release – also it would be cleared by filtration through the soil.*

Note: Direct quotations (of responses) are shown in *italics.*

As already understood by the author, two of the respondents confirmed that they keep or rear livestock at their residences (thereby supporting the choice and inclusion of those sites along the brook as sampling locations); although both claimed they do not apply any sort of chemical (such as pesticides and sheep doping chemicals). When asked how they dispose of the waste from their farm, one mentioned that “there was none”; whereas the other indicated that farmland manure was spread on the fields at about 20 metres away from the brook. Although this is acceptable according to national and international recommendations for applying farmland manure (DEFRA, 2003 and UNDP/GEF, 2004), a review of water quality concerns in livestock farming areas by Hooda *et al.,* (2000a) suggests that watercourses can still receive heavy inputs of nutrients (nitrates, ammonia and phosphorus) through surface runoff and leaching from manure spread on fields (even 100 metres away). They therefore propose among many other alternatives, that the nutrient content of manures and slurries be determined particularly for nitrogen and phosphorus, prior to any land application.

Again when asked if their farming practice may impair the water quality, the former respondent answered in the negative whereas the latter responded ‘yes’. Their explanations can be found in Table 12 (item 3) above. It, however, appears that the former respondent might not be aware of the consequences of livestock farming on the water quality or probably, was not too clear of what the question implied. This is because later field reconnaissance revealed a heap of manure found just at the bank of the brook (where the respondent resides). Again, it was observed that the pen was located on a steep slope to the brook (see Appendix 9) and therefore any droppings could easily drain into the brook, though the impact on the overall water quality may not be significant.

To further identify any other sources of pollution into the brook, respondents were asked to mention if they were also aware of any other pollution sources. Three respondents (including the two farmland owners) did not identify any other pollutant sources; whereas the other two identified some sources (given in Table 12 – item 4). Whereas, the possibility of salt contamination at Caincross was already identified and was meant to be investigated in this study, the other potential threats identified by the respondents (such as oil spills from a car repair shop and cattle poaching) were unknown prior to the assessments and therefore were not taken into consideration while choosing and sampling at those locations. It was, however, later observed that cattle poaching at Acre place (about 100 metres above the sampling location, ‘2A’ – which is also upstream of Puckshole bridge; see figure 6) has resulted in the introduction of large volumes of fine silt downstream (to the sampling site, 2A). This is also reflected in the relatively high (average) turbidity of 28.53 FTU (see Table 6) measured in the water sample. This is again supported by the fact that only two families of invertebrates were identified (see Table 8) compared to eight (*Ibid*) at 2B which was expected to be comparatively more polluted due to being downstream of the potential sewage (point source) pollution. The BMWP and ASPT values of 11 and 5.5 respectively (see Table 8), compared to 37 and 4.6 (*Ibid*) correspondingly at 2B, suggests that the site 2A is comparatively less polluted despite the substrate type. Thus the low BMWP score at 2A is an indication that whereas variety of invertebrates may be sampled from small gravels and coarse sand substrates, the same might not be true for finely silted and boggy substrates. This does not, however, imply relatively ‘poor’ quality. Whereas the type of families (no matter how few) identified may be the pollution intolerant or the most sensitive kinds and therefore implying ‘very good’ quality when the ASPT is applied, those identified (in numbers) at the relatively easily sampled substrates (such as coarse sand) may produce pollution tolerant or the most insensitive organisms and rather imply ‘poor’ quality. In other words, substrate types may quantitatively impact and affect macroinvertebrate surveys (decreasing abundance levels of organisms), but not qualitatively (by depleting particular organisms). Problems with qualitative assessments may therefore arise not because of the type of indices used but on the sampling technique, and may be overcome by taking replicate samples wherever substrate types do not allow easy sampling.

With regards to their perception of implementing sustainable urban drainage schemes (SUDS) for improving the water quality, all respondents advocated with various reasons (see Table 12 – item 5) that it could be the best or sustainable solution for the brook – an indication that they were well informed of the concepts and implications of the scheme, probably because the community action group were already very active in promoting these solutions.

One respondent, however, acknowledged the idea of implementing SUDS as the best option, but with the emphasis "*if I knew exactly what this entailed; it sounds like a sensible idea, but I don't know the details of how it could work. Presumably reed beds etc.*" This clearly indicates that not all respondents were well informed of the concepts of sustainable urban drainage systems, and therefore any introductory notes provided with the questionnaires could have been very useful as a thoughtful piece and not necessarily influence their choice.

Stakeholder assessments:

Two stakeholder organisations (Water21 and Severn Trent Water Limited) responded to the 'stakeholder questionnaires' – representing 50% feedback. Whereas the author acknowledges that failure or inability for the Stroud District Council to respond might be due the limited time possible for them to respond (as the questionnaires were sent whilst the study completion date was imminent), not much can be said of the Environment Agency's inability to respond. Nevertheless, the two sets of feedbacks received provided enough information as expected, although for ethical reasons many of the comments received have been reserved and not presented here.

With regards to past and present water quality status of the brook, Severn Trent Water indicated that they had never monitored the water quality as it is not their responsibility to do so; whereas Water21 mentioned that although it does not directly monitor the water quality, it has supported student and other groups to do so – ultimately describing the present water quality as fairly good compared to its 'worse' status about 10-20 years ago as a result of storm overflows. This data, however, was not used for the purpose of this study as Water 21 indicated the results were not reliable. Both correspondents declared their awareness of recent and past sewage leakages into the brook, providing similar causes as being misconnections and blockages/roots in the sewer pipes. Severn Trent Water Limited, being the sewerage undertaker of the area was asked in a further e-mail to highlight the problems and to indicate what measures (if any) had been taken to restore the problem, and whether there are possibilities of future occurrences. Below is the response received from its correspondent.

"Firstly the problems on the pipe bridge were overcome by rebuilding the manholes and section of sewer that crossed the brook. The manholes were built to give extra capacity and the pipe was relaid at a more gentle gradient to ease the velocity of the flow through the sewer.

Secondly a misconnection survey was undertaken in the area to identify properties that were connected in some way to the surface water system instead of the foul system. It is the houseowners responsibility to rectify any misconnections and therefore it can be a lengthy process to ensure that everyone carries out the necessary work. All misconnections contributing to the affected outfall to the brook were identified and successfully corrected.

Thirdly, a CCTV of the sewers was undertaken and highlighted that roots were encroaching into sewers, this was vastly affecting the performance of the system during rainfall. A programme of monitoring the growth and root cutting is currently in operation until a scheme to reline the sewer can be designed and undertaken" (Correspondent, Severn Trent Water).

Thus as confirmed by some of the residents (through the 'resident questionnaire' survey), repairs on the sewer pipes might have reduced the rate of (or even stopped) sewage discharges into the brook. The question, however, is whether these repairs will remain a long term sustainable solution to prevent any such unexpected problems in the future or rather become a sporadic exercise? Severn Trent Water did not comment on whether sustainable urban drainage schemes (SUDS) would be the best or the most sustainable way of improving water quality of the brook, nor suggested an alternative management scheme. Water 21 on the other hand, strongly advocated for the implementation of SUDS on the brook. Although it (Water 21) noted that in view of past failures SUDS may not look good as an immediate prospect, it stated that due to changing public perspectives across a wide range of environmentally sensitive purchases (e.g. energy, food, etc.) in light of a range of sustainability and climate change issues, a free market offering SUDS based on water engineering solutions would be the most sustainable management choice for the Ruscombe Brook.

5.1.5 PART B: Analyses of Secondary Data

Gloucestershire County Records [Record number P363A/PC21/2, (1895-1901), Receipts and Payments, - Enclosed]

An 1896 water quality data on the brook obtained from the Gloucestershire County Council (see Appendix 4.2) shows that the brook was of 'good' quality about a hundred years ago. As the results of this analysis (which was also conducted in order to investigate similar sewage pollution incidences) does not indicate the sampling points it is impossible to relate it to any of the present sampling sites and therefore unable to compare these results to evaluate the extent of pollution (if any). Besides, the period between 1896 and 2007 is long enough for the water quality to naturally undergo unnoticeable changes and therefore not providing appropriate grounds for comparing with the present study, even if the sampling points can be correlated.

Environment Agency:

Also, between May 1995 and April 1998, the Environment Agency carried out monthly water quality monitoring at Ludlow Green (the site along the brook just above the Ruscombe Farm Lake and uppermost of any identified pollution source). The results of this assessment (Appendix 4.1) also imply good water quality when compared with recommended drinking standards and for protecting aquatic life (Environment Agency, 2005). As this monitoring was carried out about six years prior to the first report of sewage leakage in the Ruscombe Brook, it has been employed to serve as background standard for evaluating the extent of pollution or the present water quality status of the brook. It must, however, be noted that this data corresponds to only one sampling point (i.e. 1A – above Ruscombe Farm Lake in the case of this study) and therefore may only be used to assess the extent to which the water quality has changed over the period between 1998 and 2007 at that particular reach of the brook. Table 13 compares results of this secondary data and that of the present study measured at the same locations, and evaluates the percentage change in concentrations of the parameters measured.

The table shows that apart from pH and alkalinity that increased (and which is not surprising as they vary with temperature, which were very different for the two studies), the only parameter that changed significantly between the two sampling periods is ammonia, with percentage change of 157% (i.e. over 1.5 times increment measured in this study over the study by the Environment Agency). This increment may be due to natural changes in the watercourse rather than any anthropogenic impact (see section 5.2.1 for further explanation).

Table 13. Comparison of the average concentrations of parameters measured at site 1A (above the Ruscombe Farm Lake) with secondary data obtained from the Environment Agency measured between May 1995 and August 1998.

	Temp. (°C)	**pH**	**Conductivity (μS)**	**NH_3 (mg/l)**	**NO_2 (mg/l)**	**NO_3 (mg/l**	**Cl^- (mg/l**	**Alkalinity (mg/l**	**BOD_5 (mg/l)**
Secondary data*	9.3	8.0	499	0.07	0.012	5.32	31.7	174	2.0
Primary data**	17.5	8.5	441	0.18	0.003	1.46	28	202	0
%change in concentration	88.2	6.3	-11.6	157	-75	-72.6	-11.7	16.1	-100

* represents average data between May 1995 and August 1998 obtained form the Environment Agency (see Appendix 4.1).

** represents data collected (in this study) at the same location as secondary data.

Stroud District Council:

Water quality data obtained from the Stroud District Council is for samples taken from the Village Spring (the major spring feeding the brook – see figure 6). The data (appendix 3.1) showed 'recent' faecal contamination of the spring. Both total coliforms count (7 per 100ml) and faecal coliform counts (1 per 100ml) exceeded the recommended counts of (0 per 100ml) established by the Private Water Regulations of 1991 – see appendix 8). The high concentrations of nitrates (35.6 mg NO_3/l) recorded in this data as compared to 7.0 mg NO_3/l (measured in this study), also suggests that the spring was of better quality during this study period compared to the October 2006 analyses. This further indicates that there was no major sewage pollution incident during the times of water sampling.

5.2 DISCUSSION

5.2.1 Discussion of Results

Ruscombe Brook has not been extensively studied and therefore its nature (in terms of self purification or recovery rate) cannot be accurately predicted. However, the relatively low water levels (depth) measured at three weather conditions (dry, moderate and wet) during the study period as well as the impact of sewage pollution observed in other similar watercourses (e.g. Mallin *et al*., 2007 and Nipper, 2000) implies that any measurable amount of sewage leaking into Ruscombe Brook may have deleterious effect on the water quality. This change in water quality (deterioration) can be easily detected from water samples (as long as the pollution incident has not occurred for more than 2 weeks – as observed from similar studies) by measuring specific chemical parameters such as nutrients (nitrogen and phosphorous) and biochemical oxygen demand (BOD).

Results of the physicochemical analyses of water samples shows that the brook is of fairly good water quality as all parameters measured are within the recommended limits for drinking and for the protection of aquatic life. This, however, does not conclusively suggest that the water quality has not deteriorated (following any major pollution) as the overall water quality prior to any incidences of sewage pollution is unknown. As already mentioned, the 1896 water quality data on the brook obtained from the Gloucestershire County Council does not indicate (where the samples were taken – be it the springs or from the brook itself) therefore providing no grounds for comparison. Besides, (as already argued in section 5.1.5) the period between 1896 and 2007 is long enough for the water quality to naturally undergo unnoticeable changes and therefore not providing appropriate grounds for comparing with the present study, even when the sampling points could be correlated.

When compared with the data obtained from the Environment Agency (see Appendix 4.1), and the physicochemical analyses of water samples taken from the same location as the secondary data (i.e. 'Ludlow Green' – for secondary data; and 'Above Ruscombe Farm' – in the case of this study) the water quality has remained relatively 'good' (see Table 13). The sharp increase in ammonia concentrations recorded in this study (i.e. over 1.5 times increment measured in this study over the previous study by the Environment Agency) may be due to natural changes in the stream and not necessarily due to anthropogenic impacts. This is because the sampling location is the uppermost reach of the brook where it is expected to be free from any point source pollution. Moreover, the average concentration of ammonia (0.18mg/l) measured at that location still represents the highest concentration recorded (among all the sampling sites selected in this study) during the base flow regime (i.e. for samples taken on 18/07/07 – see Table 6). The fact that relatively elevated levels of ammonia were recorded at sites '1' (Ruscombe Farm Lake – which was expected to be affected with runoff from livestock farm was >1 mg/l NH_3), '2A' (above Puckshole Bridge – with potential threat form cattle poaching upstream was 0.12 mg/l NH_3) and '3B' (below Little Mill Farm – with potential threat of sewage and/or livestock contamination from upstream was also >1 mg/l NH_3) than at the site under consideration (i.e. above Ruscombe Farm Lake; 0.06 mg/l NH_3) during the relatively high flows (i.e. for samples taken after the heavy storm on 02/07/07) is an indication of surface runoff (of muck) from the nearby farmlands or cattle poaching sites into the brook - leading to the elevated ammonia levels. This also substantiates the argument that the increase in concentration measured at Ludlow Green or above the Ruscombe Farm Lake between the background / secondary and the present water quality assessment is mainly due to natural changes within the brook.

Thus in general, the physicochemical analyses of water samples did not indicate or suggest any form of pollution (evident now) in the brook. Rather the measured 5-day biochemical oxygen demand (BOD_5) levels of 9 mg/l and 3 mg/l measured in samples taken at site 3A (above Little Mill Farm) during high flows and base flows respectively (see Table 7), contrary to the 0 mg/l measured at all other sites for all three sampling dates is an indication that the heavy rains on 01/07/07 prior to the 02/07/07 sampling may have caused sewage-related pollution at the location (as was evident from sanitary materials floating on the water surface at the time of sampling). Notwithstanding, this results may also indicate that the site was wrongly selected (as upstream location) to the Little Mill Farm. And may instead be the actual location where sewage effluents might have been discharged in the past.

Site ‘4’ (Caincross Lawns Pond) which was included as a sampling site on the basis of its potentially receiving de-icing salt from road run-off, on the average gave the highest recorded chloride concentration (of 35.5 mg/l) compared to the rest of the sampling sites (see Table 6). However, this does not fully confirm the issue of salt pollution at that reach of the brook as the average concentration of chloride measured at the other sampling sites do not differ significantly from this result (figure 13). Besides, when compared to similar studies (e.g. Sriyaraj and Shutes, 2001 where up to over 300 mg/l of chloride was measured in a pond receiving de-icing salt), 35.5 mg/l chloride concentration in the Caincross Lawns Pond may be argued to be too low to indicate such salt pollution. This therefore implies that the salt intrusion (resulting from road de-icing which normally occurs during winter) might have long occurred (prior to the study) and no more traceable either because the quantity of salt entering the brook is insignificant considering the volume of water in the receiving lake or that greater amount of salt that entered the lake might have been washed downstream into the Stroud Water Canal prior to sampling. It should, however, be noted that since salt pollution from de-icing salt is seasonal, different results may be obtained (and therefore would be expected) if the samples were taken during winter. It may therefore be necessary for future studies on the Ruscombe Brook to re-consider sampling throughout the hydrological year in order to confirm this result.

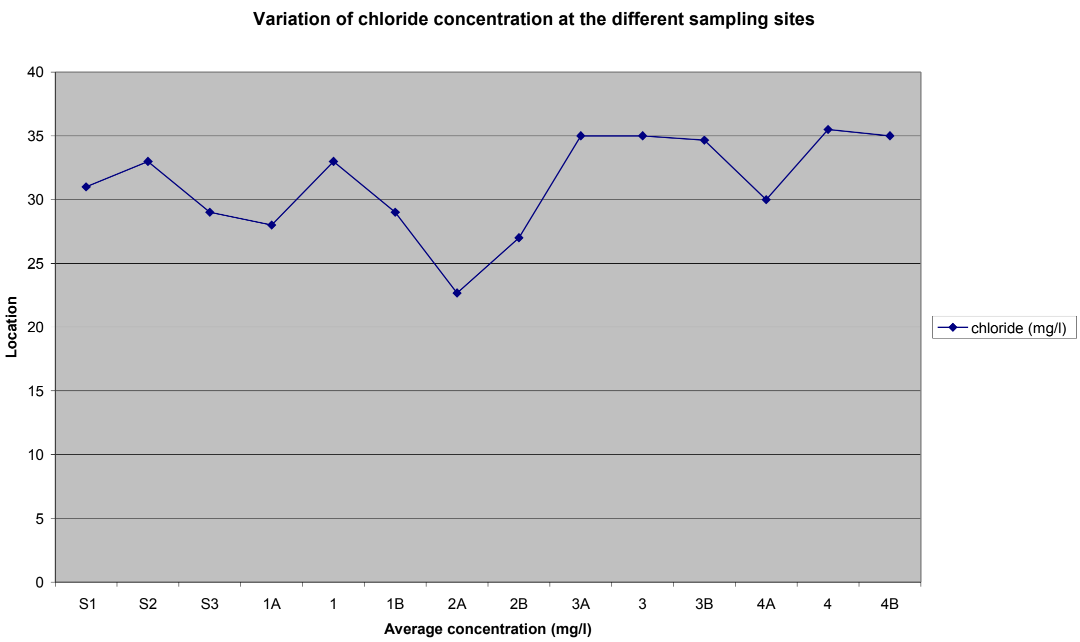


Figure 13. Comparison of chloride concentrations at the various sampling sites.

Note that most of the sampling locations recorded chloride concentrations of more than 30mg/l – and therefore the 30.5 mg/l recorded at the site in question may not be due to external causes.

The results of bacterial analyses on water samples are quite complicated as the two methodologies employed produced different results. Whereas the Colitag® method employed for the qualitative analysis of bacteria in the first batch of samples indicated that all samples were contaminated with faecal matter, the standard plate count method employed for the second and third batches indicated completely otherwise. This anomaly may not imply that either of the two methodologies is not reliable, but although errors due to improper sample preparation or storage are possible, an understanding of the principle of the Colitag® test method suggests that such results may not be surprising. For example, since the Colitag® test is colorimetric in nature, the presence of a single coliform in the sample will still give a positive test (i.e. indicate the presence of coliforms and therefore as evidence of faecal contamination) comparable to when there are about 100 or more coliforms present. Also as the second and third batches of samples were taken after two weeks of taking the first batches, it may be argued that any coliforms that were measured or detected in the first batch of samples may no longer be viable and therefore might not be detected in the second and third batches of samples, even with the Coliform® test method. Mallin *et al*., (2007) have noted that loss of faecal coliforms may occur in water column through processes such as predation by protozoan, mortality from sunlight (UV radiation), dilution by heavy rains and sedimentation. Meanwhile watershed studies have proven sediments to be reservoirs for faecal pollution (Doyle et al., 1984, 1992; Buckley et al., 1998).

The presence of both faecal and total coliforms in sediment samples (but not in water samples) at the various sampling sites is therefore an indication of past pollution incidences rather than recent contamination, and whether this incidence is due to sewage pollution is inconclusive. However, the fact that no faecal coliforms were enumerated in sediments at the site '1A' (which is uppermost of sampling site on the brook) is an indication that the brook is not anthropogenically affected upstream, but starts getting polluted downstream from the Ruscombe Farm Lake. This is further supported by the fact that faecal contamination got more severe as one moves downstream along the brook (figure 14). Similarly, 'total coliform' counts elevated with downstream distance (except in the sharp rise at site 2B which has already been discussed) – suggesting bacteria populations resulting from upstream pollution sources are easily carried downstream.

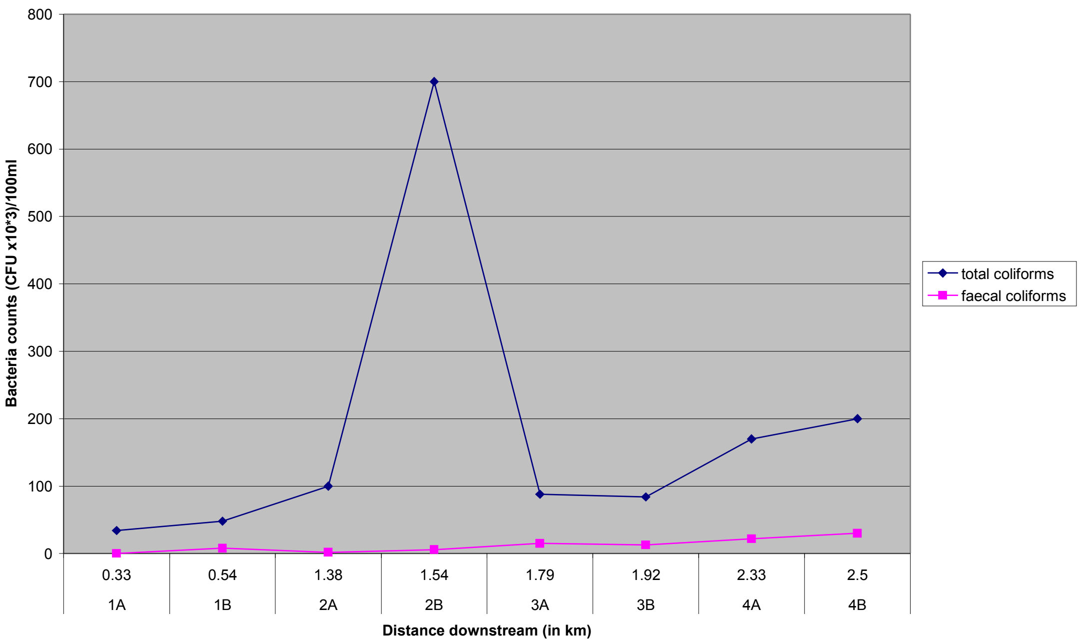


Figure 14. Faecal coliform counts measured with distance downstream.

The wide variation in ASPT scores (for the macroinvertebrate survey) between upstream and downstream sites is a strong indication that the sampling locations have been polluted in the past. Whereas this cannot be conclusively attributed to sewage pollution, the wider variation between the sites 2A and 2B (upstream and downstream reaches respectively of the Puckshole Bridge, site #2 – see figure 6) may suggest so. This is because site #2 is the location where the sewer pipe runs across the brook. Sewage pollution was therefore the major concern for the selection of this site. The fact that the water quality was still assessed as 'good' (using the LQI classification – see Table 6) at both upstream, 2A and downstream, 2B locations to the sewer pipe, however, suggests that the pollution had occurred long before the sampling began – and was therefore not readily evident. This further supports and strengthens the use of macroinvertebrate data for assessing the impacts of episodic or past wastewater or sewage discharges in watercourses.

5.2.2 Towards sustainable management of water quality of the Ruscombe Brook

Clearly, water quality of the Ruscombe Brook is not only affected by sewage discharges. Whereas these sewage discharges may only occur occasionally (through storm overflows during heavy rain events) and therefore have an unpredictable impact on the overall water quality, daily inputs of fine silt (through trampling) and farmland waste (such as manure and animal dung) through surface runoff and farm animals drinking from the brook also contribute to reductions in the water quality; and should therefore be of equal or much concern. An ideal sustainable solution may therefore involve a strategy that tackles each problem either separately or in an integrated fashion such as;

- the practice of 'Catchment-Sensitive Farming' (DEFRA, 2004 – see section 2.5; chapter 2); and
- the use of Sustainable Urban Drainage Systems (SUDS), particularly, schemes that include ponds and constructed wetlands (CIRIA, 2007).

Such management strategies will also not only serve to improve the water quality but may help meet regulatory standards, including;

- The EU Water Framework Directive, which requires a holistic approach to achieving and maintaining good water quality in all surface and groundwaters, including preventing and controlling water pollution from diffuse sources. The Directive requires the achievement of good chemical and ecological status in surface waters by 2015; and
- The EU Habitats Directive, which aims to reduce water pollution by nitrate from agricultural sources and to prevent such pollution from occurring in the future.

At locations identified as contributing to farmland or agricultural pollution to the brook, for example, a basic management approach would be to water livestock at sites well away (about 100 metres) from the brook in order to keep manure out of the water and also building fences to prevent cattle and other farm animals access to watercourse. DEFRA (2004) has noted that lack of information and environmental land management skills can also lead to increased water pollution. At a fundamental level, it explains that this could mean that many farmers are not aware of the impacts of pollution from diffuse sources and will therefore not consider modifying their land management practices to reduce their impact. Thus moving towards catchment-sensitive farming, which requires farmers and their advisers to both increase their understanding of the routes (capacity building) by which agricultural emissions or runoffs find their way into water and learn new skills and approaches to reduce these emissions may be a basic sustainable way of improving water quality in the Ruscombe Brook.

However, the use of sustainable urban drainage schemes were strongly advocated by all respondents (through 'resident questionnaire' survey) and one organisation (through the 'stakeholder questionnaire' survey) may be considered as a long term sustainable solution for controlling both point and diffuse sources of pollution in the brook. An important observation deduced from the results of physicochemical analyses is that whereas concentrations of major parameters such as nutrients (nitrogen and phosphorus) and dissolved oxygen varied considerably between upstream and downstream locations of identified point sources of pollution, the variation in their concentrations was rather slight where the two ponds along the brook were identified as directly receiving such contaminants. Although it may be argued that the quantity or concentration of pollutants being received by the ponds is too low (with regards to volume of the receiving water) and therefore its impact downstream is relatively insignificant or immeasurable, it is also an indication that the ponds are serving as a reservoir or sink for these contaminants and eventually reducing their overall load from moving downstream to deteriorate the water quality. Pollutant removals by natural wetlands / ponds are estimated to range between 70% and 96% $BOD_{5;}$ 60% and 90% nitrogen while phosphorus removal varies from season to season (USEPA, 1991). Constructed wetlands on the other hand can even reduce these contaminants much further (Kambole, 2003) and have been suggested as suitable alternatives for controlling wastewater, including those from urban road and agricultural runoffs (Cooper *et al.,* 1996).

A critical evaluation of the guide to the selection of appropriate SUDS options developed by CIRIA (2007) also suggests that the use of retention ponds or wetlands may be the ideal sustainable solution for improving water quality of the Ruscombe Brook. The criteria for evaluation and choice of this alternative has been summarised in Table 14 below.

Table 14. Evaluation of some SUDS options potential for improving water quality in Ruscombe Brook, with respect to land use characteristics of the area. Source: (based on methodologies developed by CIRIA, 2007)**.**

Criteria	**SUDS group**				
	Retention	Wetland	Infiltration	Filtration	Detention
Less developed area*	√	√	√	√†	√
Area draining to a single SUDS component (0 - 2 ha)**	√	√	√	√	√
Total suspended solids removal***	H	H	H	H	M
Nutrient removal	M	M	H	H	L
Bacteria removal	M	M	M	M	L
Community acceptability ****	H	H	M	M	L
Habitat creation potential****	H	H	L	L	M

Key:

* Criteria based on land use characteristics H - High

** Criteria base on site characteristics M - Medium

*** Criteria based on quantity and quality performance L - Low

**** Criteria based on community, environmental and amenity performance

√ - suitable

√† - may not be suitable with certain types/ techniques

It must, however, be mentioned that this evaluation is only based on a broader and general assessment with regards to one stakeholder and five residents' responses as well as a review and assessment of the literature and scientific underpinning, and does not therefore represent a final decision or recommendation for implementing SUDS on Ruscombe Brook. The design of a SUDS scheme will normally require the use of two or more techniques that are linked together to provide the appropriate management train for a specific site (CIRIA, 2007). The SUDS selection flowchart developed by CIRIA (2007; 5-13) could therefore be employed in conjunction with further studies on the catchment's specific characteristics to evaluate the best SUDS option.

5.2.3 **Summary and Critical Evaluation of the methodologies employed in the study**

During the preliminary studies (see section 4.1 – chapter 4), it became apparent that the water quality of the brook may not only be affected by sewage leakages, but also potential threats from two farmlands located along the brook (i.e. the Ruscombe Farm and Little Mill Drive – see maps at Appendix 1) and salt intrusion from road run-off at Caincross roundabout. (i.e. complex problem – nitrates may be coming from different sources – not just sewage pollution - and that there may be other pollutants involved). The aim of the study was therefore expanded to include the assessment of the overall water quality with respect to the three pollution threats – sewage leakage, livestock rearing, and salt contamination.

It was also observed and hypothesised that although some evidence of sewage pollution was traceable from floating sanitary materials at some points of the brook, its impacts on the water quality may not be observable from physicochemical studies of water samples, since the last incident of sewage pollution was reported about 5 months prior to this study (RBAG, 2005-2007) – a timeframe still long enough to trace sewage impacts in water samples (Crabill et al 1999). Nonetheless, the physicochemical monitoring (including bacterial analysis) of water quality was employed in order to identify any possible sewage leakages that might have occurred during the course of the study. The sampling strategy was therefore devised (as explained in the methodology) in order to take into consideration the temporal and spatial variation of water quality parameters; and hence also included an assessment of macroinvertebrates and sediment contamination – where pollutants have a longer residence time. A limitation to this strategy, however, is the fact that actual flow rates were not measured; and estimates on the characteristics of the flow regime were only based on measurement of the water depth.

The selection of specific sites for the water quality analyses may also imply that the contaminants were treated as point source pollution, and therefore the results may be biased where pollution was rather diffuse – particularly with faecal contamination. Crabill *et al.,* (1998), however, suggest that sampling to address the potential pollution risk from sediments (which can serve as reservoirs for faecal contamination) can help overcome this limitation. Besides, the selection and inclusion of upstream and downstream sites (to identified point sources of pollution) may also be used to account for this, especially where contaminants measure equally at both upstream and downstream sites as the point source. It may also be argued that relating the concentrations of contaminants measured to potential or actual source of pollution may be biased as both of the two major threats identified (i.e. sewage and livestock waste) results in organic pollution of watercourses. For example, elevated levels of nutrients or increased bacterial counts may be due to either sewage pollution or runoff (of manure) from farmlands; and therefore may be difficult to identify the actual cause of such elevated levels. As a measure of overcoming these biases or uncertainties, however, the 'resident questionnaire' was administered to allow residents (through their informal local knowledge of day-to-day activities occurring within the catchment) provide accurate information about the landuse characteristics peculiar to the sampling locations. This approach proved very useful in gathering accurate information and making informed evaluations and interpretations of the results. Contrary to the usual weakness of low response rates associated with 'Mail Questionnaires', 100% response was received from the resident survey (sample size was very small tough). Perhaps this is because the questionnaires were handed in person during one of the sampling times rather than sending them through the post, and also due to the fact that the residents themselves were already interested in the study and keen to be advised on the outcome.

The problem of not receiving detailed written responses was, however, encountered even where open-ended questions were asked. For example, one respondent indicated that she was fully aware of each and every sewage pollution incident that occurred in the brook and that she has photograph records showing the various incidences. Because this response was received very late (just close to the completion of the study) no follow-up was made to obtain such records from the resident in other to evaluate the scale of the impact. Meanwhile, if other means of contacting the respondents (for example, by employing face – to – face interviews instead of the mail questionnaires), answers to these queries could have been obtained. It would therefore be useful for such methodologies to be employed in studies or research works soliciting informal and local knowledge from individual and local community groups. Valuable and important historic data may not be sent through the post by respondents, but they may easily be provided for assessment and reference purposes through face-to-face interviews. It should, however, be noted that each approach or methodology has its own limitations and at best, the best practicable approach (that would provide the maximum information required) should be evaluated and employed.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The results of the study shows that the concentrations of water quality parameters are within acceptable limits implying relatively 'very good' water quality and therefore indicating no major sources of pollution (during the period of study). Bacterial analyses of water samples as well as direct estimations of water quality status using either the BMWP, ASPT or LQI indices also suggests that the overall water quality is 'good' – again indicating no major pollution. However, the wide variations (observed from ASPT values for invertebrate survey as well as total and faecal coliform counts in sediments) between upstream and downstream reaches of (identified point sources of pollution) suggests that the selected sampling locations have received some sort of pollution that has led to comparatively deteriorated water quality downstream. Whereas this can not be exclusively attributed to sewage pollution at all the sampling locations, the widest variation in ASPT scores observed between the upstream and downstream reaches respectively of the location where the sewer pipe runs across the brook (shown as #2 in figure 6) may strongly suggest so. The fact that the water quality was still assessed as 'good' quality (using the LQI classification – see Table 8) at both upstream, 2A and downstream, 2B locations to the sewer pipe, however, suggests that the pollution had occurred long before the sampling began – and was therefore not readily evident from all three methodologies adopted (i.e. physicochemical, microbiological an macroinvertebrate).

The impact of salt pollution on the brook's quality was not evident from physicochemical water quality measurements (specifically for chloride concentrations). This may, however, not indicate complete absence of salt pollution into the brook; and the author acknowledges the inability to sample at different seasons (particularly during winter) as a limitation to evaluating this impact. It should, however, be noted that the slight variations observed between the upstream and downstream reaches of that location (i.e. the Caincross Lawns

Pond) for both macroinvertebrate survey (ASPT scores) and bacteria (faecal an total coliforms) counts in sediment samples is an indication of some level of pollution. Future research should therefore reconsider the evaluation of this impact.

Pollution from the two farmlands (Ruscombe Farm Lake and Little Mill Farm) was clearly evident from measurements of ammonia concentrations. Water samples collected from both sites (after the heavy rains – i.e. 2nd batch of samples taken on 02/07/07) recorded ammonia concentrations greater than 1.0 mg/l; whereas all other sampling locations recorded reasonably very low concentrations of ammonia (see Table 6). The absence of faecal coliforms in sediment samples taken upstream of the Ruscombe Farm Lake, as compared to 8, 000 CFU counts per 100 ml of sample taken downstream of the lake is further evidence that runoffs from the farmland are having an impact on the lake and subsequently downstream. The fact that the resident at this location also confirmed (through the 'questionnaire survey') that no sewage pollution had been observed at the location, and rather the farm manure disposed off from the farm may potentially have an impact on the water quality also serves to support this primary observation.

It is therefore suggested that whereas sustainable urban drainage schemes (SUDS) – particularly pond types or reed beds and constructed wetlands may be required as long term sustainable solution for improving water quality in the brook, considerations should be also be given to reducing the inputs from the two farmlands through 'catchment sensitive farming'. Catchment sensitive farming fundamentally means that many farmers are not aware of the impacts of pollution from diffuse sources and will therefore not consider modifying their land management practices to reduce their impact. This ideology was evident in this study as one farmer (when asked) did not identify any pollution sources from the farmland; although field reconnaissance by the author revealed otherwise. By drawing their attention to the implications of their landuse characteristics and providing them with basic concepts of preventing or reducing any pollution from the farmlands (such as fencing the livestock and preventing them from coming near watercourses) consequent pollution of the watercourse will be drastically reduced.

6.2 Recommendations

Although the sampling strategy was devised to take into consideration the temporal and spatial variation of parameters measured, the results obtained may not actually reflect (or may not be used to account for) results that might be obtained if the sampling had been done at different hydrological seasons. It is therefore recommended that further studies should be carried out to monitor the water quality (for at least one hydrological year) in order to account for any uncertainties (such as salt pollution) observed in this study. Such assessments may also be likely to detect any sewage discharges in case the problem happens to be regular. This will also further inform the choice of management strategy adopted.

The use of reed beds and constructed wetlands or ponds was evaluated as long term sustainable solution for improving water quality in the brook. The nature and suitability (size and location) was, however, not extensively evaluated, and it is therefore highly recommended that further investigation on the type, size and location of these SUD schemes be carried out prior to its implementation on the brook.

It is also highly recommended that sediment sampling (especially for bacteria analyses) should be included as a major indicator for investigating faecal pollution in watercourses.

Although not usually employed in water quality assessments, it was observed that the use of local knowledge (through questionnaire survey) was useful in identifying and evaluating pollution impacts that were doubtful from stakeholder perspectives. It is therefore recommended that water quality assessments (particularly for small or ungauged catchments) should employ the use of local informal knowledge from residents in addition to formal knowledge or established facts.

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Appendix 1

Further explanation to the importance of some parameters measured in the study.

Microbial parameters (Faecal Coliforms and E-Coli)

Coliforms have little effect on aquatic ecosystems, but some of the bacteria and other pathogens associated with faecal coliforms can have serious implications for human health. As they are usually determined to indicate the extent of water contamination by faecal material (which may include humans', livestocks' and wild animals'), their presence may not necessarily imply contamination by human sewage. Human faecal wastes, however, give rise to the highest risk of waterborne diseases, since the probability of human pathogens being present is highest; and also because human pathogens are more likely to cause a threat to other humans. Although many investigations have demonstrated that pollution indicator bacteria and pathogenic bacteria survive for extended periods in sediments (e.g., Burton *et al*. 1987), their lifespan in water is only transitory; and as such measurement of faecal bacteria in water samples may only indicate recent faecal contamination (Friedrich et al., 1996). They may therefore be especially helpful in assessing the occurrence of peak events and may be used to predict these.

Other, non-microbial parameters have been suggested as indicators of contamination with domestic wastewater. These are compounds that are used in the household such as boron (used as whitener in washing powders) and caffeine, and other human excretory products such as sterols and urobilin. None of these, has been demonstrated to be widely applicable, but may be useful for specific purposes.

Nutrients/Nitrogen compounds (Nitrates, Nitrites and Ammonia)

Nitrogen, like phosphorous, is an essential nutrient for plant growth. Sources of sources of nitrogen and its compounds (nitrate, nitrite and ammonium ion) into streams include sewage, animal wastes, fertilisers, and natural sources such as organic matter. Thus levels of nitrogen can be used to indicate the impact of human settlements and landuse on the natural environment, provided "natural" sources are taken into account.

Ammonia is a useful indicator of organic pollution, and concentrations of less than 0.1mg/l are usually found in unpolluted waters. High concentrations of ammonia (greater than 2-3mg/l N) could be an indication of organic pollution such as from domestic sewage, industrial waste and fertiliser run-off (Radojević and Vladmir, 2006).

Nitrate is an essential nutrient for aquatic plants and seasonal fluctuations may occur through plant growth and decay. Although it naturally occurs at concentrations slightly exceeding 0.1mg/l, it may be enhanced by municipal and industrial wastewaters, including leachates from waste disposal sites and sanitary landfills and even measure up to 5mg/l NO_3-N for waters influenced by human activities (Chapman and Kimstach, 1996). Nitrite concentrations, however, are generally very low (about 0.001mg/l NO2-N) and really be higher than 1mg/l NO_2-N (Chapman and Kimstach, 1996). High nitrite concentrations are generally indicative of industrial effluents and are often associated with unsatisfactory microbiological water quality (Radojević and Vladmir, 2006).

Phosphorous

In natural waters and wastewaters, phosphorous (an essential nutrient for plant growth) occurs mostly as dissolved orthophosphates and polyphosphates, and organically bound phosphates. It is recommended that phosphate concentrations are expressed as phosphorous, i.e. mg/l PO_4-P (Chapman and Kimstach, 1996). Natural sources generally occur through weathering of phosphorous bearing rocks and decomposition of organic matter albeit elevated levels from anthropogenic sources such as domestic wastewaters (particularly those containing detergents), industrial effluents, and fertiliser run-off (Radojević and Vladmir, 2006). They usually occur in natural waters at very low concentrations (0.001 to 0.020mg/l PO_4-P). Seasonal fluctuations in phosphorous concentrations normally occur as they are acted upon and taken up by plants (Chapman and Kimstach, 2006).

Dissolved Oxygen:

Dissolved oxygen is a measure of the amount of oxygen gas dissolved in the water that is available for use by aquatic organisms, and it is determined to indicate the degree of pollution by organic matter, the destruction of organic substances and the level of self-purification of the water (Chapman and Kimstach, 1996). At 25^{o}C concentrations of 8-10mg/l are normally expected in unpolluted streams; whereas concentrations below 5mg/l may adversely affect the functioning and survival of biological communities, or even kill most fishes when concentrations go below 2mg/l (Chapman and Kimstach, 1996).

Biochemical Oxygen Demand (BOD)

As the name implies, it is the amount of oxygen required for the aerobic micro-organisms present in the water to oxidise the organic matter to a stable inorganic form (Velz, 1984). As an indicator of organic matter pollution, BOD values of 2mg/l O_2 or less are expected in unpolluted waters; whereas those receiving wastewaters may have values up to 10mg/l O_2 or more, particularly near to the point of wastewater discharge. Raw sewage has a BOD of about 600mg/l O_2, whereas treated sewage effluents have BOD levels ranging from 20 to 100mg/l) O_2 depending on the level of treatment applied (Chapman and Kimstach, 1996; Radojević and Vladmir, 2006).

It, however, appears quite complicated and debatable as to what limiting factors may result in the measurement of a BOD at a time. For example, whereas the oxygen demand may result from the respiration of algae and the possible oxidation of ammonia (Chapman and Kimstach, 1996); the presence of toxic substances in a sample may also affect microbial activity leading to a reduction in the measured BOD (Velz, 1984). Interpretation of BOD results therefore, may require a great deal of care and experience.

Chloride

Chlorine or chloride ion (Cl-) when in solution, may occur in natural waters through atmospheric depositions, weathering of sedimentary rocks, industrial and sewage effluents, and from agricultural and road run-off. The salting of roads during winter periods can contribute significantly to chloride increases in groundwaters (Chapman and Kimstach, 1996; Radojević and Vladmir, 2006), and may leach to surface waters during base flows. Also seasonal variations in chloride concentrations may occur in freshwaters where the impact of road salting is apparent, as this normally occurs during winter periods. In unpolluted waters, chloride concentrations are normally less than 10mg/l. Very high concentrations, however, are normally recorded at sewage and other waste outlets (Chapman and Kimstach, 1996), and therefore may be a strong indicator for sewage or faecal contamination.

Physical parameters (Temperature, pH, Conductivity)

Temperature and salinity affect the capacity of the water to hold dissolved oxygen (Chapman and Kimstach, 1996), so increases in temperature and conductivity will affect dissolved oxygen levels and therefore species diversity as well. The pH is also important because most organisms have adapted to a specific pH and may die if the pH changes even slightly. For example, the toxicity level of ammonia to fish varies tremendously within a small range of pH values (Velz, 1984).

Appendix 2

Biochemical Oxygen Demand analysis by the ISCO Manometric 5 day method

1. Switch on the ISCO Incubator and set the temperature to 20degrees C.

2. Prepare 250ml of saturated Potassium Hydroxide solution-made by dissolving pellets. Take care as this solution is **highly corrosive**- wear gloves and safety glasses at all times.

3. Ensure freshly taken samples are available and that the pH of all samples is between 6.5 and 8.5 before proceeding. Buffer with either weak Sulphuric acid or Sodium Hydroxide as appropriate.
   Check to ensure the sample is not sterile. If so, 'seeding' may be necessary.

4. Ensure the brown 500ml incubation bottles are thoroughly cleaned with 5M Hydrochloric acid and properly dried before use. Ensure there is sufficient Mercury in each manometer tube.

5. Select the suitable calibration scales for the samples-based on the value of BOD 5 you are expecting.
   (NB: It is useful to perform a Chemical Oxygen Demand test of a few samples as this can be used to indicate the likely BOD range expected. COD is nearly always greater than BOD and thus will enable a better judgement to be made).

6. Add (volumetrically) the correct amount of sample to each of the brown incubation bottles. The correct amount is stated on the calibration scale.

7. Place cotton wool buds that have been soaked in the Potassium Hydroxide solution into the small thimbles, grease the rubber seals (with Vaseline), add the stirring rods and assemble the manometer unit inside the ISCO Incubator.

8. Ensure the Incubator is operating at 20degrees C and allow the manometer unit and samples to stabilise for c. 30 minutes to degas and reach a stable temperature.

9. Finally screw the caps down firmly and zero the calibration scale for each sample against the Mercury level in the manometer tube.

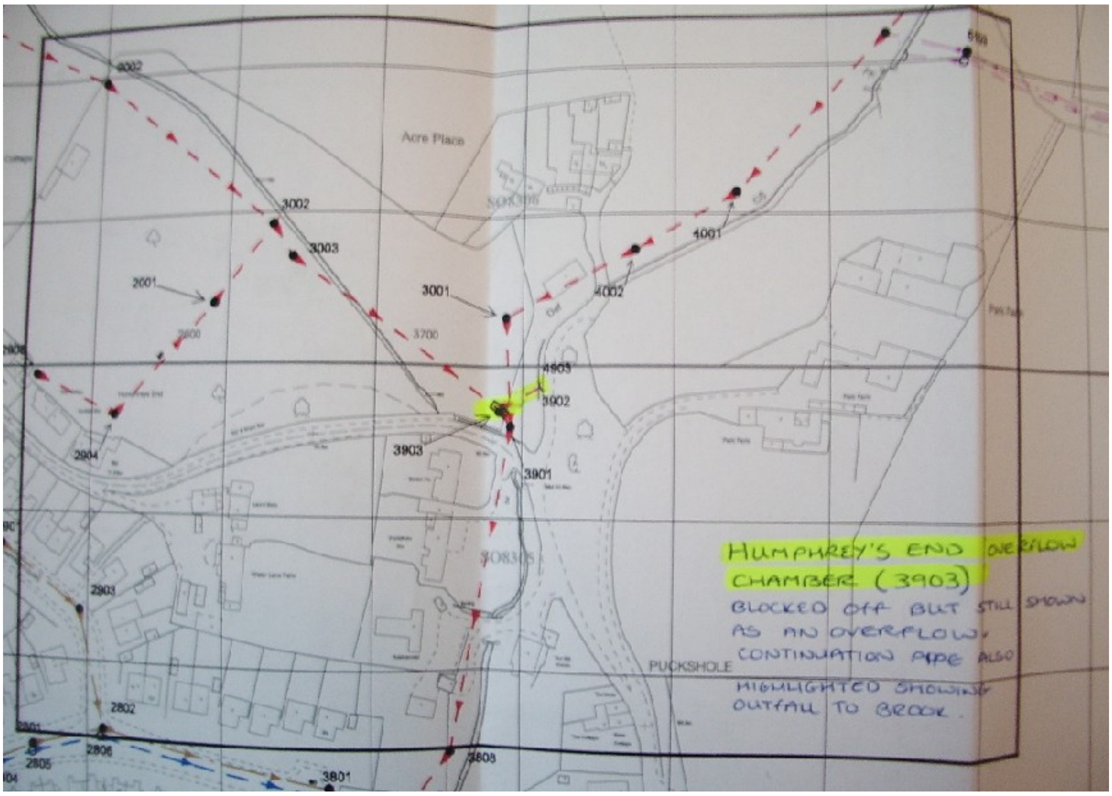
10. Close the Incubator door and check the readings daily until a final reading is taken 5 days later. This is the BOD 5 value in mg/litre of Oxygen.

11. Ensure the brown incubation bottles are cleaned with 5M Hydrochloric Acid and rinsed out with distilled water before using again.

The measuring range of the apparatus can be extended by dilution of original samples. However fully aerated synthetic dilution water must be used for this. The dilution water must be aerated for c. 20 minutes immediately before use so that it is fully Oxygen saturated.

APPENDIX 3.3

Sewer Record map from Water21



APPENDIX 5.1

Introduction to the Biological Monitoring Working Party (BMWP) Scoring System

The Biological Monitoring Working Party (BMWP) scoring system is one of the methods used by the Environment Agency for monitoring the biological quality of rivers.

Invertebrates are collected from stony riffles using kick sampling techniques and then identified to family level and recorded on a BMWP score sheet. The score sheet lists these families in order of their sensitivity to pollution and allocates a score accordingly, varying from 10 for the most sensitive families down to 1 for the most tolerant. The BMWP score for a sample is calculated by adding up these individual scores. The higher the score the better the biological quality.

The number of individual organisms within each family is recorded on a logarithmic scale of abundance categories as follows: -

Category	Abundance
A	1 - 9
B	10 - 99
C	100 - 999
D	1000 - 9999
E	10000 +

The BMWP scoring system is widely used by the Environment Agency and provides a rapid method for assessing river quality.

BMWP Invertebrate Families

The BMWP families are restricted to 82 families which have a BMWP score, The BMWP score for the family depends upon its sensitivity to organic pollution, those very sensitive to organic pollution scoring 10, down to families more tolerant of pollution scoring 3 or less. The BMWP score for the sample is the combined score of all the scoring families recorded from the sample. The 82 families that are recorded to determine the BMWP Score of the sample are listed below.

	Taxonomic Name	Common Name	BMWP Score
Flatworms	Planariidae	Flatworms	5
	Dendrocoelidae	Flatworms	5
Molluscs	Neritidae	Nerite snail	6
	Viviparidae	River snails	6
	Valvatidae	Snails	3
	Hydrobiidae	Snails	3
	Lymnaeidae	Pond snails	3
	Physidae	Bladder snails	3
	Planorbidae	Ramshorn snails	3
	Ancylidae	River limpets	6
	Unionidae	Swan mussels	6
	Sphaeriidae	Pea & orb mussels	3
Worms	Oligochaeta	Worms	1
Leeches	Piscicolidae	Fish leech	4
	Glossiphoniidae	Leeches	3
	Hirudididae	Leeches	3
	Erpobdellidae	Leeches	3
Crustaceans	Asellidae	Water hog-lice or slaters	3
	Corophiidae	Freshwater shrimps	6
	Gammaridae	Freshwater shrimps	6
	Astacidae	Freshwater crayfish	8
Mayflies	Siphlonuridae	Mayflies (large summer dun)	10
	Baetidae	Mayflies (olives etc.)	4
	Heptageniidae	Mayflies	10
	Leptophlebiidae	Mayflies	10
	Ephemerellidae	Mayflies (blue-winged olives)	10
	Potamanthidae	Mayflies	10
	Ephemeridae	Mayflies (greendrakes)	10
	Caenidae	Mayflies (Angler's Curse)	7

Stoneflies	Taeniopterygidae	Stoneflies	10
	Nemouridae	Stoneflies	7
	Leuctridae	Needle or willow stoneflies	10
	Capniidae	Stoneflies	10
	Perlodidae	Stoneflies	10
	Perlidae	Stoneflies	10
	Chloroperlidae	Stoneflies	10
Damselflies	Platycnemidae	Damselflies	6
	Coenagriidae	Damselflies	6
	Lestidae	Emerald Damselflies	8
	Calopterygidae	Demoiselle damselflies	8
Dragonflies	Cordulegasteridae	Golden-ringed dragonflies	8
	Gomphidae	Club-Tailed Dragonflies	8
	Corduliidae	Emerald Dragonflies	8
	Aeshnidae	Hawker dragonflies	8
	Libellulidae	Chaser & darter dragonflies	8
Bugs	Hydrometridae	Water measurers	5
	Gerridae	Pond skaters	5
	Nepidae	Water scorpion	5
	Naucoridae	Saucer bugs	5
	Aphelocheiridae	Saucer bugs	10
	Notonectidae	Backswimmers or water boatmen	5
	Mesoveliidae	Water Bug	5
	Pleidae	Lesser Backswimmers	5
	Corixidae	Lesser waterboatmen	5
Beetles	Haliplidae	Beetles	5
	Dytiscidae	Diving beetles	5
	Gyrinidae	Whirligig beetles	5
	Hygrobiidae	Squeek or Screech Beetle	5
	Hydrophilidae	Scavenger beetles	5
	Scirtidae	Beetles (aquatic larvae only)	5
	Dryopidae	Beetles	5
	Elmidae	Riffle beetles	5
Alderflies	Sialidae	Alderflies	4
Caddis-flies	Rhyacophilidae (& Glossiphonidae)	Caddis-flies	7
	Philopotamidae	Caseless caddis-flies	8
	Polycentropidae	Caseless caddis-flies	7
	Psychomyiidae	Caddis-flies	8
	Hydropsychidae	Caseless caddis-flies	5
	Hydroptilidae	Cased caddis-flies	6
	Phryganeidae	Cased caddis-flies	10
	Limnephilidae	Cased caddis-flies	7
	Molannidae	Cased caddis-flies	10
	Beraeidae	Cased caddis-flies	10
	Odontoceridae	Cased caddis-fly	10
	Leptoceridae	Cased caddis-flies	10
	Goeridae	Cased caddis-flies	10
	Lepidostomatidae	Cased caddis-flies	10
	Brachycentridae	Cased caddis-flies	10
	Sericostomatidae	Cased caddis-flies	10
Fly Larvae	Tipulidae	Crane-flies	5
	Chironomidae	Non-biting midges & gnats	2
	Simuliidae	Black-flies	5

Appendix 5.2

Lincoln Quality Index (LQI)

Standard ratings derived from BMWP Scores and ASPT

Habitat-poor riffles and pools			
BMWP score	**Rating X**	**ASPT**	**Rating Y**
121+	7	5.0+	7
101-120	6	4.5-4.9	6
81-100	5	4.1-4.4	5
51-80	4	3.6-4.0	4
25-50	3	3.1-3.5	3
10-24	2	2.1-3.0	2
0-9	1	0-2.0	1

Calculate the Overall Quality Rating using the formula: OQR = (X+Y)/2

Derivation of Lincoln Quality Index Values and Interpretation of Results

Overall Quality Rating	Lincoln Quality index	Interpretation
6+	A++	Excellent Quality
5.5	A+	Excellent Quality
5.0	A	Excellent Quality
4.5	B	Good Quality
4.0	C	Good Quality
3.5	D	Moderate Quality
3.0	E	Moderate Quality
2.5	F	Poor Quality
2.0	G	Poor Quality
1.5	H	Very Poor Quality
1.0	I	Very Poor Quality

APPENDIX 7.1

Resident Letter

Dear resident,

I am a postgraduate student at the University of Gloucestershire at Cheltenham. For my dissertation and as part of a scoping exercise by the Ruscombe Brook Action Group (RBAG), I am currently assessing the overall water quality and of possible sources of pollution into the brook; and to help identify/establish what controls may be required to reduce the pollution. Specifically, I am surveying the entire length of the stream to identify potential pollutant sources; and to measure water quality at these locations.

The work is to be completed by September 2007 and I would very much be grateful if you could spend a few minutes of your time to answer the questions attached to assist in making informed evaluations for the study.

Please be assured that any information obtained from this questionnaire will be used solely for the purpose of my dissertation, kept anonymous and not published elsewhere.

Thank you very much for your time.

Sincerely,

Signed

Ismaila Emahi

Mobile: 079 3936 4552

APPENDIX 7.2

RESIDENT QUESTIONNAIRE

Please tick the box which applies to you or fill in the spaces provided where appropriate.

1. Are you Male [ ]; Female? [ ]

2. Age group; 10-19 [ ]; 20-29 [ ]; 30-39 [ ]; 40-49 [ ]; 50-59 [ ]; 60+ [ ]

3. How many years have you lived in your house? …………………………..

4. Are you aware of any past or recent raw sewage leakages into the Ruscombe Brook and/or on surrounding fields? Yes [ ]; No [ ]

If you answered **No** to question 4 please proceed to question **9**; else continue from question **5**.

5. In your view, what do you think was the cause of this sewage leakage?
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

6. Could you please describe below your knowledge of what happened where and when during these incidences, and whether this has directly or indirectly affected water quality in the brook? (Please attach additional sheets, if necessary).
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6. Do you still continue to experience this problem? Yes [ ]; No [ ]

7. If **No** what do you think has prevented this incidence from further occurring?

(A) The sewer pipes identified to be leaking have been fixed or replaced. [ ]
(B) It was just a one-off event so have not experienced it again since. [ ]
(C) Don't know. [ ]

(D) Other? Please explain below
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
8. If **Yes** to question **6**, could you please briefly state, in your perception, what measures could be taken to stop this problem? ……..
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9. Do you practice any form of agricultural activities at your residence or elsewhere near the brook? Yes [ ]; No [ ]

If **No** please go to question **14**

10. If **Yes** please indicate which kind(s) apply to you. (**Please tick all that applies**)

Crop production [ ]; Animal/livestock farming [ ]; Fish farming [ ]
Other, please specify
………………………………………………………………...

11. Do you apply any kind of chemicals in any or all of the agricultural practices you have mentioned above? Yes [ ]; No [ ]

If **Yes** please list them here ……………………………………………………………
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....
....

12. If applicable, how do you dispose off the waste from your farm?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
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13. In your view, do you think the sort of farming you are practising directly or indirectly introduce some contaminants into the stream which may impact on the water quality? Yes [ ]; No [ ]; Don't know [ ]

13(a). If **No,** please explain what measures you have taken to prevent this?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
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13(b). If **Yes,** could you please describe the nature of this pollution?

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……………………………………………………………………………………
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14. Are there any other sources of pollution that you have personally identified which could also impact on the water quality? Yes [ ]; No [ ]

14(a). If **Yes** could you please explain ……………………………………………..
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………

15. In your own view do you think implementing Sustainable Urban Drainage (SUD) schemes could be the best or sustainable solution for restoring the water quality?

Yes [ ] ; No [ ]; Don't know [ ]

If **No**, please go to question **16**.

15(a). If **Yes**, please explain why? …………………………………………………
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16. If **No**, what would you propose as the best approach to restoring the water quality and why?
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APPENDIX 7.3

STAKEHOLDER QUESTIONNAIRE – Ruscombe Brook

Please be assured that the information obtained from this questionnaire will be used solely for the purpose of my dissertation, kept anonymous and not published elsewhere. Thank you very much for your time.

1. Does your organisation regularly and still monitor water quality in the Ruscombe Brook?

Yes [ ] No [ ]

1(a). If **Yes**, how often is the monitoring done?……………
………………………
……………………………………………………………………………………..
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1(b). If **No**, when was the last time the site was visited and why was the monitoring discontinued?
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2(a). What does the results of the monitoring suggest of the water quality
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………

2(b). If applicable, how does this compare with the present water quality status?
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………

3. Which of the following will best describe the water use?

Drinking [ ] Recreational [ ] Irrigation [ ]

Other, please specify ……………………………………………………………
…………………………………………………………………………………

4. With respect to your criteria of classification, what is the current status of the brook?

Very Good [ ] Good [ ] Fair [ ] Poor [ ] Very poor [ ]

Other, please specify
………………………………………………………………….

5. Are you aware of any past or recent raw sewage discharges into the brook?

5a. If so, on what scale do you perceive this problem? Please tick where appropriate.

Through Combined Sewer Overflows [ ] Sanitary Sewer Overflows [ ]
Other, please specify ……………………………………………………………..
…………………………………………………………………………………
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6. In your view, do you think this pollution has impacted or will potentially deteriorate the water quality and the quality of the river environment?
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7. If the problem is due to municipal combined sewer overflows (CSOs) and/or sanitary sewer overflows (SSOs), could you please mention the location and frequency of discharges causing such impacts, the volume of pollutants discharged, and the constituents discharged; if possible?
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8. What technologies have been used or what measures your organisation have put in place to control these CSOs and SSOs and to help restore water quality in the brook?
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8(b). Do these measures seem to work well and improve the water quality in the brook?
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…….

9(a). In case your organisation is to manage the water quality as a result of this pollution, would you consider (or recommend to the community involved), the possibility of implementing Sustainable Urban Drainage Schemes (SUDS) as a sustainable solution for 'cleaning' the brook?
Yes [ ]; No [ ]

9(b). If so, what SUDS options would you recommend considering?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………

10(a). What, in your view, are the prospects (from biodiversity, public health, economic, engagement of key people and other points of view) of implementing this scheme? (Please attach separate sheets if necessary)
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10(b). What, in your view, are the limitations (including policy perspectives) to implementing a SUDS scheme in the Ruscombe brook? (Please attach separate sheets if necessary)
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13. In your view, please indicate and explain what better alternative management schemes could be employed in restoring or improving water quality in the Ruscombe brook?
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APPENDIX 8

Private Water Supply Regulations 1991: Water Quality Parameters

Parameters	Units Of Measurement	Concentration Or Value Maximum Unless Otherwise Stated
Colour	Mg/l Pt/Co scale	20
Turbidity	FTU	4
Odour (inc. hydrogen sulphide)	Dilution no.	3 at 25°C
Taste	Dilution no.	3 at 25°C
Temperature	°C	25
Hydrogen Ion	pH value	9.5 5.5(min)
Sulphate	mg SO_4/l	250
Magnesium	Mg Mg/l	50
Sodium	Mg Na/l	150
Potassium	mg K/l	12
Nitrite	mg NO_2/l	0.1
Nitrate	mg NO_2/l	50
Ammonia	mg NH_4/l	0.5
Silver	Ug Ag/l	10
Flouride	Ug F/l	1500
Aluminium	Ug Al/l	200
Iron	Ug Fe/l	200
Copper	Ug Cu/l	3000
Manganese	Ug Mn/l	50
Zinc	Ug Zn/l	500
Phosphorus	Ug P/l	2200
Arsenic	Ug As/l	50
Cadium	Ug Cd/l	5
Cyanide	ug CN/l	50
Chromium	Ug Cr/l	50
Mercury	Ug Hg/l	1
Nickel	Ug NI/l	50
Lead	Ug Pb/l	50
Pesticides	ug/l	0.1
Conductivity	uS/cm	1500 at 20°C
Chloride	Mg/Cl/l	400
Calcium	Mg Ca/l	250
Total Hardness	Mg Ca/l	min 60
Alkalinity	mg HCO_3/l	min 30
Total coliforms	number/100ml	0
Faecal coliforms	number/100ml	0
Faecal streptococci	number/100ml	0

APPENDIX 9

SOME PICTURES TAKEN BY THE AUTHOR DURING FIELD RECONNAISANCE

Picture 1: Note the slope of the farmland near (about 10 metres to) the brook. Runoff of animal dung may easily get into the brook.

Picture 2: cropland (just about 7 metres from the brook).

Picture 3: heap of farm manure near one of the springs and just about 20 metres from the brook.

Picture 4: farm manure just at the bank of the brook (less than 2 metres away).