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Investigation and evaluation of sampling at small groundwater sources

Science Group – Air, Land & Water
February 2004

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This report summarises the findings of an assessment of sampling at small groundwater sources, which included a review of the changes in water chemistry within such water supply facilities and a sampling exercise designed to quantify these changes. The information contained within this document is for Environment Agency staff in assessing the suitability of small sources sites for inclusion within the groundwater monitoring network and to assist in the interpretation of monitoring data from these sites.

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EXECUTIVE SUMMARY

Private water supplies represent a valuable source of potential sites for inclusion within the Environment Agency's Groundwater Quality Monitoring Network (GQMN). At these locations, it may be possible to collect samples from a number of points within the water supply system, such as from a storage tank or a tap at some distance from the source. It is important to consider the likely changes in water chemistry within the supply system in order to provide guidance on sampling location and network site selection.

A literature review sought to identify the common design of these water supply systems, and the key factors likely to influence changes in water chemistry. This information was then used to identify six sites at which a sampling exercise would be undertaken. This aimed to evaluate the water chemistry within the supply system, and hence the likely impact of different sample collection points on resultant groundwater quality analyses.

Groundwater at private water supplies is typically abstracted at a borehole/well or from a spring. A water pump may be used to abstract water and to boost water flow through the supply system. The system will consist of a network of pipes, possibly with storage tanks or a pressure vessel. The components of the system may be constructed of a variety of materials including brick/concrete, plastics and metals.

The likely processes that will affect water chemistry within the supply system include:

- Changes in water temperature - affects the solubility of dissolved gases, chemical reaction rates and microbial activity.
- Changes in pressure - affects the solubility of dissolved gases and volatiles.
- Aeration of groundwater - results in the loss of dissolved gases and volatiles from solution and may affect pH and chemical equilibrium. These changes may result in processes of precipitation, sorption and ion exchange.
- Corrosion of construction materials - may result in contaminants, such as metals or components of plastics, entering the water supply system.
- Integrity of the system – corrosion or poor system design may result in the ingress of water from outside the system.

The six sites selected for the groundwater sampling exercise included examples of springs, boreholes, systems with pressure vessels, and a variety of designs and construction materials, including storage tanks and systems with long supply pipework. Water samples were analysed for a range of inorganic and organic substances, and for microbiological indicator parameters.

The significant observations made from the sampling exercise were as follows:

- Changes with time in water chemistry at any one sample collection point were found to be consistent.
- Changes in water temperature and dissolved oxygen were slight and reflected ambient temperatures, water residence times and degree of aeration.
- With the exception of metals, inorganic determinands were not affected by sample collection point. Metals were influenced by construction materials.
- Volatile organics were generally not found within the source groundwaters of these systems and no firm conclusions were made regarding loss of these substances.

- Variable pesticide and bacteria concentrations at some sample locations highlighted the need for a detailed assessment of the integrity of the site, the potential for contamination within the system and the implications of sampling/laboratory errors.
- The presence of a pressure vessel within the system, and the length of the supply system appeared to have little affect on water chemistry.

The use of small groundwater sources for the GQMN should be carefully considered. Reliable information regarding the design and operation of the water supply systems will be required on an ongoing basis in order to ensure that the sample location will provide the data precision required.

In assessing the suitability of a candidate site, the groundwater chemistry must be considered as certain chemistries will be more affected by the water distribution system than others.

In assessing the suitability of a sample collection location, a detailed knowledge of the design of the supply system would be required. The integrity of the system and the potential for contamination from external sources should be determined. The construction materials should be identified, with the likely influence on water chemistry assessed. The type and operation of any groundwater pump and the presence of storage tanks should be such that changes in water temperature, pressure and aeration are minimised.

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1. Introduction

1.1. Background

The Environment Agency has both statutory obligations and non-statutory commitments for the monitoring of groundwater quality in England and Wales. To meet these obligations, and to prepare for the implementation of the Water Framework Directive, the Agency is reviewing and developing the existing Groundwater Quality Monitoring Network (GQMN).

The review of the monitoring network has identified that there are many small groundwater sources that are used for private water supplies. These abstractions potentially represent a large base of sites that can be considered as candidate sites for inclusion into the Agency's GQMN.

These abstractions are often located in rural areas, and the designs of the abstraction point and water supply systems are site specific and highly variable. The supply may be pumped via a rising main from a borehole or well, or it may be gravity fed from a spring. There may also be any number of header and storage tanks, a pressure vessel and delivery pipework of variable length. Furthermore, the materials of construction, the maintenance of the integrity of the system and the existence of any water treatment are also site specific.

Because of the nature of these systems it is believed that changes in water chemistry may occur within the water supply system due to physical, chemical and microbiological processes. At present many sample collection points are at the end of long lengths of delivery pipework, at storage tanks or located after pressure vessels, and as such samples may not be representative of the quality of groundwater, and not necessarily comparable between sites.

The National Groundwater and Contaminated Land Centre, now part of the Science Group commissioned this investigation and evaluation of water quality sampling from small groundwater sources, with the aim of informing and developing effective guidance for the monitoring of small groundwater sources and for candidate site selection.

1.2. Project description

The objectives of the project were:

- to carry out a brief review and assessment of the types, design and use of water supply systems for small groundwater sources;

- to undertake a sampling exercise looking at water quality from different sample collection points within water supply systems from a selected number of sources and types of facilities;

- to evaluate whether the sample collection point influences the recorded groundwater quality and the likely errors that may be introduced; and

- to provide guidance on where groundwater samples should be collected and recommendations for procedures to ensure that reliable and consistent groundwater samples are collected.

1.3. Study methodology

A review was undertaken of relevant studies and reports, which aimed to identify the water quality parameters most likely to change in the water supply system. The causes of the changes in water chemistry were categorised into external and internal system influences together with physical, chemical or biological processes. The review also sought quantified examples of water quality changes within water supply systems.

The range of water supply systems associated with small groundwater sources was identified through a brief review of Agency site records, predominantly those held within the North West Region. The various potential sample collection points within each type of system were identified and evaluated, in order to determine factors that may result in altered groundwater chemistry.

A sampling exercise was undertaken to provide quantified data to supplement the information obtained from the literature review. An initial shortlist was produced of eleven sites from the site characterisation information reviewed from the North West Region, and sites put forward for inclusion within the South West Region and EA Wales. These were selected to cover the range of water supply systems, and sites where a number of potential sampling locations were present. Each of the eleven sites was visited in order to assess their suitability for inclusion within the sampling exercise. The assessment was based on the configuration of the system, site access conditions, and health and safety considerations.

From the shortlist of eleven, six sites were selected for monitoring. The sampling exercise entailed taking up to five samples at each potential sample location within the supply system. Samples were analysed for a suite of determinands specified by the Agency at their own laboratories.

The water quality data were evaluated using simple statistical and comparative techniques. Errors such as those likely to have been introduced during sampling, sample transportation and laboratory analysis were included within the evaluation. The review of the data looked for variations in results between different sample locations, based on an assessment of statistically significant changes in levels of a determinand from one location to the next. Significant changes in data for any single sample location were also assessed, based on changes in water chemistry from one sample time to the next.

2. Water supply systems

2.1 Background

This chapter describes the main components that are typically found within the water supply system associated with small groundwater sources. It is based on an overview of site characterisation records held by the North West Region. The variability of the main components of the supply system (namely the source type, water pump, storage tanks, pressure vessels and feedwater pipework) and the factors that influence water chemistry, are discussed. The typical locations within the supply system from which samples of groundwater can be obtained are also described.

The construction and layout of water supply systems associated with small groundwater sources is known to be highly site specific. These private water supplies are often constructed by the site owner, are designed to meet local needs and may have been adapted over many years.

Section 93 of The Water Industry Act 1991 defines private supplies as any supply of water not provided by a statutorily appointed water undertaker (also referred to as unregulated supplies). The Act places a duty on Local Authorities to ensure that they are informed about the wholesomeness and sufficiency of private water supplies. The Private Water Supply Regulations 1991 provides the requirements for monitoring of private supplies.

The Water Supply (Water Fittings) Regulations 1999 provide requirements for water fittings for regulated supplies provided by a statutory water undertaker. In the UK, there is no legislation setting out minimum requirements for the design of supply systems and water fittings used in private supplies. However, should the design or construction of the supply system be such that the quality of the supply is at risk, then the Local Authority has powers to require improvements to be made.

There are UK guidelines, issued by the Drinking Water Inspectorate and many of the Local Authorities, on safeguarding water quality at the point of use. These guidelines include some design recommendations related to the water supply systems, although they are predominantly concerned with the prevention of contamination of the source and the safe storage of water in tanks. There is further guidance issued by organisations such as the Construction Industry Research and Information Association (CIRIA) on design and maintenance of water supply boreholes.

2.2 Configuration of the supply system

In order to assess the range of water supply systems currently used for small groundwater sources in the UK, a brief review was undertaken of sampling site information held by the Groundwater Department of the Environment Agency, North West Region, in Warrington. This revealed the variation in system design but also confirmed the principle components that would enable the classification of the supply systems into a number of generic types.

The design of water supply systems for small groundwater sources varies from site to site. It depends upon factors such as the type of source, its distance from the point of use, the age of the installation, the intended use of the water and whether there is a requirement for water treatment.

The principal types of supply from small groundwater sources are boreholes, wells and springs. The key components of the water supply system depend upon site-specific factors and will include some or all of the following:

1. Source – the borehole, well or spring from which the groundwater is abstracted.

2. Water pump – systems are either gravity fed or pumped. The water pump may be installed within the borehole/well at the surface or within the supply pipework to assist with water boosting, circulation or transfer.

3. Feedwater pipework – the network of pipes that transfer water between the source and any treatment system, heating system or the point of use.

4. Water storage – storage or header tanks may be utilised to provide a required volume of water and sufficient head of water to maintain pressure within the supply pipework.

5. Pressure control – a consistent pressure may be maintained within the supply pipework by means of a pressure vessel.

6. Level control – typically a float switch will control the level of water within a storage tank by activating the pump when a predetermined 'low' level of water is reached, and deactivating the pump when the 'high' water level is reached. Systems with a pressure vessel have an automatic pressure switch that turns the pump on when the pressure in the system drops.

7. Water treatment – depending upon the quality of the water and the type of contaminant, a water treatment system may be integrated into the supply.

2.3 Source type

Wells and boreholes

The term 'well' is usually applied to the brick-lined sources of larger diameter than boreholes, typically sourcing shallower groundwater. Older wells have usually been hand-dug. Boreholes differ from wells in that they are usually deeper and of narrower diameter, and usually comprise lined or unlined pre-drilled holes. Boreholes are typically constructed with metal or plastic casing and well screen installed within the ground. Some boreholes do not have well screen casing and are left as open holes. Wells may have an internal metal casing installed at a later date to maintain the structural integrity of the source.

In order to ensure longevity of the borehole or well and to minimise contamination of the supply, the construction materials need to be resistant to corrosion by water, substances within the water and corrosive ground conditions. Construction design will vary depending upon the age of the borehole/well, the depth of the groundwater source, the abstraction requirements and the geology. There is generally very limited data on construction design of boreholes and wells at these small groundwater sources.

Springs and catchpits

Spring sources are of simple design and will usually consist of a catchpit constructed within the ground into which the groundwater flows, usually via a pipe.

The design of spring sources is highly variable and is dependent upon construction age, the geology, the surrounding land use at the source and often the intended use of the water. For example, where the source is at some distance from the point of use, located within a rural/agricultural setting and the water is not used for drinking, then contamination of the source may not be of high concern and the design of the spring can be very basic. Conversely where the spring is located close to a settlement where vandalism may be an issue and the water is used for drinking, the construction design is usually more robust in order to ensure that the water does not become contaminated.

Catchpits may be constructed of brick or concrete, and occasionally plastic. Pipework associated with the source, channelling water into and out of the catchpit, may be metal, plastic or clay. Catchpits may be buried or have access at the surface via a metal manhole cover. In rural locations where water is used for agricultural purposes, then the catchpit may have a makeshift cover of metal sheeting or asbestos cement board, or there may be no cover.

As with boreholes/wells, there is generally very poor information on the design of the spring catchpit, although a visual inspection will usually allow the determination of the design. Where several springs are combined into one supply system, it is common for the location of some of the individual spring sources not to be known.

2.4 Water pumps

Boreholes and wells typically have a water pump that transfers water from below ground level to the surface water supply system. In areas of artesian groundwater conditions, where water overflows from the source due to high natural hydraulic pressure, a water pump will not necessarily be required. Springs more commonly supply gravity fed systems, although there may be a water pump at some point within the system to maintain water flow, or to transfer water to another level for example within a house.

The most common types of pump used in boreholes are submersible, located below the water table towards the base of the installation. Surface pumps are sited at ground level close to the top of the borehole or well. Table 1 summarises the most common types of groundwater pump. Suction lift pumps are usually only capable of lifting water from around 7m below ground level, and are therefore used in shallow boreholes and wells. Positive displacement pumps are capable of lifting water from significantly greater depths.

Water supply systems may also have in-line pumps used to boost transfer of water. Such pumps may also have pressuriser attachments to increase water pressure within the feedwater pipework.

Table 1: Common groundwater pumps

Type	Pump mechanism	Description
Positive Displacement Pumps	Centrifugal submersible	A rotating impeller, or series of impellers, located within the pump cylinder causes water to be accelerated outwards and then upwards through the pump.
	Progressive cavity (helical rotor)	A corkscrew shaped rotor inside a sleeve rotates, causing water to be trapped within the cavities of the rotor and lifting it in an upward direction through the pump.
	Gear drive	A pair of meshing gears is rotated within the pump causing water to be trapped between the teeth of the gears and lifted.
	Piston	A piston moves back and forth inside a two-valve cylinder, allowing water to pass through the valves and upwards.
Suction Lift Pumps	Surface centrifugal	A rotating impeller located above ground creates a vacuum within the rising main causing the groundwater to rise. The water then passes through the pump where it is accelerated outwards and upwards through the supply system.
	Surface piston	As the piston is pulled upwards, low pressure is created in the cylinder (suction) causing water to move upwards through the valves.
	Diaphragm and pitcher	A flexible diaphragm between two valves is pumped back and forth, usually by a lever.

2.5 Pressure vessels and storage tanks

Pressure vessels are used to maintain pressure within the feedwater pipework. They can range in capacity from less than 10 to over 5000 litres. Pressure vessels are constructed of metal with an internal diaphragm that may be fixed or replaceable. The diaphragm separates air from the water allowing the system to be pressurised. Most systems are set to operate at 1.4 to 2.8 bars (20 to 40 psi). When water is used, the pressure in the system drops and the pressure switch activates the pump, filling the pressure vessel to the required pressure again.

The design of storage and header tanks is highly variable, suiting the needs of each individual site. Storage can be in single or multiple tanks, which can be constructed of concrete, metal (galvanised iron and steel, copper), cement products, plastic or fibreglass. Header tanks located within lofts are normally of lighter weight metal or plastic construction.

2.6 Feedwater pipework

The feedwater pipework is variable in length and construction materials, depending upon the age of the system, local geographical setting and the intended water use.

Feedwater pipework associated with boreholes or wells may be located above and/or below ground. The pipework is closed, transferring water between the headworks of the borehole, perhaps via a pressure vessel to storage and/or header tanks before the point of use. The pipework may be constructed of metal (steel, iron, galvanised metal, copper, lead) or plastic.

Feedwater pipework associated with springs may be located above and/or below ground. It is not uncommon for there to be sections of open pipework such as concrete or clay troughs near to the source in addition to metal and plastic pipes.

2.7 Water treatment

Within the water supply system, water treatment facilities may be present as an individual system or as a combination of systems. Typical water treatment methods applied in the UK include those summarised in Table 2.

Table 2: Water treatment methods

Method	Description
Sediment filter	For removal of suspended particles, coarse sediment filters (screens) are often located at the groundwater abstraction point, with fine particle filters used closer to the point of use.
Activated carbon	For removal of chlorine and organics, resulting in improved taste and odour
Ceramic filter	For removal of very fine suspended particles and bacteria, these are typically used at the point of use.
Ultra violet	UV disinfection destroys bacteria, moulds, algae and viruses. These are usually located close to the point of water storage or use.
Reverse osmosis	This consists of a membrane and storage tank and will remove heavy metals, bacteria and viruses. These are usually located close to the point of water storage or use.
Ion exchange resins	Ion exchange resins are designed to remove hardness minerals from water. These water softeners typically consist of a resin (ion exchange) tank and a brine tank that regenerates the resin. Nitrate selective resins are used to remove nitrate and sulphates.

As this study is aimed at identifying effects of supply systems on raw water quality, the effect of water treatment is not considered further.

2.8 Potential sample locations

Possible locations for sample collection at any small groundwater source are dictated by the construction and layout of the source and supply system, i.e. it is not always possible to sample the source itself.

Potential sample locations within the water supply system are listed in Table 3. Obviously, any in-line water treatment system will result in altered water chemistry beyond the point of treatment and will no longer reflect raw groundwater chemistry.

Table 3: Potential sample locations within the water supply system

Location	Potential sample locations
Spring source	Inlet pipe to the catchpit Water standing within the catchpit
Borehole/well source	Tap on the borehole headworks where there is a submersible pump Pump/bail from an open borehole
Pressure vessel	Tap on the inlet to the pressure vessel Tap on the outlet of the pressure vessel
Storage/header tanks	Inlet pipe or valve to the tank Water standing within the tank
Feedwater pipework	Open troughs or pipes Taps on the supply pipework Point of water use

3. Literature review

3.1 Introduction

The aims of the literature review were to determine the likely changes in water chemistry that may be attributed to the configuration/construction of the water supply system, and assess whether the water chemistry is likely to be biased by the choice of sample location. There is very little published literature of direct relevance to small groundwater sources, and hence literature relating to source water monitoring, compliance monitoring and monitoring within larger supply systems was included within the review.

This chapter presents the aims and methodology for the literature review and details the findings. The processes within the system that will initiate a change in water chemistry are defined and examples of the resulting changes given. The specific effects of groundwater pumps are detailed, as there is considerable information on this subject. Corrosion of construction materials and microbiological activity within the system are also discussed. Finally, the likely implications of poor system integrity, allowing contamination of water from external sources, are reviewed.

3.2 Aims of the literature review

The aims of the literature review were as follows:

1. To review existing published information on the effect of water supply systems on water chemistry. The review has sought information on water supply systems associated with small groundwater sources, such as private drinking water supplies. Information specific to this subject was not found and in the absence of this, pertinent general information relating to groundwater monitoring and large supplies has been included in the review.

2. To review the suite of analysis for the water samples to be collected as part of the sampling exercise. The chosen suite was to include parameters that may be affected by the supply system. Consideration was to be given to other determinands that may be of more general interest to external parties.

3. To consider changes in water chemistry that may occur during and after sampling, in order that such factors can be minimised and their implications considered in the evaluation of monitoring data obtained from the sampling exercise.

3.3 Methodology

The following information sources were included within the review:

1. A keyword search of the DialogWeb and the British Library online databases was undertaken. These databases contain references to worldwide literature on every aspect of water, wastewater and the aquatic environment. The search included the following subjects: groundwater; wastewater treatment; resource development and management; water sampling and analysis; environmental management; toxicology; water treatment; river management; tidal waters; sewerage systems,

and aquatic toxicology. The reference sources include journals, conference proceedings, reports and books.

2. Internet sites including those of the US Environmental Protection Agency (USEPA), the World Health Organisation, the UK Drinking Water Inspectorate and British Standards were accessed for relevant information.

3. The work of the following UK research organisations and institutions currently working in this field were also included:

- the Chartered Institute of Environmental Health (CIEH)
- the Chartered Institute of Water and Environmental Management (CIWEM)
- Water Engineering and Development Centre (WEDC, Loughborough University)
- Centre for Research into Environment and Health (CREH, Aberystwyth University)
- Robens’ Centre for Public and Environmental Health (University of Surrey)

3.4 Overview of literature

The literature review quickly illustrated that there was limited published information reporting changes in water chemistry in the supply systems associated with small groundwater sources. Where such information does exist, it predominantly relates to microbiological contamination of drinking water supplies.

The criteria for inclusion of information within the review was therefore broadened to include large water supply systems, the monitoring of changes in water chemistry at the point of abstraction and the assessment of water chemistry at the point of use.

3.4.1 Groundwater quality monitoring

The changes in groundwater chemistry during the monitoring and sampling from observation boreholes are well documented. Such changes occur due to the borehole design and installation, borehole development, sampling protocols, sample preservation and transportation. Within the UK and the USA there are published guidelines describing measures that can be taken to minimise these changes, including British Standards, Environment Agency Protocols and USEPA Standard Operating Procedures.

Changes in water chemistry that occur during the sampling of groundwater monitoring boreholes are likely to occur at any stage of the water supply system. The changes are caused by temperature increases, aeration, gas exchange, degassing and sorption effects that in turn affect other chemical and microbiological processes.

Changes in groundwater chemistry are also known to be caused by reactions between groundwater and the construction materials of the borehole installation and the sampling equipment. These reactions will also occur between the water and the construction materials of the supply system and will include processes of chemical attack (corrosion), microbial colonisation, precipitation/dissolution, sorption/desorption and leaching effects.

Short and long term temporal variations in source water chemistry have also been studied. Particularly rapid changes in source water chemistry have been identified due to heavy rainfall and flooding. These changes can then be seen in the supply systems depending upon the water residence time within the system.

The determinands included within source water monitoring programmes vary depending upon the purpose of the monitoring exercise. For example, monitoring being undertaken to evaluate potential use as a public supply will look at a large range of water quality indicator parameters, whereas monitoring a known contamination issue will concentrate on specific relevant determinands.

3.4.2 Compliance monitoring

Compliance monitoring is undertaken to demonstrate the quality of water at the point of use. In the UK, for private drinking water supplies from small sources compliance monitoring is usually the only monitoring that is routinely undertaken.

Published UK and US guidelines on sampling from private drinking water abstractions for compliance monitoring include some measures to minimise changes in water quality due to sampling. These changes typically relate to microbial contamination at the sampling location and the effect of aerators on sample taps.

The suite of analysis for compliance monitoring is typically controlled by regulatory requirements and will include determinands that affect the aesthetic quality of drinking water supplies (taste, odour, turbidity, hardness) as well as the human health criteria of wholesomeness (microbiological and chemical contamination with minimum criteria for hardness and alkalinity).

3.4.3 Performance monitoring of supply systems

Monitoring within the supply system is typically undertaken for two reasons – to assess the performance of the system and to investigate contamination of the system.

Performance monitoring is undertaken routinely on larger water systems in order to identify changes in water chemistry. These changes may be a result of failures in the operation of treatment systems, failures of infrastructure that may lead to contamination of the supply and the assessment of water quality at critical points within the supply system such as dead end and low pressure points. Performance monitoring will also determine seasonal variations in water quality and can be used as an on-going assessment of the quality of the source.

The published literature provides guidance on the analytical determinands that should be included within performance monitoring, the frequency of sampling and the location of sample locations within the supply system. For large systems the general approach is to zone the system and to sample from both fixed and random sample locations for a general suite of indicator determinands that reflect microbiological quality, chemicals of known human health risk, aesthetic parameters and parameters that control operational efficiency.

Where there is a non-compliance with permitted water quality criteria at the point of use, monitoring at locations within the supply system may be undertaken to determine the location of the source of contamination and hence identify the cause.

3.4.4 Processes initiating change

There are physical processes acting on water supply systems that may result in a change in water chemistry. These processes include:

- water temperature changes;
- water pressure changes;
- aeration of the water (with associated temperature and pressure changes);
- interaction of the water with the infrastructure of the supply system;
- changes in water chemistry at source, or ingress of water from another source.

These processes are inter-related and complex and can result in a change in water quality. Figure 1 presents a simplified diagram of the inter-relationship of some of these processes.

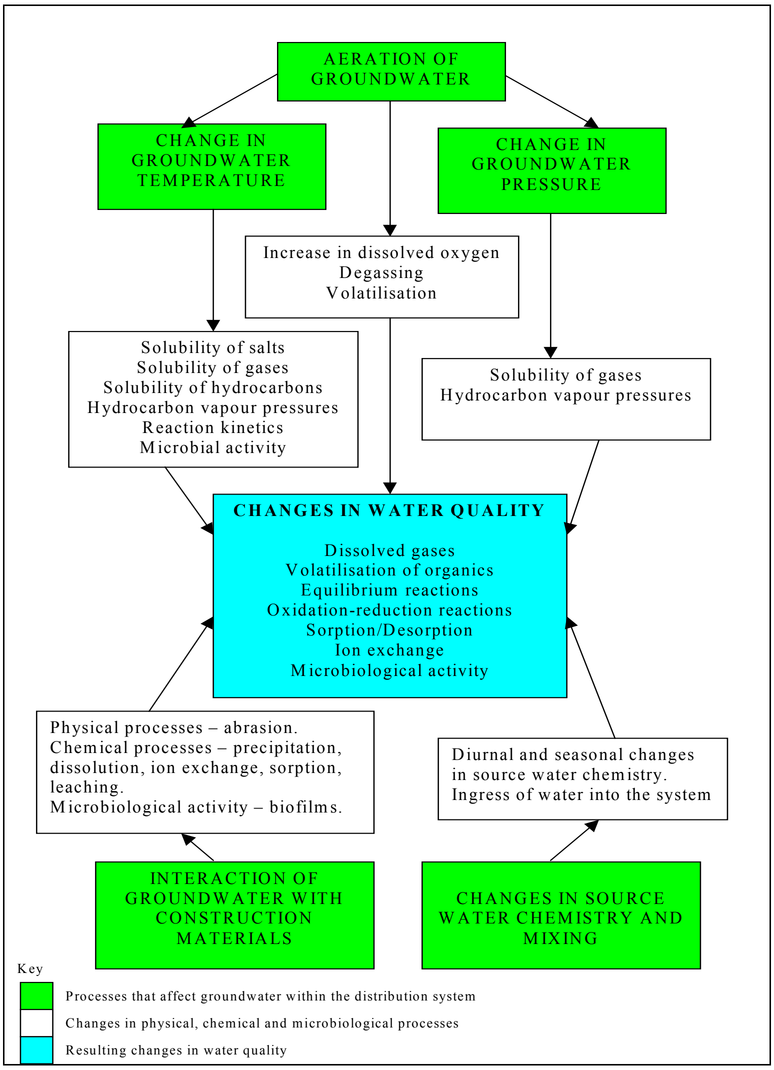


Figure 1: Simplified relationship of processes affecting water chemistry in water supply systems

3.5 Physical processes

3.5.1 Changes in water temperature

As water passes from the source through a piped network system, possibly via storage tanks, to the point of use, the temperature of the water will generally rise. Groundwater temperatures typically range from 10°C to 12°C, with shallow groundwater subject to seasonal temperature variations. It might be expected that at the point of use the water temperature will have risen by a few degrees, even up to ambient temperatures of greater than 20°C, depending upon the residence time of water within different sections of the system. Alternatively, water temperatures can decrease, for example within buried water pipes during winter months when the ground is frozen, or in storage tanks in rooms that are not heated. In these circumstances, the water temperature can approach 0°C. Temperature changes are therefore likely to occur at the following locations:

- the pump within boreholes or wells;
- system booster pumps within the distribution system;
- the catchpit for spring supplies;
- water storage/header tanks;
- within the supply system pipework as it passes through varying temperature environments (from below ground to within heated buildings).

Paul and Puls (1992) demonstrated that the type and flow rate of groundwater pumps can affect the temperature of groundwater as it is pumped from a borehole. Bladder pumps had the least influence on groundwater temperature, however temperatures were still observed to rise from 13°C to 24°C. Submersible pumps were observed to increase groundwater temperatures a further 5°C above temperatures from bladder pumps. Higher temperatures were also observed when operating submersible pumps at lower flow rates. Figure 2, presenting data from Paul and Puls (1992), shows the marked change in recorded groundwater temperature with pump type and pump speed.

Submersible pumps are commonly used in boreholes associated with small groundwater sources. From the above data it can be seen that the speed of the pump (i.e. the groundwater flow rate) can affect water temperature, with higher flow rates giving rise to high water temperatures. Also, the potential effect of groundwater pumps intermittently switching on and off can be seen, as would occur with pressure valves and level devices regulating flow. Under these circumstances, it is possible that pumped water temperature will rise by varying degrees, depending upon the operation and type of pump.

An increase in water temperature is likely to have the following effects:

- a decrease in solubility of gases;
- an increase in gas vapour pressures;
- the increase in solubility of most salts;
- a decrease in the solubility of carbonates;
- an increase in solubility of hydrocarbons;
- a change in reaction kinetics.

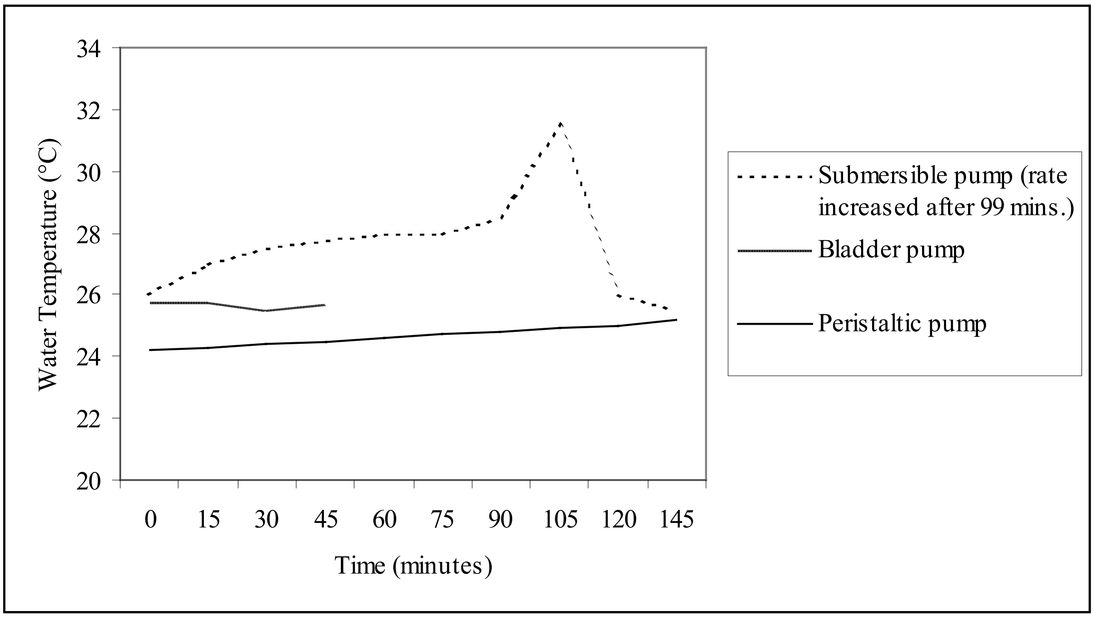


Figure 2: Equilibration of temperature values during purging and sampling (Source: Paul and Puls, 1992).

3.5.2 Changes in pressure

Changes in pressure within the water supply system are likely to occur at the following locations:

- the pump within boreholes or wells;
- other system booster pumps within the water supply system;
- the catchpit for spring supplies;
- water storage/header tanks;
- pressure vessels;
- points within the supply system where there are leaks;
- sampling locations;
- a general pressure drop across the entire system.

These will generally lead to a decrease in pressure, with the exception of pressure tanks where water will be subjected to an increase in pressure. The results of the literature review have not permitted quantification of changes in pressure within such systems.

A decrease in pressure, within a closed water system is likely to have the following effects:

- A decrease in the solubility of gases;
- An increase in gas vapour pressure.

3.5.3 Aeration processes

Aeration of groundwater (exposure to air) is likely to also result in changes in temperature and pressure. Groundwater generally has a low dissolved oxygen content and this will increase with aeration. Degassing of dissolved gases and volatilisation of volatile and semi-volatile organics will also occur. Aeration of groundwater within the water supply system and is likely to occur at the following locations:

- the pump for boreholes and wells;
- the catchpit for spring supplies;
- water storage/header tanks;
- sampling locations.

The effects of aeration, changes in temperature and pressure have been previously discussed.

3.5.4 Effect of the groundwater pump type

There are several types of pump that may be used to abstract and transfer water through the supply system. The method by which they operate can result in pressure changes, temperature increases and aeration of the water. Table 4 is taken from Karklins (1996) and summarises the main types of groundwater pumps and their relative effect on chemical parameters that are sensitive to such physical changes.

Table 4: Groundwater pump type and water sample alteration

Device		**Degree of alteration of water chemistry**	**Comments**
Positive Displacement Pumps	Centrifugal submersible	Low	Higher pumping rates result in increased water turbulence and pressure changes
	Progressive cavity (helical rotor)	Low to moderate	
	Gear drive	Probably low to moderate	Pressure changes due to cavitation from pump gears
	Piston	Variable	Action of the piston creates pressure changes
Suction Pumps	Surface centrifugal	Very high	The vacuum applied to the water causes degassing
	Surface piston	Variable	Action of the piston creates pressure changes

3.6 Chemical processes

3.6.1 Solubility of dissolved gases

The solubility of dissolved gases is an important characteristic that is greatly affected by temperature and pressure changes.

In general, gases are less soluble in waters of higher temperature as shown in the solubility data of Table 5. Rising temperatures will therefore result in a reduction in dissolved gas concentrations.

Table 5: Solubility of dissolved gases as a function of temperature

Temperature (°C)	Oxygen solubility (mg/l)	Carbon Dioxide solubility (mg/l)	Methane solubility (mg/l)	Nitrogen solubility (mg/l)
5	12.8	2774	341	20.4
35	7.1	1105	17.3	11.6

Gas solubility is also directly proportional to gas pressure. A decrease in pressure results in a decrease in the solubility of dissolved gases in water, as shown in Table 6. Pressure decreases will therefore result in an increase in dissolved gas concentrations.

Table 6: **Solubility of dissolved oxygen as a function of pressure**

Pressure (mm Hg)	Oxygen solubility (mg/100g water)
0	0
200	1.1
400	2.2
600	3.3
800	4.3

The change in concentration of dissolved oxygen in water is an indication of the degree of aeration and degassing, produced through changes in pressure, temperature and exposure to the air.

Paul and Puls (1992) reported changes in dissolved oxygen concentrations with different types of groundwater sampling pump. Peristaltic pumps subject water samples to strong negative pressures that cause degassing, whereas bladder pumps only allow the water to come into contact with the bladder and hence aeration is minimised. Figure 3 presents data from Paul and Puls (1992) and illustrates the variation in dissolved oxygen concentrations with pump type at the same monitoring location.

Submersible pumps, commonly utilised in boreholes in private water supplies are likely to result in an initial decrease in dissolved oxygen concentrations in water as the pump is started. This is due to changes in pressure and temperature causing degassing of dissolved oxygen. The potential implications of groundwater pumps switching on and off intermittently can be seen in this example, where water with variable dissolved oxygen concentrations may be pumped through the supply system.

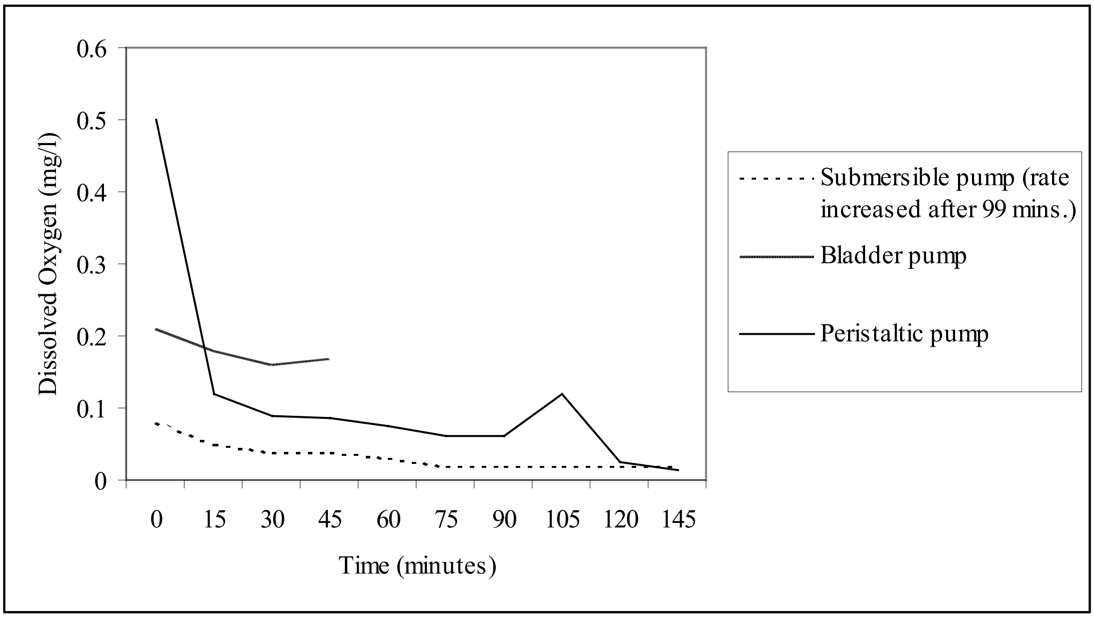


Figure 3: Equilibration of dissolved oxygen during purging and sampling (Source: Paul and Puls, 1992).

3.6.2 Volatilisation

Volatilisation is a process that is driven by changes in temperature and pressure. As temperatures increase from 5°C up to 30°C, the solubility of hydrocarbons increases typically 2 to 3 times.

Vance (2002) reports percentage increases in vapour pressure in the region of 500% for volatile organics such as benzene, ethylbenzene, toluene, trichloroethane and tetrachloroethene, as a result of temperature increases from 5°C to 35°C.

Barker and Dickhout (1988) carried out laboratory studies to assess the loss of volatile organics from groundwater charged with dissolved gases (methane and carbon dioxide). The study utilised different types of groundwater pumps producing varying degrees of pressure change. The study determined that degassing of methane and carbon dioxide (initiated due to pressure changes through the use of a suction lift pump) resulted in the reduction of tetrachloroethane concentrations by 37% and trichloroethene by 25%.

Baerg *et.al.* (1992) carried out similar studies looking at water that was not charged with dissolved gases. Their studies revealed that reductions of tetrachloroethane and trichloroethene concentrations by 12% and 7% respectively. Baerg et al (1992 concluded that a decrease in pressure resulting in degassing of dissolved gases within the water therefore significantly increases the loss of volatile compounds.

Karklins (1996) provided a table (reproduced as Table 7) of volatile organic compounds and their “relative potential” for volatilisation from water samples.

Table 7: **Potential for substances to volatilise from water**

Substance	Potential for volatilising from water
Acetone	Low
Ammonia	Moderate
Anthracene	Low
Atrazine	Low
Benzene	High
Benzo (a) pyrene	Moderate
Bromodichloromethane	High
Carbon tetrachloride	High
Chloroethane	Moderate
Chloroform	High
Dichlorobenzene	High
Dioxins	High
Endrin	Low
Ethylbenzene	High
Fluoride	Low
Heptachlor	High
Lindane	Low
Mercury	High
Methylisobutylketone+ (MIK)	Moderate
Methylethyleketone* (MEK)	Low
Phenol	Low
PCBs	High
Tetrachloroethylene	High
Toluene	High
Trichloroethylene	High
Vinyl chloride	High
Xylene	High
+ Now called 4-Methyl-2-pentanone * Now called 2-Butanone	

3.6.3 Chemical equilibrium

Chemical equilibria are affected by changes in dissolved gas concentrations. This effect is most noticeable for the carbonate system equilibria, whereby aeration and degassing can significantly affect water pH.

According to Shaver (1993), the degassing of dissolved carbon dioxide from groundwater changes the ratios of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) in solution. The change in alkalinity of the water may cause a subsequent rise in pH. This is expressed in the carbonate equilibrium equations as follows.

Carbon dioxide gas dissolves to form aqueous carbon dioxide:

$$CO_2\,(g) \rightleftharpoons CO_2\,(aq)$$

Equilibrium is then established between aqueous carbon dioxide and carbonic acid:

$CO_2\ (aq) + H_2O\ (l \rightleftharpoons H_2CO_3\ (aq)$

Carbonic acid will then dissociate to form the carbonate ion in two steps:

$$H_2CO_3\ (aq) \rightleftharpoons H^+ + HCO_3^-$$
$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

Degassing will result in a reduction in aqueous carbon dioxide and a shift in the equilibrium away from the dissociation of carbonic acid and the production of hydrogen ions.

Shaver (1993) reports on microbial respiration in groundwaters and the production of carbon dioxide. The resulting increase in aqueous carbon dioxide concentrations in groundwater can lower the pH and increase bicarbonate alkalinity. This is due to the increase in formation of aqueous carbon dioxide driving the dissociation of carbonic acid.

Nielsen and Yeates (1985) assessed the effects of pressure reduction associated with the intricate valve mechanisms of piston pumps. The study confirmed that changes in pH occur following the degassing of carbon dioxide from solution.

3.6.4 Oxidation and reduction reactions

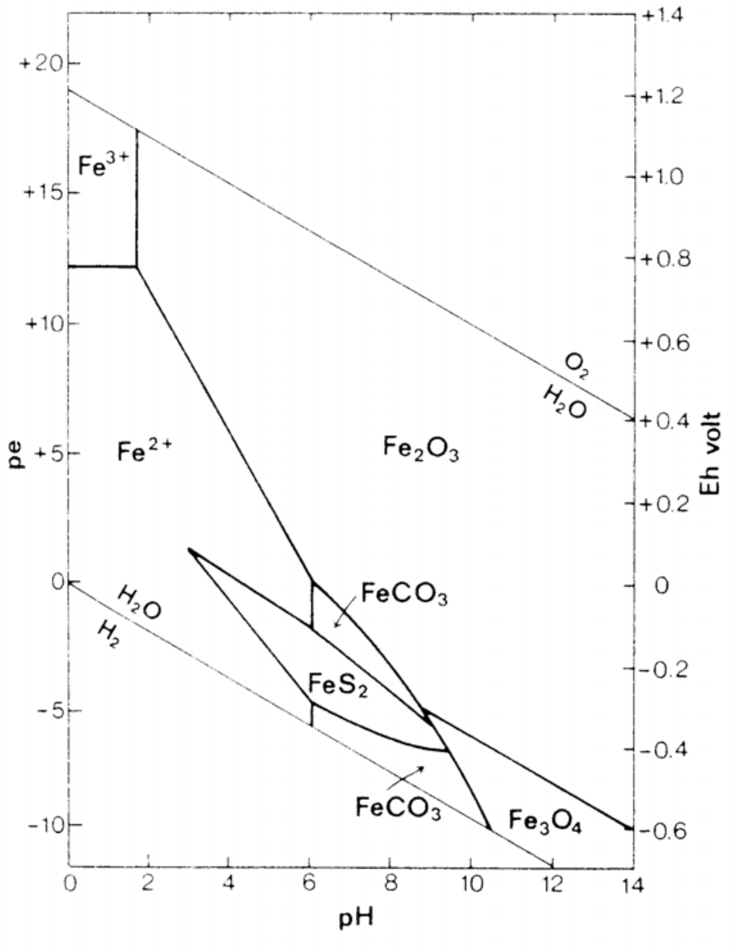
Oxidation reactions in water will consume dissolved oxygen. Changes in dissolved oxygen concentrations, which may result from aeration of the water or a change in microbial activity, will therefore drive these reactions. The following are sensitive to changes in oxidation state:

- Metals – oxidation of reduced metals such as iron and manganese;
- Inorganic nitrogen compounds – oxidation of ammonium to nitrate (nitrification);
- Inorganic sulphur compounds – oxidation of sulphide to sulphate;
- Organic material - oxidation producing intermediary compounds and ultimately releasing carbon dioxide.

The following are sensitive reduction reactions that commonly occur in groundwaters:

- Metals – reduction of oxidised metals such as iron and manganese;
- Inorganic nitrogen compounds – reduction of nitrate to nitrite (denitrification);
- Inorganic sulphur compounds – reduction of sulphate to sulphide;
- Organic material – methane fermentation.

Vance (2002) reports that iron is the dominant species that buffers oxidation reactions in groundwater. Also that in some organic rich groundwaters, total organic carbon can equal iron in its capacity to buffer these reactions. The Redox potential (Eh) and pH of groundwater will control the speciation of many substances. On oxidation metals such as iron and manganese may precipitate as metal oxides. This effect is presented in Eh-pH diagrams, for example for iron, Figure 4 shows that water in contact with air will have an Eh in range of 0.35 to 0.50 volts. Oxidation will convert soluble ferrous iron (Fe^{2+}) to insoluble ferric iron (Fe^{3+}), which precipitates as ferric hydroxide ($Fe(OH)_3$).



Taken from: Appelo and Postma. Geochemistry, Groundwater and Pollution (1994)

Figure 4: Eh-pH diagram for iron species

Metal precipitates may form coatings of metal oxides on construction materials or may flocculate increasing suspended solids. These metal oxide coatings and increases in suspended solids can increase sorption processes.

3.6.5 Sorption effects and ion exchange

Both inorganic and organic species can be subject to sorption. There are two levels at which sorption of compounds within groundwater will occur:

- sorption onto suspended solids;
- sorption directly onto the construction materials of the supply system, or coatings that have formed on the construction materials.

The effects of sorption on construction materials of supply systems are considered in more detail in Section 3.8. Many sorbed ions are not permanently sorbed but can exchange for other ions in solution. The chemical nature/strength of bond of the sorbed ions depends upon the concentration of ions in solution, and hence any changes in water chemistry passing through a supply system can result in ion exchange due to a change in ionic strength. This can lead to renewed dissolution and precipitation throughout a system.

3.6.6 Reaction kinetics

The rate of chemical reactions increases with an increase in water temperature. This will result in a more rapid production of the end product of non-reversible reactions and equilibrium for reversible reactions.

Parker and Krenkel (1969) reported an approximate doubling of the rate of chemical change with an increase in temperature of 10°C.

3.7 Microbial activity

Bacteria have a narrow temperature range in which they experience maximum growth and metabolic activity. Water temperatures below 5°C tend to inhibit microbial activity, while activity is enhanced at temperatures ranging from 20°C to 35°C when, if other conditions are also favourable, populations of bacteria can double their number in a very short time period.

The bacteriological quality of water will deteriorate within a supply system if the water has significant assimilible organic carbon or ammonia concentrations due to increased microbial populations. The World Health Organisation (1993) cite an organic carbon content of 0.25mg/l and a water temperature above 20°C as requiring treatment to remove nuisance bacteria, however it should be noted that groundwater is normally in the order of 10°C.

Many oxidation and reduction reactions are promoted by the activity of bacteria. Sulphate reducing bacteria convert sulphate to sulphide, whilst other bacteria cause oxidation of sulphide to sulphate. Nitrifying bacteria oxidise nitrogen in the form of ammonia to nitrite and nitrate.

Rates of hydrocarbon and chlorinated solvent biodegradation may double for every 10 degrees increase in temperature over the temperature range between 5 and 25°C, due to increased microbial populations.

3.8 Interaction with construction materials

The interaction and/or reaction of water with construction materials used for the supply system can affect the chemistry of the water. These effects may be due to:

1. Physical process of degradation or corrosion of the construction materials (such as abrasion).
2. The leaching of compounds from the construction materials.
3. The sorption (both absorption but predominantly adsorption) and ion exchange of compounds from the groundwater and possible later desorption due to changes in water chemistry.
4. Redox reactions.
5. Microbial action.

The materials used in the construction of water supply systems are varied and likely to include:

- concrete and cement (including asbestos cement);

- bricks and mortar;
- metals - stainless steel, galvanised steel, carbon steel, iron, lead, copper and brass;
- plastics - rigid materials such as PVC, HDPE, fibreglass and PTFE;
- plastics – flexible materials such as uPVC, polypropylene, polyethylene, neoprene.

The effect of construction materials on supply systems has been studied in relation to groundwater source monitoring and large supply systems. The effects can be significant and difficult to predict and will be governed by the source water chemistry, the volume of water passing through the system and residence time (hence the dilution effects).

The impact of corrosion on water quality within supply systems is due to the addition of corrosion products to the water, and the potential for a breach of the integrity of the system allowing ingress and mixing of water from another source and exposure to air.

3.8.1 Metal corrosion

Metal corrosion is an oxidation/reduction reaction that occurs where an electrolytic field is established between metals in solution and a solid metal surface. The majority of metals will corrode, the extent to which this occurs depends upon the characteristics of the solid metal, the water and the surrounding environment.

For example, water with high concentrations of sodium and chloride has increased conductivity, and this accelerates corrosion. Hard waters are less likely to cause corrosion, and scaling of the pipes will act as a physical barrier also in these instances. The other factors that influence corrosion include:

- low pH, which increases the dissolution of metals from the pipework;
- high water temperatures resulting in increased chemical reaction rates;
- high water flow rates causing increased physical abrasion;
- the presence of physical abrasives such as suspended solids or sand.

The World Health Organisation (1997) reports the following conditions under which corrosion of metal is most likely to occur:

- copper - corrosion occurs at pH values below 6.5 and hardness of less than 60mg/l, pitting at carbon dioxide concentrations over 5mg/l and high dissolved oxygen levels.

- lead – corrosion generally occurs in waters of low pH and low alkalinity. The World Health Organisation advises pH is maintained between 8 and 8.5 in lead pipes.

The Environment Agency (2000) study on the effects of ground contamination on building materials also indicates that corrosion of metal will occur under the following conditions:

- stainless Steel – corrosion is dependent upon chloride content but generally will not occur below 200mg/l chloride.
- zinc galvanising – corroded by salts and acids.

In water supply systems, corrosion of metal pipes causes an increase in dissolved metal concentrations in the water within the system. The determinands of usual interest in identifying the results of corrosion include the following metals:

- iron, zinc, nickel and chromium from steel pipework;
- copper;
- lead.

3.8.2 Concrete and cement deterioration

Concrete, cement, mortar and asbestos building materials can be used for the construction of catchpits and wells, holding tanks and pipework within water supply systems. The deterioration of concrete and cement will arise from abrasive processes and from chemical attack.

Abrasive processes are likely to arise from suspended solids and sand within the supply system. Chemical corrosion of concrete/cement products may occur through processes of hydrolysis, ion exchange reactions between calcium in hydroxide form and ions in solution and expansive reactions occurring as a result of salt crystallisation. Chemical corrosion of cement occurs through reaction with acid solutions, sulphates, chlorides, magnesium, ammonium and chromium. Organic compounds generally do not affect concrete, although lubricating oils that contain vegetable oils can cause gradual surface degradation.

The World Health Organisation (1993) discusses the aggressiveness of a water to cement in terms of the Langelier index (a measure of potential precipitation or dissolution of calcium carbonate) and states that a pH of 8.5 or greater may be necessary to control cement corrosion (in aggressive environments).

Concrete and cement are also vulnerable to microbial attack where anaerobic and aerobic cycles result in the proliferation of sulphate reducing bacteria.

3.8.3 Plastic corrosion

Plastic pipes and products are used ubiquitously in supply systems for small groundwater sources and are considered to be ‘relatively inert’ and robust. They are predominantly manufactured from polyvinyl chloride (PVC) and polyethylene.

The corrosion of plastics occurs through the degradation of their polymeric constituents, loss of plasticisers and other additives that change the physical properties of the material. The main deterioration processes in plastic corrosion are outlined in the Environment Agency report on the effects of ground contamination on building materials (Environment Agency, 2000). These are summarised as:

- polymer degradation through exposure to sunlight, heat, moisture and chemical agents;
- solvation through the diffusion of solvent molecules;
- environmental stress cracking that can be brought about by alcohols, soap and mechanical stress;
- microbial degradation;
- corrosion by gross hydrocarbon contamination.

The deterioration of plastics may result in a change in water chemistry, for example through the leaching of plasticisers into the water supply. Furthermore, deterioration will have implications for the integrity of the supply system, creating risks of contamination from external sources.

A review of plastic pipe performance is given in Environment Agency (2000) report. An example of plastic deterioration is seen in instances of severe corrosion associated with gross contamination by hydrocarbons such as aviation fuel or petrol.

3.8.4 Sorption and ion exchange

Inorganic and organic species can be absorbed or adsorbed onto the surfaces of construction materials, or onto coatings (precipitates or biofilms) that have formed on the construction materials. Chemicals within the construction materials themselves can desorb (leach) into the water resulting in ‘contamination’. Furthermore, species that have been sorbed can, due to a change in water chemistry, become desorbed again (ion exchange).

Parker *et.al.* (1992) and Nielsen and Yeates (1985) have evaluated the relative inertness of various materials that are used in the construction of water supply systems. ‘Inertness’ is defined as the ability to absorb or leach contaminants and the resistance to chemical reaction and degradation. Table 8 provides a list of materials in order of inertness.

Table 8: **Sorption effect – ‘relative inertness’**

Relative inertness	Rigid materials	Flexible materials
Most inert	PTFE (Teflon)	PTFE (Teflon)
↓	Stainless steel 316	Polypropylene
	Stainless steel 304	Flexible PVC
	PVC	Viton rubber
	Low carbon steel	Polyethylene
	Galvanised steel	Tygon rubber
	Carbon steel	Silicone/Neoprene
Least inert	Brass	

The compounds most susceptible to sorption processes are volatile organic carbons (VOCs), dissolved metals, semi- and non-volatile organic carbon and pesticides. The studies have shown that sorption occurs rapidly, within 5 to 10 minutes of exposure for the least inert materials such as silicone rubber.

Table 9 is taken from Barcelona *et.al.* (1985) and illustrates the loss of volatile solvents (a mixture of chloroform, trichloromethane, tetrachloroethane and tetrachloroethene) from water through absorption onto different types of plastic.

Table 9: Percentage loss table for various tubing materials and diameters

Tube diameter	Teflon	Polypropylene	Polyethylene	uPVC	Silicon rubber	Residence time (mins)
1/4"	4%	6%	10%	14%	15%	4.5
3/8"	1%	2%	3%	4%	4%	12.0
1/2"	1%	1%	1%	2%	2%	19.5

3.8.5 Biofilms and microbial corrosion

Biofilms are colonies of micro-organisms that can occur as surface coverings, often in multiple layers, or as thin patches within water supply systems, e.g. on the walls of containers or pipes. Biofilms can also occur on sediment or on suspended particles.

Biofilms can form in groundwater boreholes, wells or springs due to improper construction. They can clog the surrounding area and create dead zones within the well, thus affecting the quantity and quality of water entering the supply system. The biofilm has the effect of forming a micro-zone of low pH or high concentrations of corrosive ions. This acts as a media for the oxidation processes, removing the products of corrosion and affecting the structure of surfaces within the supply system.

Flemming (2002) has studied the organisms that colonise biofilms and has identified the following impacts relevant to water quality within supply systems:

- contamination of water producing elevated colony forming unit (cfu) numbers in water samples taken for analysis;
- development of a biomass that may result in nutrient leaching;
- provision of habitats for bacteria, viruses, fungi etc. therefore increasing microbial activity;
- initiation of microbially influenced corrosion; and
- increase in pressure drop due to surface roughness.

The most significant bacteria involved with corrosion are the sulphate reducing and iron bacteria (World Health Organisation, 1993). Cast iron water products in particular are susceptible to corrosion by sulphate reducing bacteria. Fischer (1988) has shown that 6mm thick cast iron pipes can become perforated due to microbial corrosion within 4 years.

3.9 Integrity of the supply system

3.9.1 Ingress of water into the supply system

The ingress of water into the supply system has the potential to introduce contaminants and dilute the existing water chemistry. Such ingress will potentially occur within open systems and in piped systems at low pressure points.

Guidance is provided to private well owners from many sources on the actions necessary to protect the quality of water at the source. The Drinking Water Inspectorate (2001) gives general guidance on collection arrangements for boreholes and springs and measures to ensure surface water does not enter the supply at times of heavy rainfall. Within the USA and Australia, each state provides guidance for private well owners. Typically this includes guidance on the siting of wells, the installation of boreholes, the maintenance of the system and the testing of water quality. Little advice appears to be provided with regards to the integrity of the supply system.

Howard (2001) puts forward the following factors as indicators of a breach in the sanitary integrity of a groundwater supply system:

- turbidity – reflecting the introduction of surface water;
- colour – reflecting the introduction of surface water and also indicating corrosion of iron pipes, or the dissolution of dyes and cements; and
- dilution of groundwater parameters with the ingress of rainfall.

Research into *Cryptosporidium* and other bacteria in private water supplies demonstrates the issue of integrity of water supplies. The most recent data obtain by Watkins (2001) presents the results of sampling at seven sites within the UK. Sites were samples twice a day between May and June 2000, and then again between October and November 2000. The study determined that heavy rainfall and flooding affected water quality at four of the seven sites. The contamination with bacteria was attributed to animal contamination at the water supply source. The study also found significant variation in bacteria levels between the seasons, reflecting the degree of contamination. In addition, diurnal variations in bacteria levels were also detected.

The Scottish Executive's consultation paper on water supply regulation, cites six case studies where bacterial contamination of private water supplies has occurred through either contamination at source or contamination occurring within the supply system, for example at storage tanks.

The concept of 'Sanitary Surveys' is of increasing importance and will be a vital part of the assessment of groundwater monitoring at small sources. Howard (2001) promotes the visual inspection of water supply systems prior to monitoring, and provides a number of checklists for different types of supply.

4. Investigation of water quality at small groundwater sources

4.1 Introduction

In order to quantify the likely changes in water chemistry within the supply systems of small groundwater sources, a sampling exercise was carried out at selected sites typical of the range of facilities. Samples of water were taken from between three and five sampling locations within the supply system. At each sample location up to five samples were taken over a monitoring period of one day.

This chapter includes a discussion of:

- the process of selecting the sites for inclusion within the sampling exercise;
- a description of each site;
- the sampling and field analytical protocols, with an outline of the laboratory analysis that was carried out;
- the quality assurance aspects of the data, such as variance between field and laboratory measured determinands and observed changes in water chemistry with time; and
- the results, based on an evaluation of the statistical significance in changes in water chemistry observed from one sample location to the next.

4.2 Site selection process

Sites for inclusion within the sampling exercise were selected to cover the range of sampling facilities and configurations of supply systems at typical private water supplies. The most common system configurations include a combination of the following:

- gravity-fed spring sources;
- borehole supplies with submersible pumps;
- supplies with a pressure vessel within the system;
- supplies with a storage/header tank within the system;
- supply systems with short distribution pipework;
- supply systems with long distribution pipework.

A shortlist of eleven sites was compiled following a review of site records held by the North West Region, and nominated sites from the South West Region and Environment Agency Wales. These sites were visited in order to assess their suitability for inclusion within the study. Suitability for inclusion was based on specific criteria, the co-operation of the site owner, the presence of suitable sampling locations, ease of access to sampling locations and health and safety risks for the sampling staff.

From the shortlist of eleven sites, six were selected for the study.

4.3 Water sampling and analysis

At each site it was first confirmed that all water supply equipment, such as pumps and pressure vessels, were operational as normal and had been for the previous few hours. This was to ensure that the water within the supply system was representative of the site's usual water quality and that there was no water that had a residence time longer than would be typical.

It is noted that for all sites, there had been no heavy rainfall events within the three days before the sampling, such events would have increased the risk of ingress of surface water into the system during or immediately preceding the sampling exercise.

Groundwater was sampled at between three and five sample locations within the supply system at each site. Between three and five samples were taken throughout the day at each sample location, depending upon site operational conditions at the time of sampling.

At spring catchpits and storage/header tanks, groundwater samples were taken by using a clean container to bail a sample. When sampling from sample taps, such as at pressure vessel and borehole headworks, the tap was opened and water allowed to run for over 5 minutes before sampling was undertaken in order to ensure that the sample tap was flushed with representative groundwater.

Visual and olfactory observations were made on all samples. The field measurements of temperature, pH, electrical conductivity and dissolved oxygen were recorded using Hanna Instruments' hand held meters. Recordings were taken against each sample once the readings had stabilised (usually after a few minutes). Alkalinity measurements were made using a Hanna Instruments' alkalinity field test kit that utilises the phenolphthalein/bromphenol blue method. Where practical, a Sheffield low flow-through cell was utilised to allow continuous recording of field parameters. All field test equipment was calibrated on a daily basis using solutions of relevant standard concentrations. Between each sample, the sampling and field test equipment was thoroughly cleaned in order to minimise the risks of cross contamination of samples.

Samples were collected in bottles, provided by the Environment Agency's laboratory, of an appropriate type and with sample preservatives where required. The sample bottles were transported in cool boxes to the Agency's laboratory at the end of each day.

A replicate set of samples for major ions and metals was taken at three of the sites for one sample round. Table 10 indicates the sample bottle type and whether preservatives were required.

Table 10: Sample bottles and preservatives

Determinands	Bottle type	Fixative
Arsenic & Selenium	A 125ml plastic	No
Major Ions	B 1 litre clear PET bottle	No
Mercury	C 250ml glass	Yes
Metals	D 125ml narrow neck polypropylene	No
Bacteriological	E 1 litre sterile clear PET	No
Pesticides	F 1 litre glass screw cap	No
Chlorpyriphos Methyl	G 1 litre glass	No
Volatile Organics	H 250ml plastic	No

Determinands	**Bottle type**	**Fixative**
Pesticides	I 1 litre glass screw cap PTFE lined	No

Samples for bacteriological testing are highly susceptible to changes in temperature. It is generally advised that samples are tested within 2 hours of collection in order to ensure that microbial activity has not significantly changes. This was not undertaken as part of this exercise, as successive samples were taken on one day and all samples sent to the laboratory the same day. The bacteriological analyses are therefore broadly indicative only. Results will be significant where there is a change between a positive presence of bacteria and no bacteria. Changes in the concentrations of bacteria may simply be due to increased microbial activity in one sample over another due to the length of time between sample collection and analysis.

The analytical suite used for the sampling exercise was specified by the Environment Agency following their methodology (Environment Agency, 2003). This was deemed appropriate, as it would be the suite of analysis that would be performed on all samples taken from the National Groundwater Quality Monitoring Network.

The analysis of samples was undertaken by the Environment Agency's laboratories at Nottingham and Leeds. Table 11 presents the suite of analysis and the Environment Agency suite reference codes. All tests except nitrate and faecal streptococci (confirmed) are UKAS accredited. Samples were analysed for determinands within the following suites:

- Suite I1 Field determinands (SEC were also determined in the laboratory)
- Suite I2 Major ions and total metals (alkalinity was also determined in the field)
- Suite I4 Special inorganics
- Suite O1 ONP pesticides
- Suite O2 OCP pesticides
- Suite O6 VOCs
- Suite M1 Total coliforms

All samples were tested for major ions, total metals and field determinands. One sample from each sample location was also analysed for the organic suites and bacteriological determinands.

Table 11: Environment Agency analytical suite for the groundwater monitoring network

I1	I2	I3	I4	O1	O2	O3
Field	**Anions and Metals**	**Dissolved Metals (Filtered)**	**Special inorganics**	**ONP pesticides**	**OCP pesticides**	**Acid herbicides**
DO	Ammonium	Iron	Antimony	Atrazine	1,2,3 Trichlorobenzene	2,3,6 TBA
pH	Chloride	Manganese	Arsenic	Atrazine Desethyl	1,2,4 Trichlorobenzene	2,4 D
SEC	Nitrate		Mercury	Atrazine Desisopropyl	1,3,5 Trichlorobenzene	2,4 DB
Temp	Nitrite		Selenium	Azinphos-Ethyl	2,3,5,6 Tetrachlorothioanisole	2,4,5 T
	TON		bromate	Azinphos-Methyl	2,3,5,6 Tetrchloroanailine	Benazolin
	Orthophosphate		Bromide	Bendiocarb	Aldrin	Bentazone
	Silica		Cyanide	Bupirimate	Chlordane cis	Bromoxynil
	Total Hardness		Fluoride	Carbophenothion	Chlordane trans	Chlopyralid
	Alkalinity			Chlorfenvinphos	Chlorothalonil	Dicamba
	pH (Lab)			Chlorpyriphos-ethyl	Chlorpropham	Dichlorprop
	TOC			Chlorpyriphos-methyl	DDE OP	Fluoroxypyr
	Aluminium			Coumaphos	DDE PP	Imazapyr
	Barium			Cyanazine	DDT OP	Ioxynil
	Beryllium			Desmetryn	DDT PP	MCPA
	Boron			Diazinon	Dichlobenil	MCPB
	Cadmium			Dichlorvos	Dieldrin	Mecoprop
	Calcium			Dimethoate	Endosulphan I	Trichlopyr
	Chromium			Ethion	Endosulphan Ii	
	Cobalt			Ethofumesate	Endrin	
	Copper			Fenchlorphos	HCH Alpha	
	Iron			Fenitrothion	HCH Beta	
	Lead			Fenpropimorph	HCH Delta	
	Magnesium			Fenthion	HCH Gamma	
	Manganese			Flutriafol	Heptachlor	
	Nickel			Fonofos	Heptachlor epoxide	
	Potassium			Iodofenphos	Hexachlorbenzene	
	Silver			Iprodione	Hexachlorobutadiene	
	Sodium			Irgarol 1051	Isodrin	
	Strontium			Malathion	Methoxychlor	
	Sulphate*			Metalaxyl	PCB 101	
	Vanadium			Metazochlor	PCB 105	
	Zinc			Mevinphos	PCB 118	
	Total metals			Naproamide	PCB 138	
				Parathion-methyl	PCB 153	
				Parathion-ethyl	PCB 156	
				Pirimicarb	PCB 180	
				Pirimiphos-methyl	PCB 28	
				Pirimphos-ethyl	PCB 52	
				Prochloraz	Permethrin-cis	
				Promethryne	Permethrin-trans	
				Propazine	Propachlor	
				Propetamphos	TDE OP	
				Propyzamide	TDE PP	
				Simazine	Tecnazene	
				Terbutryn	Trifluralin	
				Triazophos		
				Trietazine		

4.4 Description of sites

Photographs of the sample locations at each site are included within the Project Record accompanying this report.

4.4.1 Site A, Swansea, West Glamorgan

Site A is a hotel that has a private water supply from a spring, which provides water for potable domestic use. The hotel and spring are surrounded by agricultural grazing land. The supply system comprises a typical brick built catchpit with a long plastic (alkathene) feedwater pipe (approximately 1,000m) supplying the property. The catchpit has extensive vegetation rootlets with some sediment in the bottom. Within the property, water is stored in plastic header tanks and distributed through copper piping. Figure 5 presents the schematic layout of the water supply system.

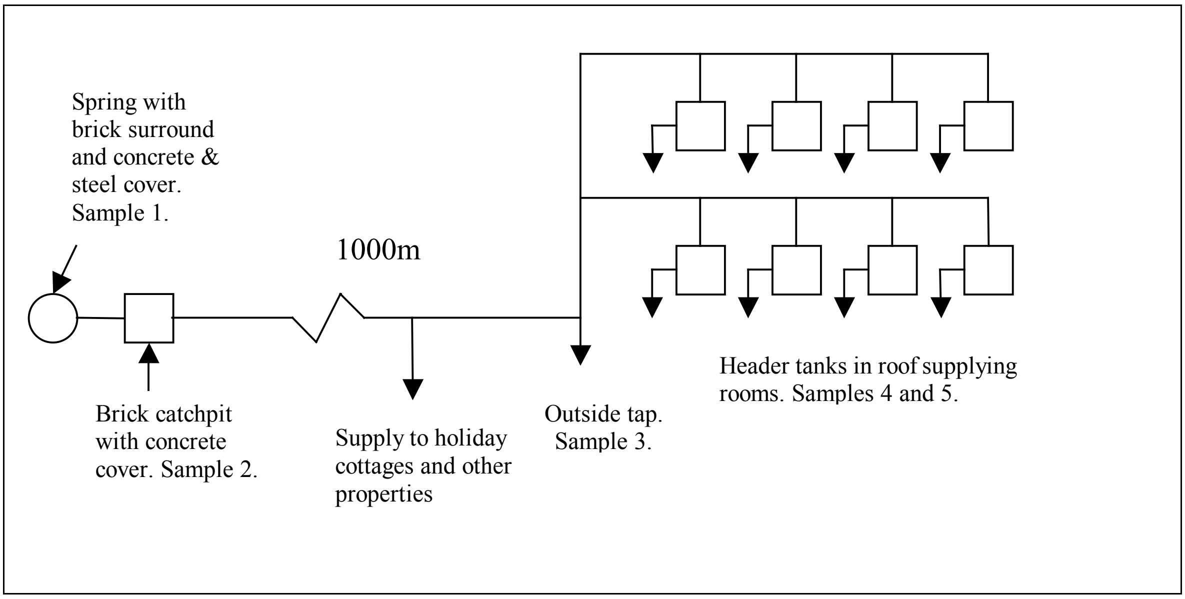


Figure 5: Schematic layout – Site A

Five points within the supply system were sampled – the spring, the adjacent catch pit, the tap outside the hotel, the header tank and a cold water tap inside the hotel.

4.4.2 Far End Farm, Garsdale, Cumbria

Far End Farm has a spring supply that provides the farm with water for agricultural and domestic use. The surrounding land use is agricultural grazing. The spring has a brick lined catchpit with a stainless steel filter. A 3m pipe connects the catchpit to a plastic storage tank that is part buried. From the tank, a 350m alkathene pipe directs water to the treatment plant. The water is treated before use. The storage tank is prone to silting and is cleaned out on an annual basis by the site owner. Figure 6 presents the schematic layout of the water supply system at Far End Farm.

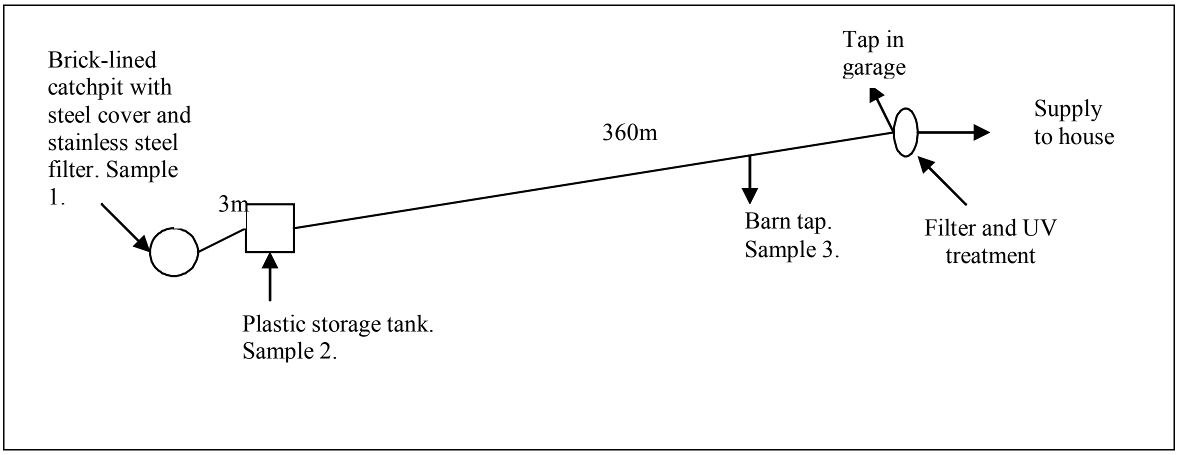


Figure 6: Schematic layout – Far End Farm

Three sample locations were monitored – the spring, the storage tank and a tap at an outbuilding where untreated water was obtainable.

4.4.3 Highlands Farm, Collingbourne, Wiltshire

Highlands Farm has a borehole that supplies the farm for domestic and agricultural use. The borehole is 82m deep and fitted with a groundwater pump abstracting water from the Chalk. The type of pump and the construction details of the borehole are not included in the records reviewed. From the borehole, groundwater passes into a pressure vessel via 1m of steel pipe. From the pressure vessel a 300m steel pipe supplies water to the farmhouse where plastic and copper pipework connects to a header tank and the various taps within the building. Before the farmhouse, part of the water supply is diverted along alkathene pipework to the stables. Figure 7 presents the schematic layout of the water supply system at Highlands Farm.

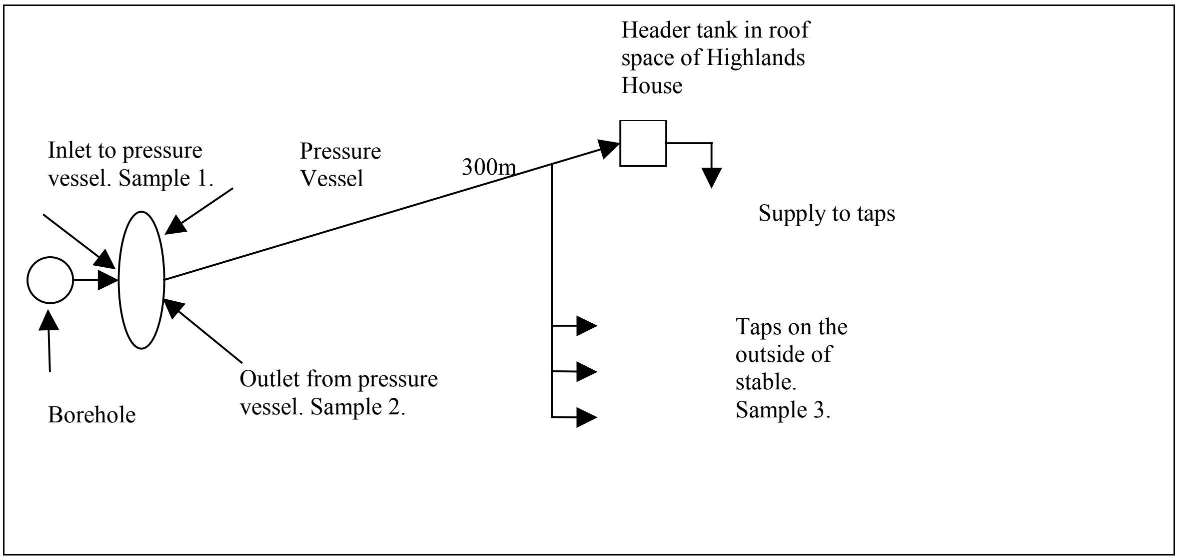


Figure 7: Schematic layout – Highlands Farm

Three sample locations were monitored – the inlet to the pressure vessel, the outlet of the pressure vessel and a cold water tap at the stables. The groundwater pump was not operational during the monitoring exercise and hence the number of samples that were obtained was limited. Furthermore, the weather was cold and the pipework feeding the stables was frozen.

4.4.4 Newlands Mill Farm, Wigton, Cumbria

Newlands Mill Farm has a borehole from which groundwater from the Carboniferous Limestone is abstracted for agricultural and domestic uses. The borehole is 80m in depth is 150mm diameter, and is PVC plastic lined with screen to the base. The borehole is installed with a DAB SA52B submersible pump. From the borehole the supply system is split passing along two 30m long, 50mm diameter PVC pipes to two 500 litre pressure vessels. From the pressure vessel water passes untreated to a trough along an 80m PVC pipe. Also from the pressure vessel water passes to a treatment plant and then to one of three header tanks. The pump operates intermittently through the day depending upon water demand. The typical daily abstraction is approximately 5m^3. Figure 8 presents the schematic layout of the water supply system at Newlands Mill Farm.

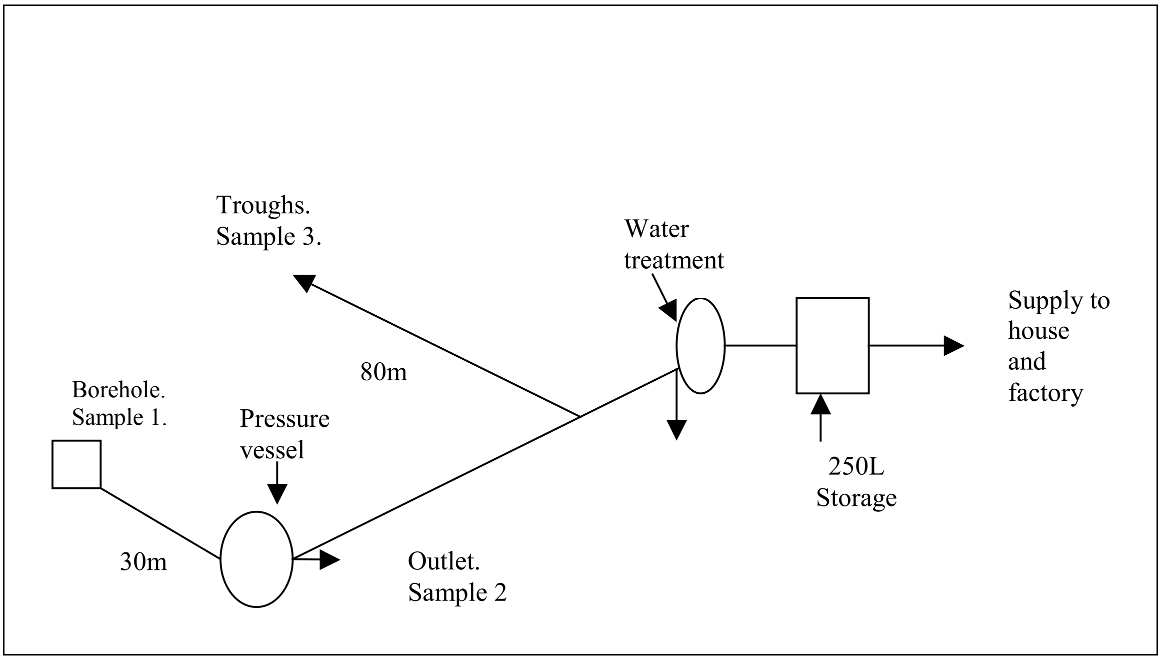


Figure 8: Schematic Layout – Newlands Mill Farm

Three points were sampled –at the borehole headworks, the outlet to the pressure vessel and the outlet at the trough.

4.4.5 Pirelli Tyres, Carlisle, Cumbria

Pirelli tyres abstract groundwater from two boreholes sunk into the St Bees Sandstone. The abstracted water is used for industrial processes. Borehole 1 (used for this study) is 137m deep, 305mm in diameter and is cased to 54.9m (type of casing unknown). It is fitted with a submersible Beresford groundwater pump at 61m below ground level. Water is pumped to a 1,140m^3 pond that is used for cooling water, and to a storage tank within the factory. The pump is operated intermittently based on demand by level switches at the pond and the storage tank. The feedwater pipework is steel, with the inlet to the storage tank and the tank itself is constructed of iron. The pipework and tank are visibly corroded internally.

The storage tank at Pirelli is located within the boiler house where the ambient air temperature is 25°C. The water within the tank therefore warms in this environment, but is filled intermittently with cold groundwater causing a drop in water temperature. Hence the water temperature within the storage tank is likely to fluctuate throughout the day.

Figure 9 presents the schematic layout of the water supply system at Pirelli Tyres.

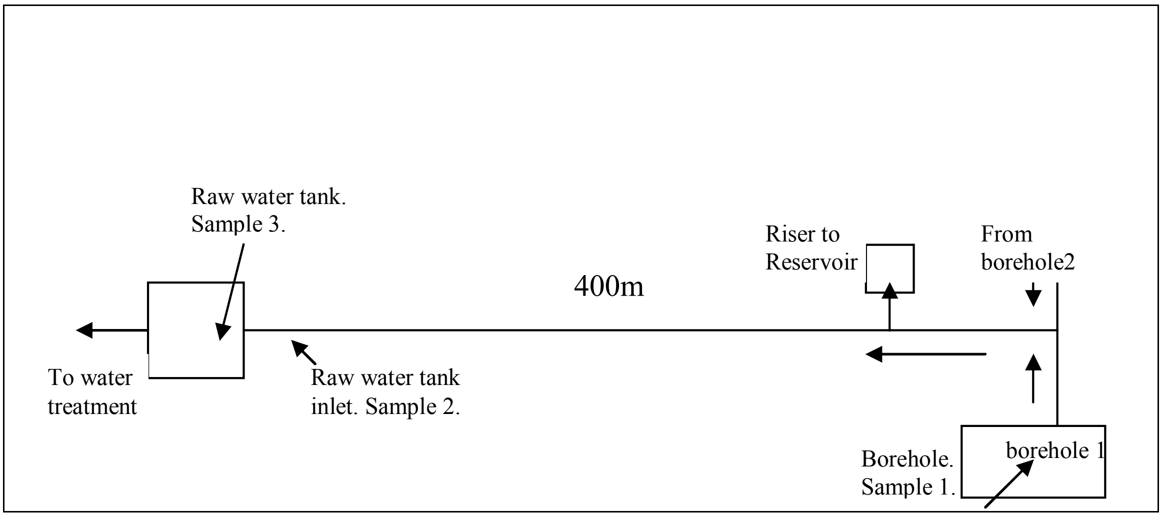


Figure 9: Schematic layout – Pirelli Tyres

Three points were sampled – a tap at the borehole 1 headworks, the inlet to storage tank and the water in the tank itself.

4.4.6 Frank Bird Poultry, Penrith, Cumbria

Frank Bird Poultry abstract groundwater, for industrial food processing, from a borehole in the Penrith Sandstone. The borehole is 173m deep and has steel casing to 120m. The borehole is installed with a submersible pump that pumps groundwater along a 25m PVC pipe to a 15m^3 galvanised steel storage tank. The pump is operated intermittently between 6am and 6pm daily, based on demand, and is activated by an automatic level switch in the storage tank. From the storage tank, the water passes along PVC pipes into the poultry processing area.

Figure 10 presents the schematic layout of the water supply system at Frank Bird Poultry.

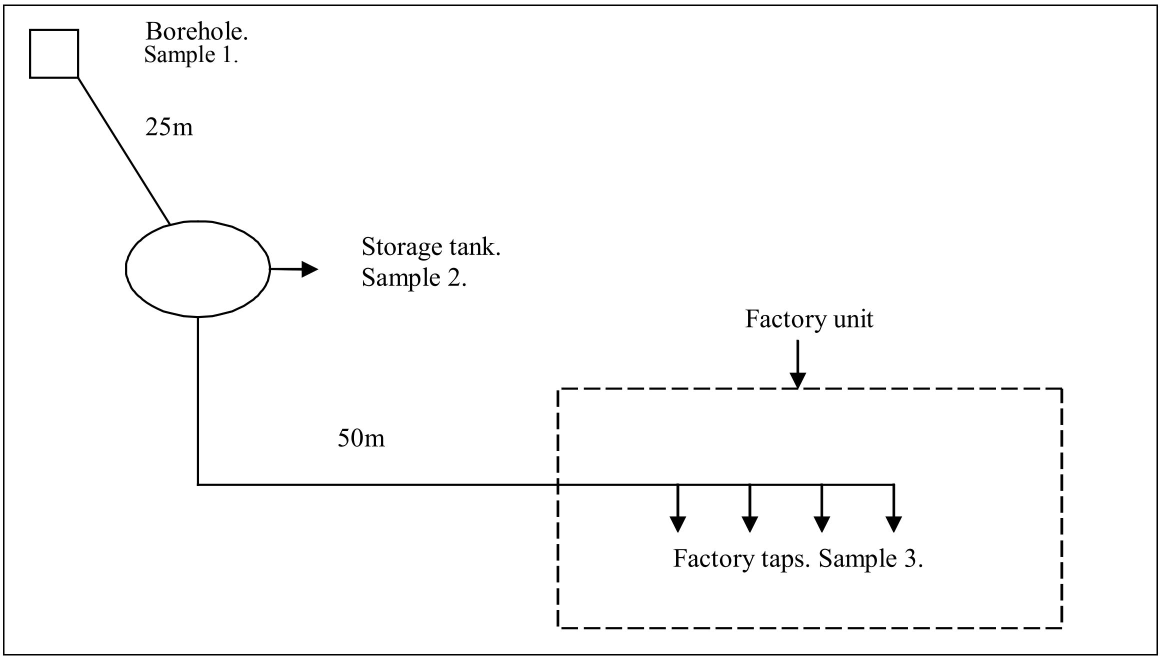


Figure 10: Schematic layout – Frank Bird Poultry

Three points were sampled – a tap at the borehole headworks, the storage tank and from a tap within the factory.

4.5 Results

The field test data and laboratory results for each site are summarised in the following appendices:

Appendix A	Site A
Appendix B	Far End Farm
Appendix C	Highlands Farm
Appendix D	Newlands Farm
Appendix E	Pirelli Tyres
Appendix F	Frank Bird Poultry

The accompanying Project Record provides the full data set comprising field and laboratory analytical data and field sampling observations.

4.6 General overview of results

4.6.1 Field versus laboratory data

The determination of the pH, electrical conductivity and alkalinity of samples taken at each location were made both in the field and by laboratory analysis. These parameters are likely to change during sample storage and transportation due to sample instability, and hence the comparison of field and laboratory data is an important quality assurance tool. The degree to which they will change will be influenced by the initial water chemistry (some chemistries being more prone to change than others), the type of sample container, the method of filling of the container, the use of sample preservatives and the temperature of storage. The data collected as part of the sampling exercise are compared in Figure 11.

Figure 11a

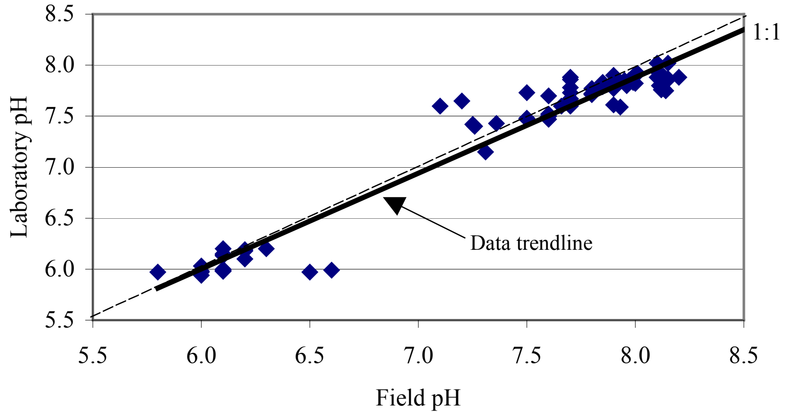


Figure 11b

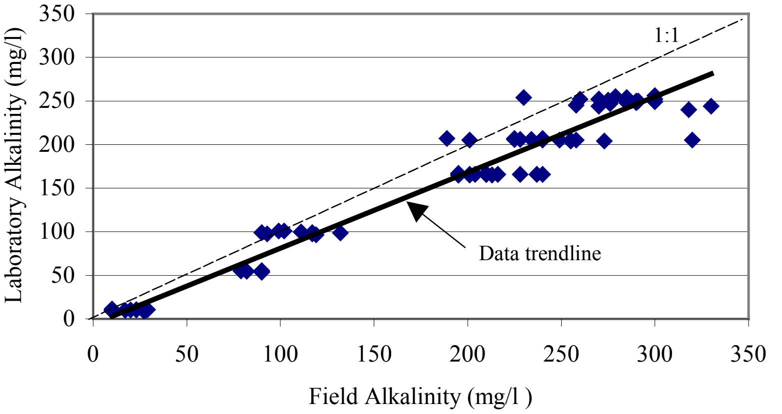


Figure 11c

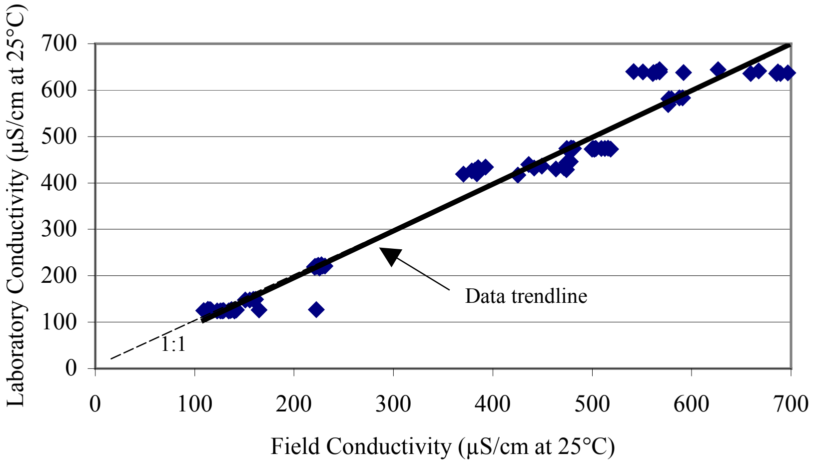


Figure 11: Field versus laboratory measurements of pH, Alkalinity and Electrical Conductivity (all samples)

Changes in the pH and alkalinity of the samples during transportation to the laboratory occur typically due to loss of dissolved carbon dioxide from solution, initiated as a result of changes in temperature and pressure. The regression line for the graph plotting field against laboratory pH (Figure 11a) shows good correlation. For alkalinity (Figure 11b), laboratory results are lower than field results, with a regression slope of 0.95.

Electrical conductivity field data has been corrected to 25°C, in order to compare this data with the laboratory results. The graph (Figure 11c) shows that there is no significant change in electrical conductivity between field measurement and the laboratory analysis. The observed changes in pH, alkalinity and electrical conductivity between the field and laboratory are not considered to be significant.

Laboratory determination of dissolved oxygen was not carried out. This may have shown similar changes to alkalinity, where aeration of the sample due to sample transportation and laboratory analysis may have resulted in an increase in dissolved oxygen.

4.6.2 Replicate samples

Replicate samples (two discrete samples) were taken of the following:

- Far End Farm – visit 5 at the spring, storage tank and barn tap.
- Frank Bird Poultry – visit 5 at the borehole, storage tank and factory tap.
- Newlands Mill Farm – visit 5 at the borehole, pressure vessel inlet and trough.

Replicate samples of this type provide an estimation of the contribution of both sampling and analytical error. The replicate samples were analysed for metals and inorganics. In the majority of instances, the variance between replicate samples was very low. The exception was the analysis of metals in replicate samples, as presented in Table 12.

The variations in metal concentrations between the replicate samples are typically within the range of concentrations found for all samples taken at each location. For example at the tap at Frank Bird Poultry, replicate samples were taken on the final visit to this location. The concentrations of iron in each sample were <30µg/l and 57.6µg/l. However, the concentrations of iron in all 6 samples taken from this location ranged from <30µg/l to 97µg/l and therefore the difference between the replicate samples is within the range for all samples.

The greatest degree of variation between the replicate samples is for Far End Farm. For each location, the range of concentrations for the replicate samples lies within the range for all samples taken at that location. Hence the replicate analysis still provide an assurance that changes in water chemistry due to sampling, transportation and laboratory analysis have been minimised.

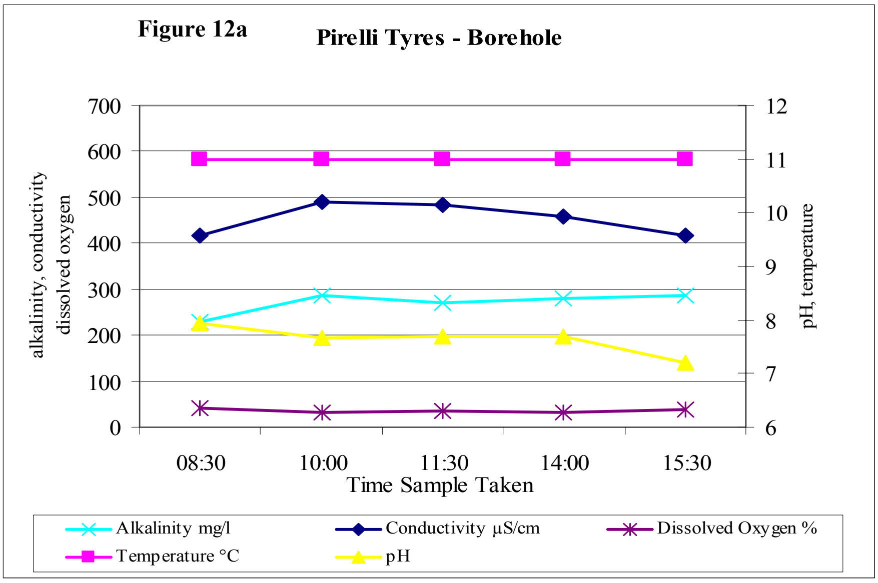
Table 12: Replicate analysis of samples – variations in metal concentrations

Site	Data	Metal concentration (µg/l)						
		Copper	Chromium	Lead	Aluminium	Iron	Manganese	Zinc
Far End Farm Spring	All visits	0.968 – 1.66	<0.5 – 11.1	0.814 – 2.22	86.5 – 144	534 – 933	27.7 – 72.3	<5 – 10.3
	Visit 5	1.12	2.09	1.75	138	890	69.4	6.59
	Visit 5	0.968	11.1	0.968	97.7	661	35.6	<5
Far End Farm Tank	All visits	0.953 – 1.17	<0.5 – 0.783	0.413 – 0.733	66.8 – 81.1	354 – 395	11.5 – 19.8	<5 – 8.65
	Visit 5	1.04	0.503	0.47	68.9	356	11.5	<5
	Visit 5	0.953	<0.5	0.413	66.8	354	11.5	<5
Far End Farm Barn Tap	All visits	3.39 – 9.85	<0.5	0.458 – 0.736	57.3 – 60.7	318 – 336	<10	<5 – 10.6
	Visit 5	3.73	<0.5	0.458	59.3	332	<10	<5
	Visit 5	3.39	<0.5	0.475	60.7	336	<10	<5
Frank Bird Borehole	All visits	<0.5 – 18.2	<0.500	<0.4 – 1.23	<10	<30	19.9 – 20.8	38.6 – 92.4
	Visit 5	18.2	<0.500	1.23	<10	<30	20.3	92.4
	Visit 5	11.5	<0.500	0.615	<10	<30	20.8	59.7
Frank Bird Tank	All visits	<0.5	<0.5 – 0.657	<0.4 – 0.864	<10	<30 – 211	<10	32.5 – 38.1
	Visit 5	<0.5	<0.5	<0.4	<10	<30	<10	33.8
	Visit 5	<0.5	0.535	<0.4	<10	<30	<10	33
Frank Bird Tap	All visits	0.74 – 2.25	<0.5 – 0.541	<0.4 – 0.848	<10	<30 – 97	<10 – 12	51.9 – 67
	Visit 5	0.74	<0.5	<0.4	<10	57.6	10.7	61.4
	Visit 5	0.994	0.541	<0.4	<10	<30	<10	51.9
Newlands Mill Borehole	All visits	0.531 – 1.63	<0.5	<0.4 – 0.586	<10	104 – 1450	<10	11 – 54.6
	Visit 5	0.531	<0.5	<0.4	<10	154	<10	18.5
	Visit 5	0.583	<0.5	<0.4	<10	104	<10	11
Newlands Mill PV Outlet	All visits	1.41 – 13.3	<0.5	<0.4 – 1.93	<10	101 – 506	<10	7.1 – 15.9
	Visit 5	1.41	<0.5	<0.4	<10	115	<10	7.1
	Visit 5	1.45	<0.5	<0.4	<10	101	<10	7.08
Newlands Mill Trough	All visits	0.88 – 19.3	<0.5 – 3.33	<0.4 – 45.5	<10 – 94.7	<30 – 9460	<10 – 60.4	5.98 – 119
	Visit 5	0.88	<0.5	<0.4	<10	<30	<10	5.98
	Visit 5	1.27	<0.5	<0.4	<10	63.1	<10	7.01

4.6.3 Changes in field results over time

The field determination of sample temperature, pH, electrical conductivity, alkalinity and dissolved oxygen was undertaken at each sample location. This provides an indication of temporal changes in water chemistry for any given sampling location.

The data provided in Appendix E show that for the majority of sample locations, determinands remained consistent throughout the sample period (i.e. from visit 1 through to 5, typically representing a period of 6 to 8 hours). The greatest level of variation was seen in samples taken at Pirelli Tyres, and this is presented graphically in Figure 12.



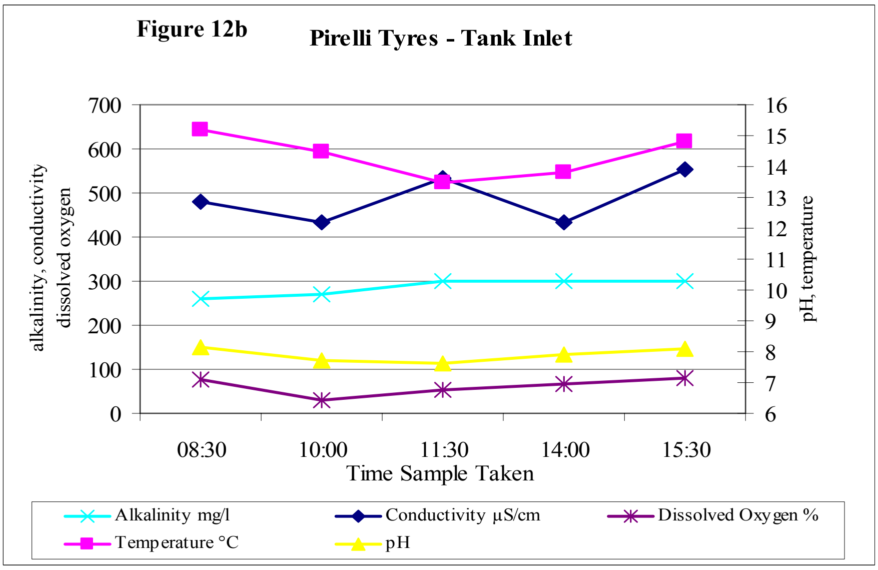


Figure 12: Pirelli Tyres – changes in field determinands over time

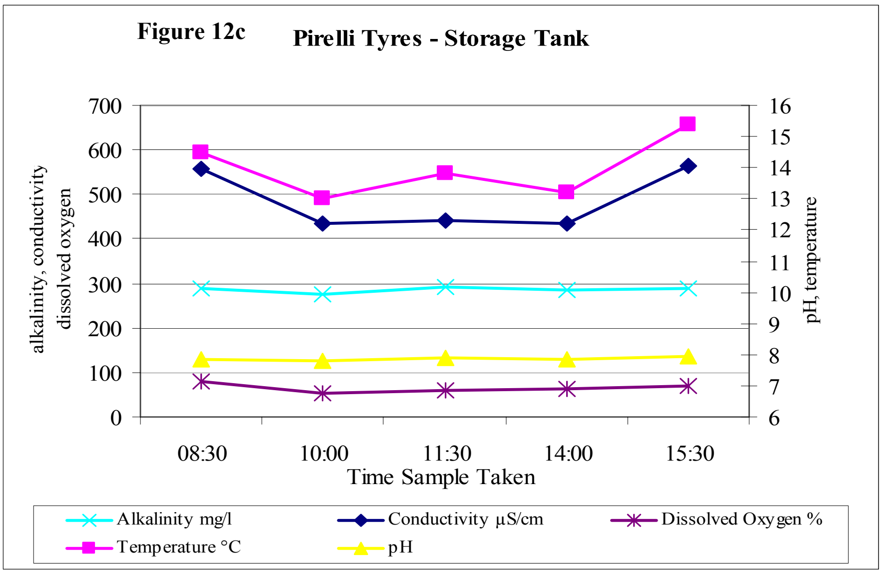


Figure 13 Continued: Pirelli Tyres – changes in field determinands over time

4.6.4 Changes in laboratory results over time

The laboratory determination of sample physical parameters, major ions and metals was undertaken at each sample location. In addition to changes in field determinands, this laboratory data provides an indication in temporal changes in water chemistry for any given sampling location.

The data show that the majority of determinands remained consistent throughout the sample period (i.e. from visit 1 through to 5, typically representing a period of 6 to 8 hours) at each sample location. There was little indication of a change in source chemistry that could then be seen travelling through the water supply and storage system.

The time-series data show no statistically significant trends in concentration of determinands between one sample and the next, with the exception of metals.

Taking into account the level of variation in metal concentrations seen within the replicate samples, the following observations are made for each site:

1. Site A – the metal concentrations at the spring and the outside tap remained constant throughout the sampling period. At the catchpit, header tank and room tap there is a slight fluctuation in concentrations of metals such as iron, zinc and copper.

2. Far End Farm – the concentrations of all metals within samples from each location are consistent over time, with the exception of aluminium and iron in samples from the spring. The second visit showed a marked drop in concentrations of aluminium from 144µg/l to 86.5µg/l and iron from 933µg/l to 534µg/l, before rising back to the approximate initial concentrations on the third visit.

3. Highlands Farm – the limited set of data for this site indicates that between the two visits, there was little variation within metal concentrations at each sample location.

4. Newlands Mill Farm – the concentration of iron in the borehole drops from the first

to the second visit from 1450 to 208µg/l, with a similar drop in iron concentration within the pressure vessel from 506 to 120µg/l over the first three visits. The first sample taken at the borehole also had an iron concentration of 1,450µg/l, compared with an average of 150µg/l in all other samples at this location. The reason for this fall in iron concentration after the first visit was not determined, but it demonstrates that changes in water chemistry can occur quite abruptly and for no discernible reason.

The second sample at the trough at Newlands Mill shows a marked increase in concentrations of all metal, as shown in Figure 13, corresponding to a visual change in water colour.

5. Pirelli Tyres – there is little variation over time in metal concentrations at each sample location.

6. Frank Bird Poultry – the metal concentrations at all sample locations are generally consistent over time. An increase in copper concentration (from 0.5 to 18.2µg/l) at the borehole was recorded in the last sample. A drop in iron concentration was recorded at the storage tank from 211 µg/l in the first sample to <30µg/l in subsequent samples.

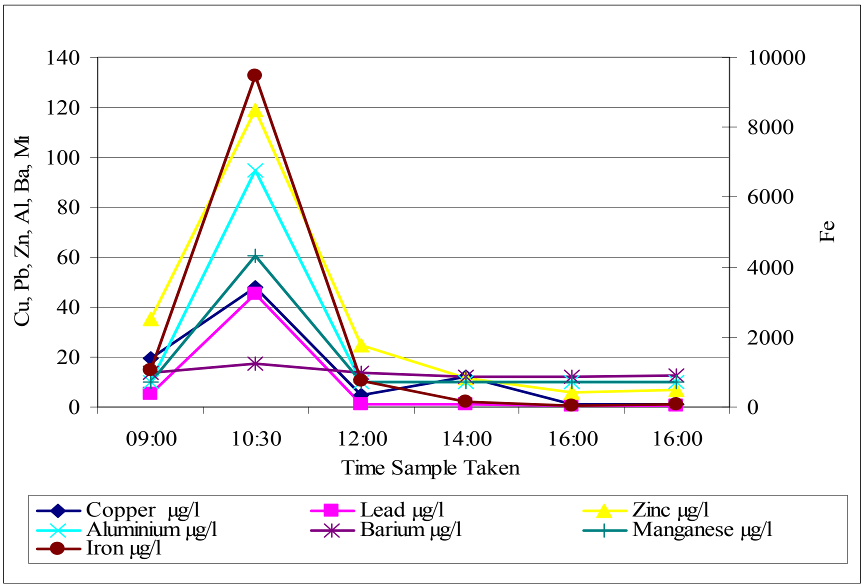


Figure 14: Newlands Mill Farm Trough – changes in metal concentrations

These changes may reflect temporal changes within water chemistry at the sampling location or they may be an artefact of the amount and type of solids within the samples. Alternatively these changes may have occurred during storage and transportation of samples to the laboratory. There is generally a poor correlation between the variation in metal concentrations and changes in field and laboratory pH and electrical conductivity.

4.7 Spatial variation in chemistry

In order to assess changes in water chemistry within the supply system of each site, the average concentrations of each determinand at each sample location was used. The average was used in preference to the mean or mode value as for several sites, there are only three samples per sample location.

Where determinands are reported as being below the lower detection limit, these are taken as being present at the detection limit for the purposes of averaging. The validity of this averaging process is discussed for each site based on the quality control data from field determinations and replicate samples for that site. The results for each site are then evaluated by comparing changes in these average concentrations between sample locations and commenting upon the likely cause of any changes observed.

For organic and bacteriological determinands, a single sample was taken from each sample location, and hence this averaging and quality control evaluation is not possible.

4.7.1 Site A – spring source

The field and laboratory data for all sample locations at Site A show a good level of consistency, and temporal variations in metal concentrations are generally low. On this basis, the averaging of the four sets of data for each sample location will be unlikely to hide any fluctuations in water chemistry.

No volatile or semi-volatile organics were detected in any of the samples and hence the loss of these substances within this supply system can not be evaluated.

The spring and the catchpit at the source are adjacent to each other, both being constructed of brick and concrete and connected by a short length of clay pipe. Between these two locations there is likely to be very little change in the physical factors that will affect the water chemistry such as pressure, temperature and the degree of aeration. Concentrations of major ions and metals are consistent between these two sample locations. The bacteriological analysis shows some contamination of the spring sample location with faecal streptococci (35cfu/100ml) and total coliforms (12cfu/100ml), which is reduced within the catchpit sample location. These levels of bacteria are not uncommon at such sources and the water at this site is treated before use.

From the source, groundwater is then transferred through alkathene pipe, a distance of 1,000m to the hotel. At the outside tap sample location the water temperature had risen 2°C, with a slight increase in dissolved oxygen that can be attributed to aeration. There is a noticeable rise in copper concentration along the delivery system to this point, this is shown in Figure 14. The bacteriological analysis shows that the faecal streptococci were no longer present and the total coliforms count was significantly reduced (5/100ml).

From the pipework outside the hotel, the groundwater is transferred to a plastic header tank via alkathene and copper pipework. Within the tank, there is a potential for aeration of the groundwater to have occurred. The water temperature had not risen here and there was a slight drop in dissolved oxygen concentration indicating that the water has not been aerated here. There was a further marked increase in copper concentrations from 18 to 191µg/l. This was most probably due to the leaching of copper from the pipework due to the slightly acid water (pH 6 to 6.2). There was no bacteriological contamination at this sample location.

From the header tank, the groundwater passes via copper pipework to the hotel rooms where the pH levels remain unchanged but there is a further significant increase in copper to from 191 to 733µg/l.

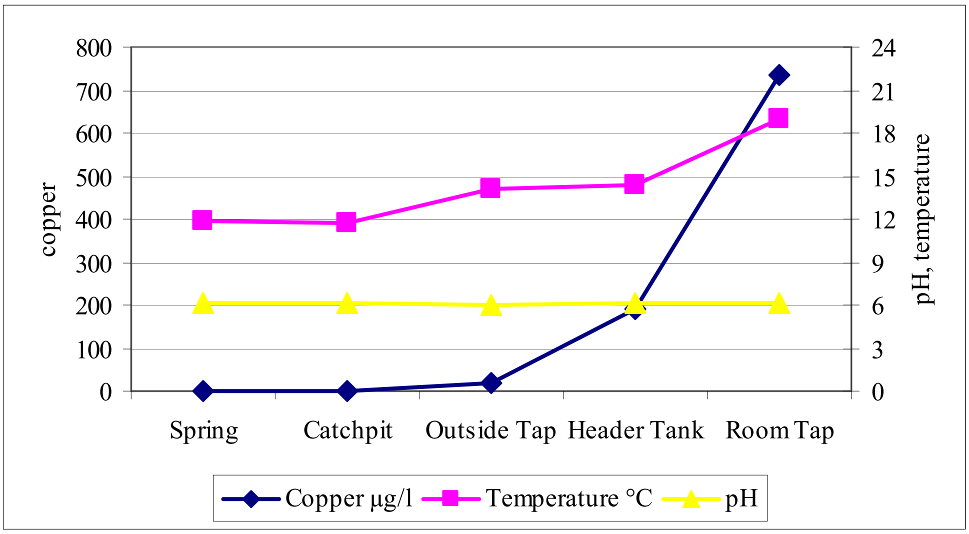


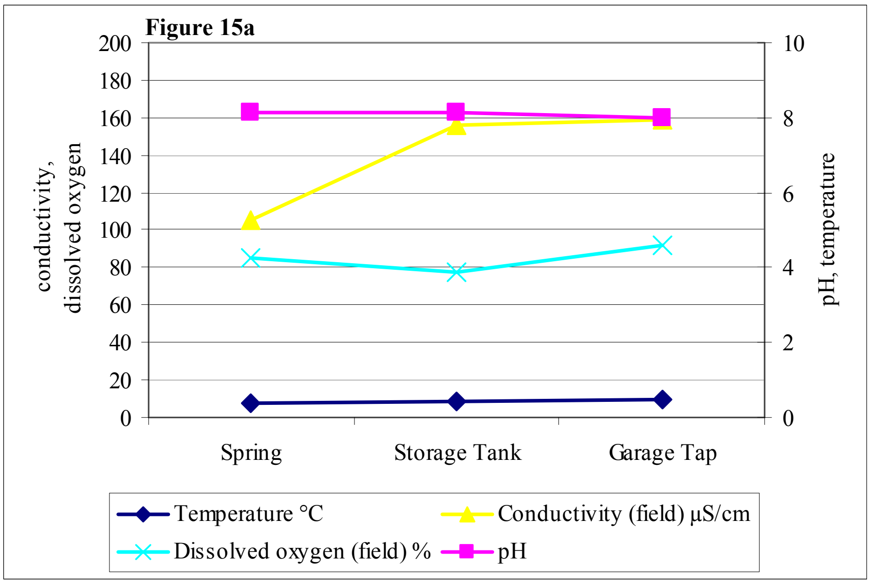
Figure 15: Site A – changes in water chemistry: copper

4.7.2 Far End Farm – spring source

The field and laboratory data for all sample locations at Far End Farm show a good level of consistency. Temporal variations in aluminium and iron concentrations at the spring were recorded, however it is considered that this will only slightly affect the average concentrations for this site. On this basis, the averaging of the five sets of data for each sample location is unlikely to hide any changes in water chemistry due to reactions in the supply system.

The spring and the storage tank at the source are located 3m apart. The spring chamber is of brick construction and the storage tank is plastic. Between these two locations there was likely to be little change in the physical factors that affect the water chemistry such as pressure, temperature and the degree of aeration. Between the two locations the water temperature increased by 1°C (Figure 15a). The pH remains constant; however there is a slight increase in alkalinity and conductivity. The concentrations of major ions are consistent between these two sample locations. The concentrations of most metals decreased between the spring and the storage tank, possible due to precipitation or sorption process as the storage tank is prone to silting (Figure 15b).

The source and the storage tank showed considerable contamination by bacteria (Figure 15c) with higher concentrations within the storage tank than at the spring. This indicates an increase in bacterial activity and colonisation within the tank, and may be due to the reduced cleanliness and silting of the tank. The levels of bacteria seen here are not uncommon for this type of source and the water is treated before use.



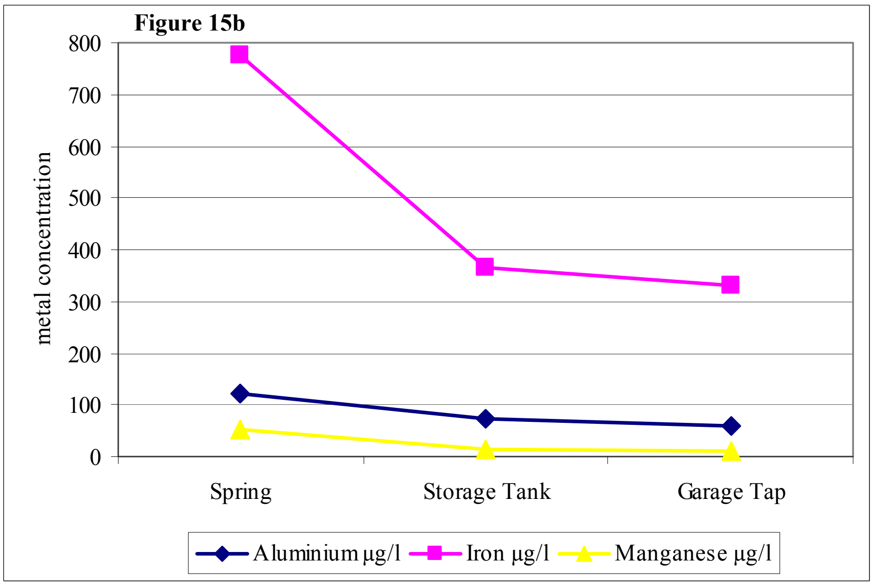


Figure 16: Far End Farm – Changes in Water Chemistry in the Supply System

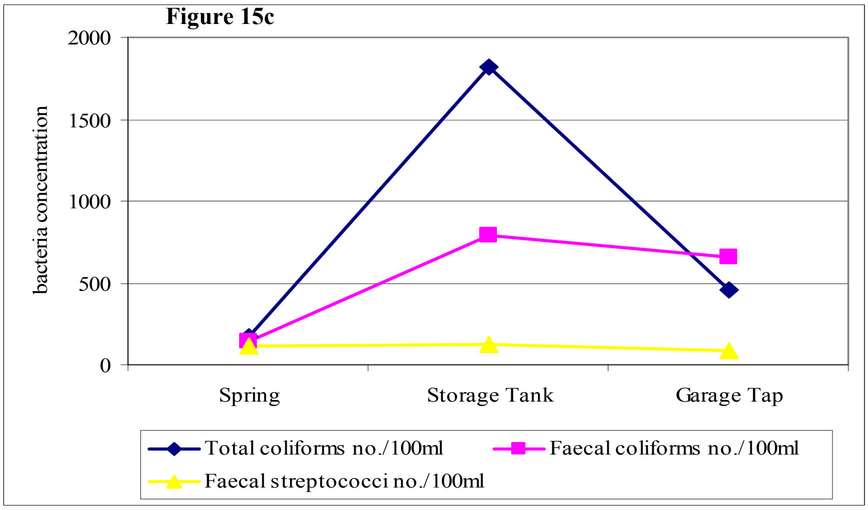


Figure 17 Continued: Far End Farm – Changes in Water Chemistry in the Supply System

The organic analysis (Table 13) shows the spring to have concentrations of Hexachlorocyclohexane (HCH) Gamma at above the detection limit. This concentration decreases to below the detection limit in the storage tank. The storage tank itself has elevated concentrations of Atrazine, Chlorfenvinphos, Propetamphos and Simazine that were not seen in the spring.

Table 13: Far End Farm – changes in water chemistry: pesticides

Determinand	Units	Spring	Storage tank	Garaget
HCH Gamma	µg/l	0.0058	<0.001	<0.001
Atrazine	µg/l	<0.03	0.0605	<0.03
Chlorfenvinphos	µg/l	<0.001	0.00115	<0.001
Propetamphos	µg/l	<0.001	0.0016	<0.001
Simazine	µg/l	<0.03	0.0586	<0.03

There are a number of potential explanations for this. It may indicate that the water here has been contaminated from another source, perhaps through clearing of sediment from the tank, or perhaps historic contamination of the spring has resulted in residual contamination of the storage tank or sediment within the tank that is now leaching into the supply water. Alternatively, the results may reflect contamination of the sample during field work or experimental error at the laboratory.

From the storage tank, the water is then transferred a distance of 400m via alkathene and copper pipework to the farm outbuildings. The temperature had risen by 1°C at the garage tap, the pH remained constant and a slight increase in electrical conductivity was recorded. Concentrations of metals decreased marginally.

Levels of bacteria at Far End Farm decreased between the storage tank and the garage tap. The concentrations of pesticides reduced to below detection limits (Table 13).

4.7.3 Highlands Farm – borehole with pressure vessel

The data for Highlands Farm is limited to two samples visits, taking samples from before and after the pressure vessel, and one data set for the barn tap. No samples were obtained for organic or bacteriological analysis (failure of the groundwater pump had resulted in insufficient groundwater within the system for sampling).

The field and laboratory data for all sample locations at Highlands Farm show a good level of consistency. For the samples before and after the pressure vessel, there is very little change over time and hence the averaging of the two sets of data for each sample location is considered appropriate.

The sample locations are sited at the inlet and outlet to the pressure vessel and are constructed of mild steel. Between these two locations the temperature of the water fell marginally, no change in pH (7.3) was recorded and concentrations of alkalinity, conductivity and dissolved oxygen were consistent. For major ions and metals, no significant change in concentration between these two sample locations was observed.

From the pressure vessel outlet, water is transferred to the farm property, a distance of 300m via copper and plastic pipework to a plastic header tank. From there, the water is distributed to taps via copper pipework. Through this supply system, the water is subject to changes in temperature and pressure and may undergo processes of aeration and oxidation. Between the pressure vessel and the tap at the barn, the water temperature fell by 1°C and the pH rose slightly to pH 7.7. Conductivity and alkalinity remained relatively constant, with a slight rise in dissolved oxygen. For the major ions and metals there is little change in concentration with the exception of copper, as shown in Figure 16.

There was a marked rise in copper concentration between the pressure vessel and the barn tap. The concentrations of other metals remained constant and this rise in copper is therefore likely to be attributable to leaching from the copper pipework.

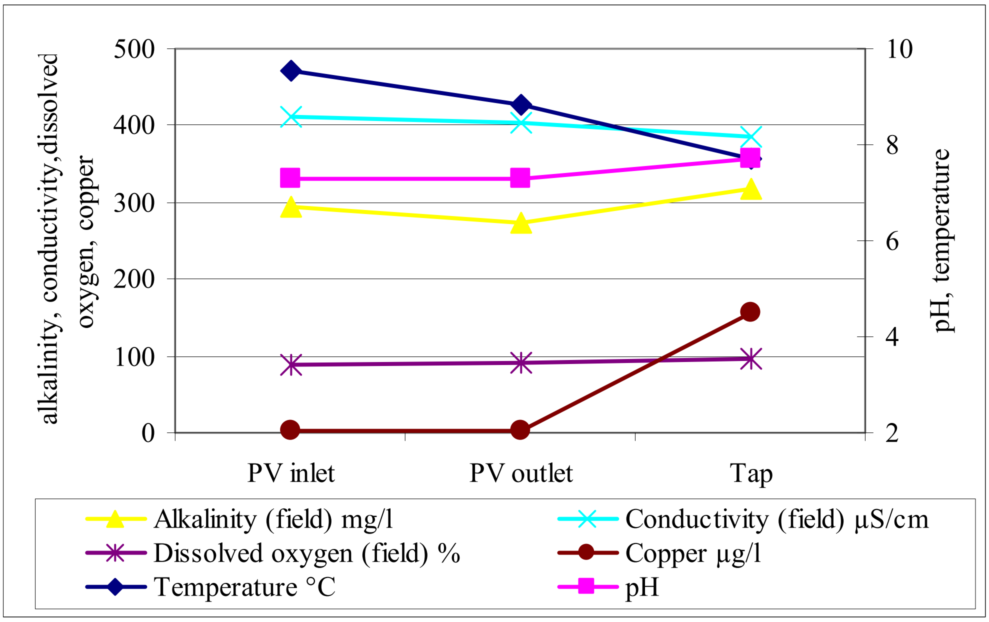


Figure 18: Highlands Farm – changes in water chemistry: field determinands and copper

4.7.4 Newlands Mill Farm – borehole with pressure vessel

As previously discussed (Section 4.6.4.), the field and laboratory data shows a moderate level of consistency with time at each sample location, with slight fluctuations in field determinands and more marked variations in metal concentrations. At Newlands Mill, the first sample at the borehole revealed a concentration of iron to be a factor of ten greater than the average over the remaining samples. This result was removed from the averaging of the data as it seems to represent elevated levels associated with the start up of the groundwater pump. Also at Newlands Mill Trough, the second sample visit showed a significant change in metal concentrations (Figure 13) at this location that was not seen in the remainder of the samples. For the purpose of the interpretation of changes within the system, the full data set for this sample has been removed from the averaging of the five sets of data for each sample location.

No volatile or semi-volatile organics were detected in any of the samples taken at this site and hence it is not possible to evaluate the loss of these substances within this supply system.

From the sample location at the borehole, the groundwater passes 30m through a PVC pipe to a galvanised steel pressure vessel. The sample location at the pressure vessel is via a length of soft tubing that is attached to the outlet. This pathway presents changes in pressure and temperature that potentially will result in changes in water chemistry. The field determinands remained constant (Figure 17a), with only a slight decrease in dissolved oxygen concentration. There is a marked drop in zinc concentrations and a slight rise in iron, copper and lead concentrations (Figure 17b). This may be attributable to a change in the Redox state of the water and an interaction with the galvanised steel pipework and pressure vessel resulting in dissolution/leaching.

The borehole water shows bacteriological contamination, which is not significantly changed by passage through to the pressure vessel (Figure 17c).

From the pressure vessel, the water is transferred to the farm buildings. The next sample location is a trough fed by an alkathene pipe, approximately 80m from the pressure vessel. The field determinands show little change from the pressure vessel, but with a rise in dissolved oxygen concentration due to further aeration of the water. Concentrations of iron, copper, lead and zinc increased, presumably as a result of dissolution or leaching processes. Bacteria levels are slightly reduced.

Figure 17a

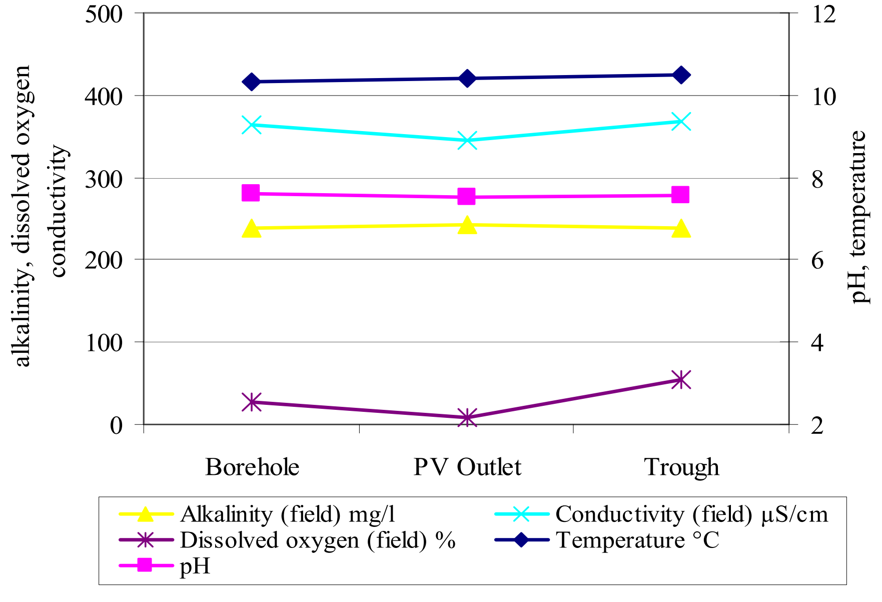


Figure 17b

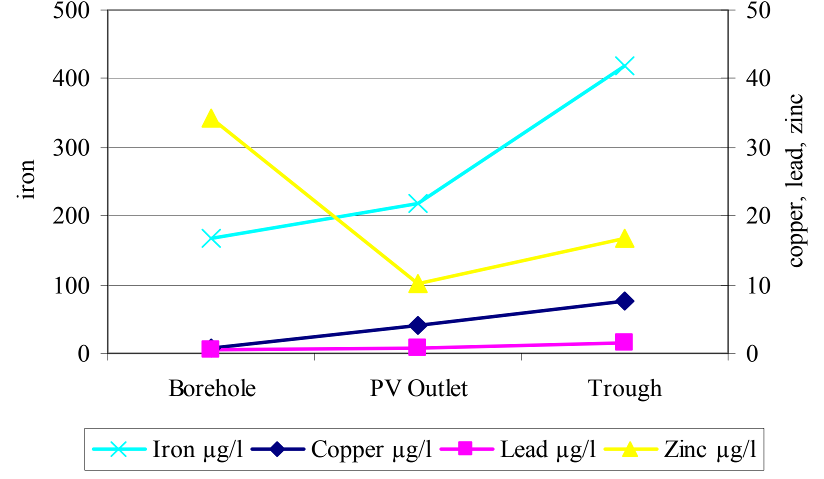


Figure 17c

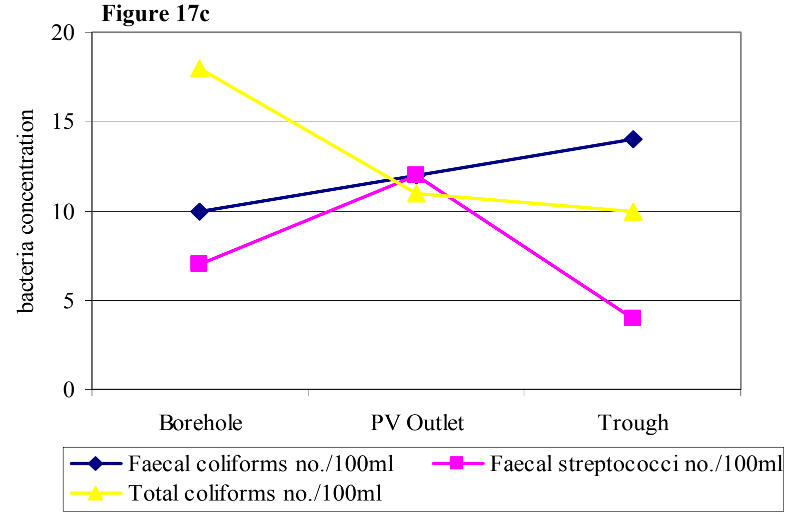


Figure 19: Newlands Mill– changes in water chemistry in the distribution system

4.7.5 Pirelli Tyres – borehole with storage tank

As discussed in section 4.6.3, temporal variations in field determinands at each sampling location were recorded. This was due to the intermittent operation of the groundwater pump discharging cold water into a warm storage tank. These fluctuations are not likely to adversely influence the average result for each site.

Results are not available for bacteriological analysis of samples from Pirelli.

From the borehole, groundwater is passed via a 400m steel pipe to the raw water tank in the boiler house. This supply system is likely to result in temperature and pressure changes that may initiate chemical changes within the water. Between the borehole and the inlet to the storage tank, groundwater temperatures on average rose 3°C, with little change in pH, conductivity and alkalinity. The dissolved oxygen concentrations rose significantly indicating aeration of the water (Figure 18). There were no significant changes in major ions and metals between the borehole and the tank inlet pipe.

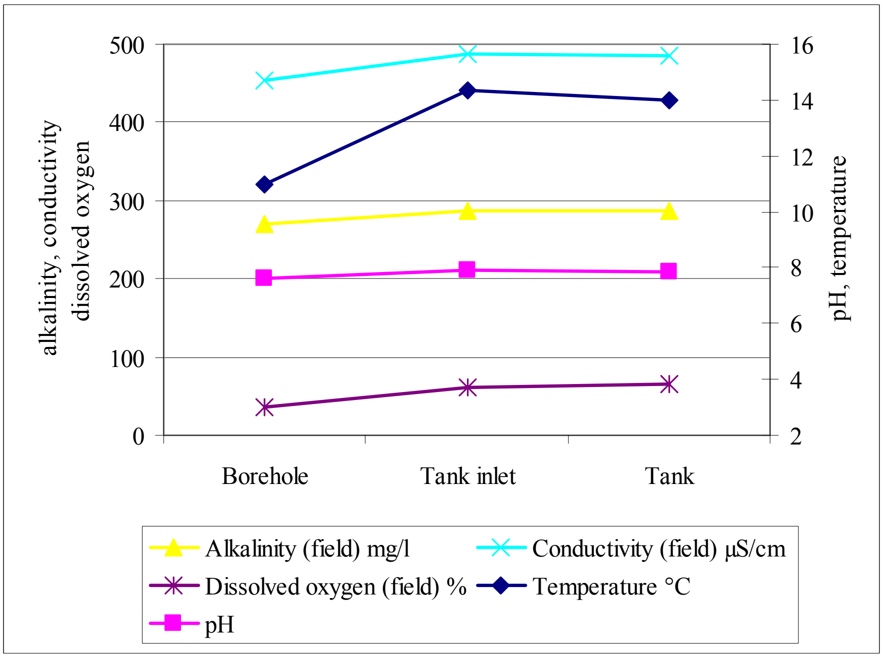


Figure 20 : Pirelli Tyres – changes in water chemistry: field determinands

1,1,1-Trichloroethane was detected in the borehole supply at a concentration of 0.121µg/l. At the inlet to the tank the solvent concentration was below the detectable limit of 0.1µg/l. The loss of solvent is likely to be attributable to aeration of the groundwater.

The storage tank is constructed of cast iron and shows signs of scaling and corrosion. Between the inlet of raw water into the tank and the water standing in the tank significant changes in any of the field or laboratory determinands were not recorded. The potential effects of corrosion and aeration, such as changes in metal concentrations and dissolved oxygen, are therefore not seen.

4.7.6 Frank Bird Poultry – borehole with storage tank

The field and laboratory data generally shows a good level of consistency over time for all sample locations at Frank Bird Poultry, and hence averaging of the data from the five sample visits was considered appropriate.

No volatile or semi-volatile organics or bacteria were detected in any of the samples taken at this site.

The borehole at Frank Bird Poultry has a sampling tap at the headworks. From the borehole groundwater is transferred a distance of 20m via alkathene pipework to a steel storage tank where a tap is fitted at the base. Between the borehole and the tank outlet there was a temperature drop of less than 1°C. The other field determinands were generally constant, with a slight drop in conductivity (Figure 19). The concentration of major ions remain generally unchanged (Figure 20), however there is a significant reduction in copper and zinc concentrations and an increase in iron concentrations. This may be attributable to a change in Redox state due to aeration, changes in microbiological activity or the interaction of water with the steel tank.

From the storage tank to the tap in the factory processing area, the water is distributed via 50m of steel and plastic pipework. The field determinands and major ions continued to remain constant, with a slight rise in conductivity. Concentrations of zinc and copper rise slightly, however iron concentrations reduced slightly at the factory tap indicating a slight change in Redox state and may be attributed to reaction of the water with the pipework and/or changes in microbiological activity.

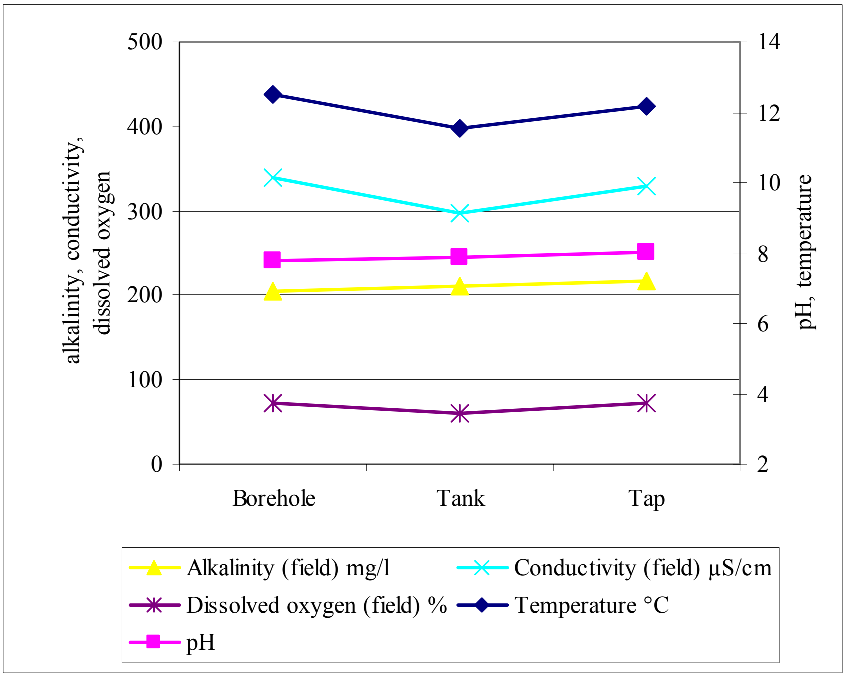


Figure 21: Frank Bird Poultry – changes in water chemistry: field determinands

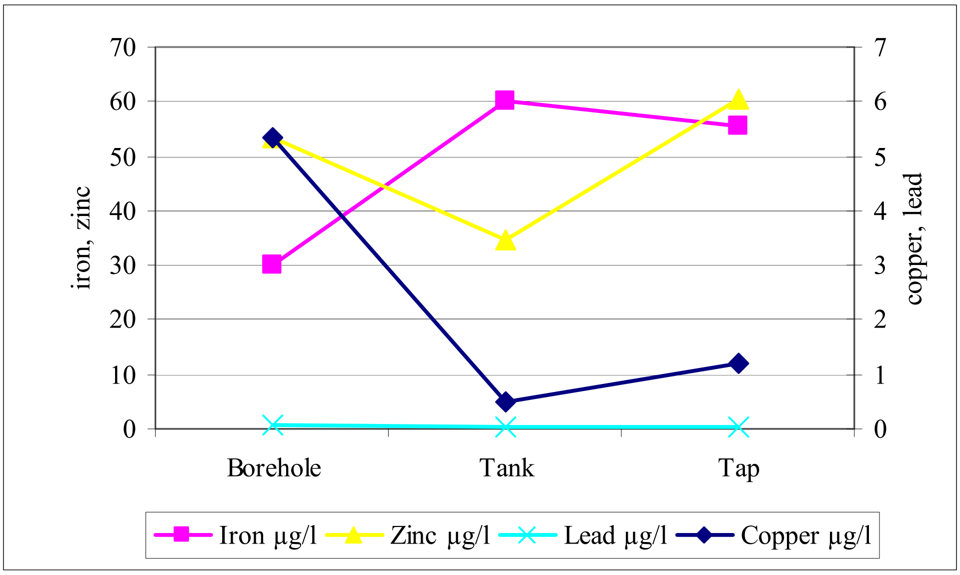


Figure 22: Frank Bird Poultry – changes in water chemistry: metals

4.8 Conclusions of the sampling exercise

At each sample location, water chemistry field determinands and major ions were generally consistent over time. Metal concentrations, principally iron, copper, zinc and aluminium were more prone to temporal fluctuation. These changes were generally independent of pH and temperature changes and may reflect the inherent instability of metal compounds in water during sampling, transportation to the laboratory and analysis.

At Site A and Far End Farm, there was little change in inorganic and organic water chemistry between the source and the spring catchpit/storage tank. Source bacteria levels were reduced in the brick catchpit at Site A, but were significantly increased in the plastic storage tank at Far End Farm. The plastic storage tank at Far End Farm also revealed pesticide concentrations not present within the source. This may indicate that the storage tank has become contaminated by water from another source or has been contaminated in the past and residual contamination is now leaching from the plastic affecting the water chemistry at this point. However, as levels of bacteria and pesticide were very low, results may reflect errors introduced during sampling or laboratory analysis.

For the two sites with pressure vessels (Highlands Farm and Newlands Mill) there was no significant change in inorganic water chemistry and bacteria levels before and after the pressure vessel. The limited change in alkalinity and dissolved oxygen indicates that loss of dissolved gases in the pressure vessel is not significant. Data are not available for organic substances at these sites, and hence the loss of volatile organics due to passage of water through the pressure vessel cannot be determined by this study.

Of the six sites sampled, three were sampled before and after a storage/header tank within the water supply system. These samples indicate that there is a slight increase in dissolved oxygen concentrations associated with aeration of the water, but little change in major ion and metal concentrations.

The length of the supply pipework had a limited affect upon water chemistry. For systems with both long (1,000m) and short (30m) lengths of pipework, comparable changes in water chemistry were seen. Concentrations of dissolved oxygen increased marginally, with little change in pH and alkalinity. Major ions and inorganic compounds were generally unchanged; with a slight decrease in metal concentrations along metal pipework and a reduction in concentrations of bacteria, volatile and semi-volatile organics.

The construction materials of the supply system were seen to affect water chemistry. The potential for plastics to sorb organic compounds and then release them back into the water was potentially observed at a plastic storage tank. However, this observation may have been due to contamination of the water in the storage tank from a source external to the system, or from contamination of the sample during field or laboratory work. Repeat sampling would be necessary to confirm results.

Variations in metal concentrations may be attributed to Redox reactions between the water and metal pipework/tanks. The most significant change in water chemistry is attributed to leaching of copper from copper water pipes. At one site, this resulted in a 4000% increase in copper concentration over a distance of approximately 40m.

5. Summary and conclusions

5.1 Overview

The literature review revealed that there is little published information specifically on changes in water chemistry within the supply systems of small groundwater supplies. Research instead concentrated on investigations into the cause of contamination of such supplies, and how to improve water quality by treatment at the point of use.

The physical, chemical and biological processes that are likely to affect water quality within these private supplies are similar to processes that affect water chemistry during groundwater sampling. Monitoring of the performance of large water distribution systems also provides information on these processes. There has been considerable research published on these topics. The review has enabled the characterisation of the processes and the determination of the likely changes in water quality. The review provided mainly theoretical examples, with a few quantified examples that can be used for comparison with the findings of the sampling exercise.

The assessment of the types, design and use of water supply systems for small groundwater sources reveals that these are highly site-specific. There are a number of system components such as catchpits, groundwater pumps, storage tanks, distribution pipework and pressure vessels. The combination of these components results in a number of generic types of distribution system. However the age of construction, intended water use and physical site layout are a few of the factors that affect the design of a system at any given site.

The sites included within the sampling exercise were selected to represent typical water supply systems associated with small groundwater sources. Even though these represented the generic system types, site-specific factors, such as high water temperature and potential contamination of the system, influenced the water chemistry at most of the sites.

The sampling exercise confirmed a number of findings reported in the published literature. Major ions appear to be stable with little change in their concentration within the water supply system. Metals were generally less stable and were influenced by construction materials as well as sampling, sample transportation and analysis. The most significant change in metal concentrations observed was copper in water that had passed through copper pipes. Some system influences on organic and microbiological determinands were observed during the sampling exercise, however firm conclusions can not be drawn from the limited available data.

5.2 Types, design and use of water supply systems

The review of Environment Agency records of small groundwater supplies confirmed the variability of design of these systems. The most significant factor controlling supply system design is whether the source is a spring or a borehole/well.

Springs are predominantly gravity fed, although there are sites where a pump is used to transfer water, usually because the point of use is at a higher level than the source. The integrity of the supply system is critical for spring sources that are prone to ingress of surface water run-off during periods of heavy rainfall. Dilution of groundwater parameters combined with changes in colour and turbidity are usual indicators of contamination by surface water run-off. Studies of drinking water supplies have shown that contaminants such as *Cryptosporidium* can be introduced to the system through the ingress of surface water run-off.

Boreholes/wells are usually fitted with a submersible pump. The construction materials used for the borehole and the type of groundwater pump are not always recorded in the existing site characterisation records. In a similar way to springs, boreholes, where the integrity of the headworks is poor, are at risk of contamination from surface water run-off.

Pressure vessels within water supply systems are usually of simple manufactured design and are typically constructed of steel. The size and number of pressure vessel within the system will vary depending upon water use. Storage tanks can be constructed of a range of materials, for example older tanks being of cast iron and more modern tanks of galvanised steel or plastic. Storage tanks may not be covered and can therefore lead to contamination from external sources. Storage tanks are also prone to silting and the amount of silt can give rise to changes in water quality over time.

The length of water distribution pipework varies considerably, as do the construction materials. Often, as the pipework is buried, the construction materials are not known and the integrity of the pipework can not be confirmed. Clay pipes are often used in older systems, with more modern systems having plastic and copper pipes. Lead pipes are also likely to be common, although none of the sites studied in the sampling exercise had lead pipework.

The water supply systems of private water supplies have many points where the physical, chemical and biological processes that affect water quality are likely to change. The most significant changes are likely to occur when water is pumped to the ground surface from a borehole. This sampling exercise has not been able to assess this factor, as the first sample location at borehole sources was after the groundwater pump. There has been substantial research quantifying the effect of pumping groundwater on water quality. This was reviewed as part of this study. The points within the supply system where water quality is most likely to change are where there is an increase in water temperature combined with aeration. This will most likely occur at the groundwater pump, in open pipework and at storage/header tanks. Water residence times and ambient temperatures at these points within the system will be critical factors controlling the degree of temperature change and aeration.

The operation of the system is also likely to affect water quality. Where there is a constant supply and a constant level of use, then water quality at any given point is not likely to change with time. However, sites that have groundwater pumps that operate intermittently are more likely to give rise to pulses of water passing through the system as it is discharged and then filled. Stationary water within the system allows interaction to occur between the water and the construction materials, altering the water chemistry. Pulses of water from the source results in mixing with water already stored within the system and permits reaction between the two waters. This can represent a significant factor in assessing water quality. It can be difficult to determine whether water usage since the previous sampling visit has remained the same and therefore whether residence times within the system are comparable, hence what impact this has had on water quality

5.3 Processes initiating changes in water quality

The chemistry of the groundwater at source will determine, to a certain extent, the type and degree of change in chemistry within the water supply system.

The review determined the processes that would initiate changes in water quality could be classified as follows:

- changes in water temperature and pressure;
- aeration, which would also give rise to temperature and pressure changes;
- interaction of the water with construction materials;
- mixing of water from external sources; and
- changes in water quality at source.

The site-specific factors that may influence these processes were considered to be as follows:

- the type of source (i.e. borehole/well or a spring);
- the length of the water distribution pipework;
- the presence of storage or header tanks;
- the presence of a pressure vessel;
- the construction of the system including materials and layout; and
- the system use and maintenance practices at the site.

5.3.1 Water temperature and pressure changes

Water temperature affects the solubility of dissolved gases, the solubility of salts and hydrocarbons; vapour pressures and volatilisation, chemical reaction rates, and microbial activity. The literature review concluded that increases in temperature are likely to be one of the most significant factors that would influence water quality within the supply system.

Pressure changes are often associated with temperature changes, and will affect the solubility of dissolved gases and vapour pressures of volatile and semi-volatile hydrocarbons. Groundwater with high dissolved gas concentrations will be more susceptible to changes in dissolved gas concentrations. The degassing of these waters will then also act to increase volatilisation of volatile organic compounds.

The use of groundwater pumps can result in a change in water temperature and pressure, the degree of change is dependant upon the type of groundwater pump and its pumping rate. For submersible pumps, the most common type of pump in use in the water systems of small supplies, research has shown that high water temperatures are produced when the pump is first started. Low flow rates are also more likely to result in increased water temperature than high flow rates due to the residence time of water within the pump.

Research has also shown that pumps such as surface centrifugal and piston pumps, which operate by applying pressure to the water, will have the most marked affect on water pressure. Gear driven and helical rotor pumps, such as may be located in-line within the distribution pipework, may also have an affect on water pressure.

For sites with groundwater pumps, the sampling exercise did not reveal significant rises in groundwater temperature from the anticipated temperatures of water within the ground of 10°C or 12°C. This is perhaps due to the fact that the pumps were in continuous operation at high flow rates during sampling.

Within the distribution system, water temperatures are a function of ambient temperatures and residence times of water within areas of higher or lower air temperature. The sampling exercise was carried out during winter months and moderate rises in water temperature of upto 3°C through the supply system were observed at several sites. During the summer, with higher ambient air temperatures, more marked temperatures rises may be expected.

Significant changes in water temperature were observed at storage tanks in rooms that were heated, such as at the Pirelli boiler house or the loft header tanks at Site A. Here water temperatures rose 4.5°C and 6.5°C respectively. This level of temperature rise is likely to initiate changes in chemical and microbiological processes, and increase chemical reaction rates, although little change in water chemistry was recorded (with the exception of copper at Site A).

5.3.2 Aeration and volatilisation

Studies have shown that aeration, with its associated pressure and sometimes temperature changes, can cause degassing of dissolved gases and volatilisation of volatile and semi-volatile compounds. High dissolved gas concentrations in groundwater are likely to increase volatilisation as the process of degassing has a marked effect on vapour pressure.

Aeration will occur within groundwater pumps and any points within the supply system where water is in contact with air, such as storage tanks, open pipework and at taps and other points of use. The degree of aeration will be a function of the surface area of water relative to air, which can be enhanced by turbulence, and the residence time of the water in that part of the system.

Dissolved oxygen is an indicator of aeration, as groundwater should have a low dissolved oxygen concentration. The sampling exercise revealed that at all sites, groundwaters had been aerated to some degree at the first sample location of the system, with dissolved oxygen concentrations averaging 70% at these points. The most marked changes in dissolved oxygen concentration were seen within a pressure vessel, where the dissolved oxygen concentration was reduced by a third.

Increases in dissolved oxygen concentrations will result in complex and inter-related changes in water chemistry. Dissolved oxygen will drive Redox reactions, affect chemical equilibrium and microbial activity. This can result in changes in water pH and alkalinity, cause the precipitation or dissolution of metal oxides, which in turn can lead to changes in sorption and ion exchange processes.

The literature review identified examples of volatilisation where approximately 10% of volatile chlorinated solvents were lost due to aeration of groundwater. This percentage loss increased to approximately 30% when the groundwaters were charged with high dissolved gas concentrations. Within the sampling exercise, the loss of volatile organics was observed within the limited data set and is indicative of these processes. However, the findings are largely inconclusive as there is insufficient data for a valid statistical analysis.

5.3.3 Chemical reactions

The effects of increases in water temperature, decreases in pressure and aeration will affect chemical equilibria such as the carbonate system. Changes in dissolved gas concentrations will change the ratios of carbonate and bicarbonate. Dissociation of carbonate species will buffer these changes and a rise in alkalinity through the supply system was observed at most sites.

Increases in dissolved oxygen concentrations are likely to promote oxidation reactions. Changes in water chemistry purely due to changes in dissolved oxygen could not be differentiated from the contribution of metal corrosion of construction materials. The complex relationships of chemical equilibria, Redox reactions, sorption and ion exchange could not be fully determined from the sampling study. This would require complex modelling of water residence times, construction materials and a better knowledge of the system integrities and microbiological activities.

5.3.4 Interaction with construction materials

Research on corrosion of construction materials within water distribution systems presents many examples of changes in water quality. Corrosion may be due to: physical abrasion releasing substances in to the water; chemical interactions such as Redox reactions between metals in solution and metal pipework (metal corrosion); leaching or dissolution of substances from within the construction material; sorption and desorption processes. Microbial colonisation of construction materials, such as the formation of biofilms can produce a microenvironment within the system that can affect water quality.

These interactions of water and construction materials will occur anywhere within the system, however factors such as the type of material, water temperature, water flow rates and water turbulence will affect the degree of corrosion.

Research has shown that abrasion and chemical corrosion of concrete and cement products can result in an increase in suspended solids. The sampling exercise did not discover examples of corrosion of concrete/cement and hence no conclusions can be drawn on this subject.

Interaction of groundwater with metal and plastic products has been studied in relation to the use of materials in groundwater sampling equipment, and the stability of building products in aggressive ground conditions.

Research has shown that plastic and metal materials can absorb metals and organics from groundwater. Plastics are generally more likely to absorb substances than metals. Polypropylenes are less likely to absorb organics than polyethlyenes and uPVC, and stainless steels are less likely to sorb organics than galvanised steel. Studies have shown that between 5% and 10% of volatile solvents can be absorbed from groundwater onto plastics, with the residence time of the water and the type of plastic being controlling factors. Plastics also have the potential to leach constituents or to desorb substances back into the groundwater. The sampling exercise discovered a plastic storage tank with pesticide contaminated groundwater where the source did not contain pesticides. One explanation for this could be that the tank had been contaminated in the past by these pesticides and that these were now leaching out of the plastic into the supply. However the limited data for this site means that these findings were inconclusive.

Metal corrosion is potentially a significant factor in assessing the interactions of groundwater with the supply system construction materials. Corrosion of steel pipework within water supply systems will result in a change in concentrations of iron, zinc, nickel and chromium. This effect was potentially observed during the sampling exercise at Frank Bird Poultry. Between the borehole and the steel storage tank, groundwater is transferred in plastic pipework. Water in the tank had lower copper and zinc concentrations and higher iron concentrations, which may be due to metal corrosion or precipitation within the tank. However the changes in metal concentrations were not significantly higher than the variation observed at most sites in the study.

The most significant observed effect on water chemistry was the increase in copper concentrations due to the presence of copper pipes. Increases of upto 4,000% for acid groundwaters were observed during the sampling exercise, however significant increases were also observed for neutral groundwaters. Similar increases in lead concentrations related to lead pipes should be expected.

The literature review identified that supply pipework provides an environment for the growth of biofilms, which can affect organic/inorganic water chemistry as well as bacteria levels within the water. The sampling exercise identified that bacteria levels were not significantly affected by the supply pipework, however the effect of biofilms was probably not observed at the selected sites.

6 Recommendations

6.1 Further evaluation of water quality

The literature review has determined that organic contaminants within groundwater are susceptible to processes of biodegradation, volatilisation and sorption within the water supply systems associated with small groundwater sources. Factors such as water temperature, changes in pressure, degassing and microbial activity can influence these processes. For many of the sites included within the sampling study, there were no organic contaminants at the first sample location within the water distribution system and hence there were not any changes through the system to observe. Interpretations have been made on the limited data obtained that is generally inconclusive. Further investigation is warranted into changes in concentrations of organic contaminants within water supply systems. This investigation should seek to obtain more data and target a smaller number of organic contaminants selected to represent a range of volatilities. The sites assessed should also be selected to provide a range of facility types and construction materials.

Microbiological activity within water supply systems is a complex inter-relationship of chemical, physical and microbiological processes. The literature review has revealed instances where microbial activity is enhanced or is inhibited. The sampling exercise produced some data on bacterial contaminants within these systems, based on which limited conclusions were drawn. Sampling and analysis for bacteria and viruses within groundwater requires special field and laboratory techniques. An improved study specifically designed for investigating microbial activity would provide more conclusive data on which guidance for site selection and sampling could be based. The study will need to take into account quality control procedures specific for sampling and analysis of bacteriological samples. This may include requirements such as sterilising sample locations before sample collection and the analysis of samples within 8 hours of collection.

6.2 Assessment of suitable sampling locations

Before selecting a small groundwater source as a Groundwater Quality Monitoring Network (GWQN) site, a detailed assessment of the site is needed. The suitability of the site will need to be assessed on an ongoing basis, with the site owner providing reliable information regarding changes to the system design and operation.

In evaluating the suitability for inclusion within the GWQN of a sample location within the water supply system of a private supply, the following factors need to be considered:

1. The integrity of the supply system upto the sample location point must be assured, especially for spring sources. This should be determined on a site-by-site basis, for integrity during normal conditions and during periods of heavy rain and flood.

2. The effect of the groundwater pump type and its operational pumping rate are important factors to be considered in evaluating the suitability of a sample location at a private supply. Submersible centrifugal pumps should be satisfactory, however surface suction pumps should be avoided. The pump rate for most private supplies

should be sufficiently high to minimise the temperature increases that can be seen at low flow rates.

3. The water temperature at the sample location should be as close to the groundwater temperature as possible, and generally no more than 5°C higher. The supply system before the sample location should be reviewed in order to assess the likelihood of ambient temperatures warming the groundwater. This will occur where water is stored in tanks within heated buildings, or areas that are prone to surface heating during the summer months.

4. A sample tap at the headworks of a borehole, or a spring catchpit, will always present the best location within a water supply system for sampling. The presence of storage tanks, pressure vessels and long supply pipework may give rise to slight changes in dissolved oxygen concentrations, and are likely to have little significant effect upon the chemistry of major ions, inorganics and metals (excluding corrosion effects). However these present a significant likelihood of loss of volatile and semi-volatile organics and should therefore be avoided.

5. The residence time of the water within the system between the source and the sample location should be minimised. For example, at storage and header tanks, the intermittent operation of pumps and pressure vessels can result in pulses of cold water being discharged into water that has been resident in the tank for some time. Samples should only be taken at or after storage tanks if the volume of water used or purged from the tank can assure that the water sampled has not been standing for some time. Otherwise, it may be necessary to purge the system before sampling is carried out

6. The condition of supply system and the likelihood of the presence/development of biofilms or corrosion of construction materials should be assessed. The construction materials should be identified in order to determine the potential for reaction of these with the groundwater.

7. The likely source groundwater chemistry should be evaluated and its effect upon the construction materials determined. This will include: pH for corrosion of copper, lead and zinc galvanising; chloride concentrations and their effect upon steel; and salt concentrations and effects on zinc galvanising.

8. Before adding a site to the Groundwater Quality Monitoring Network, it is recommended that a full suite of analysis is undertaken and assessed, in order to identify any site specific issues or areas for concern.

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APPENDIX A:
ANALYTICAL DATA – SITE A

Analyte	**Units**	**Spring**	**Catchpit**	**Outside Tap**	**Header Tank**	**Room Tap**
TEMPERATURE	°C	11.9	11.8	14.2	14.4	19.0
PH (FIELD)	pH UNITS	6.2	6.2	6.0	6.1	6.2
PH (LABORATORY)	pH UNITS	5.98	6.00	5.97	6.13	6.19
ALKALINITY (FIELD)	mg/l	27	28	14	22	18
ALKALINITY PH 4.5 - AS CACO3	mg/l	10.1	10.6	9.4	10.0	10.5
CONDUCTIVITY (FIELD)	µS/cm	108	111	96	111	110
CONDUCTIVITY @25C	µS/cm	127	127	124	125	125
DISSOLVED OXYGEN (FIELD)	%	61.7	63.6	92.6	83.5	88.0
AMMONIA - AS N	mg/l	0.03	0.03	0.03	0.03	0.03
CHLORIDE ION - AS CL	mg/l	23.1	22.8	22.5	22.4	22.1
NITRITE - AS N	mg/l	0.004	0.004	0.004	0.004	0.004
NITROGEN TOTAL OXIDISED - AS N	mg/l	0.444	0.366	0.378	0.386	0.409
ORTHOPHOSPHATE - AS P	mg/l	0.041	0.021	0.020	0.033	0.066
BROMIDE ION - AS BR	mg/l	0.05	0.05	0.06	0.06	0.05
FLUORIDE - AS F	mg/l	0.05	0.05	0.05	0.05	0.05
CADMIUM - AS CD	µg/l	0.1	0.1	0.1	0.2	0.1
CHROMIUM - AS CR	µg/l	0.5	0.5	0.5	0.5	0.5
COPPER - AS CU	µg/l	0.5	0.9	18.2	191.7	733.8
LEAD - AS PB	µg/l	0.4	0.9	2.4	15.4	5.2
NICKEL - AS NI	µg/l	5	5	5	5	5
ZINC - AS ZN	µg/l	13.5	55.3	8.4	26.8	60.4
ARSENIC - AS AS	µg/l	1	1	1	1	1
ALUMINIUM - AS AL	µg/l	15.2	32.7	10.3	22.9	10.7
BARIUM - AS BA	µg/l	13.5	14.4	12.9	11.8	11.3
BORON - AS B	µg/l	100	100	100	100	100
CALCIUM - AS CA	mg/l	5.89	6.08	5.69	5.76	5.76
IRON - AS FE	µg/l	33	61	30	82	30
MAGNESIUM - AS MG	mg/l	2.05	2.07	2.09	2.10	2.14
MANGANESE - AS MN	µg/l	10	10	10	10	10
POTASSIUM - AS K	mg/l	0.580	0.603	0.602	0.610	0.590
SODIUM - AS NA	mg/l	12.5	12.5	12.3	12.5	12.2
STRONTIUM - AS SR	µg/l	14	15	14	15	14
SULPHATE - AS SO4	mg/l	8.30	8.29	8.63	8.78	8.64
MERCURY - AS HG	µg/l	0.024	0.015	0.018	0.015	0.014
BERYLLIUM - AS BE	µg/l	1	1	1	1	1
COBALT - AS CO	µg/l	1	1	1	1	1
SILVER - AS AG	µg/l	1	1	1	1	1
VANADIUM - AS V	µg/l	1	1	1	1	1

Analyte	Units	Spring	Catchpit	Outside Tap	Header Tank	Room Tap
SILICATE REACTIVE DISSOLVED - AS SIO2	mg/l	5.76	5.74	5.66	5.60	5.58
SELENIUM - AS SE	µg/l	1	1	1	1	1
NITRATE - AS N	mg/l	0.5	0.5	0.5	0.5	0.5
1,1,1-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1	<0.1	<0.1
1,1,2-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1	<0.1	<0.1
1,2-DICHLOROETHANE {ETHYLENE	µg/l	<1	<1	<1	<1	<1
1,3-DICHLOROBENZENE	µg/l	<1	<1	<1	<1	<1
1,4-DICHLOROBENZENE	µg/l	<1	<1	<1	<1	<1
BENZENE	µg/l	<3	<3	<3	<3	<3
BROMODICHLOROMETHANE	µg/l	<0.05	<0.05	<0.05	<0.05	<0.05
ETHYLBENZENE	µg/l	<10	<10	<10	<10	<10
TETRACHLOROETHENE	µg/l	<0.1	<0.1	<0.1	<0.1	<0.1
TETRACHLOROMETHANE {CARBON	µg/l	<0.1	<0.1	<0.1	<0.1	<0.1
TOLUENE (METHYLBENZENE)	µg/l	<4	<4	<4	<4	<4
TRIBROMOMETHANE {BROMOFORM}	µg/l	<0.2	<0.2	<0.2	<0.2	<0.2
TRICHLOROETHENE	µg/l	<0.1	<0.1	<0.1	<0.1	<0.1
FLUMETHRIN	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
CHLORPYRIFOS	µg/l	<0.02	<0.02	<0.02	<0.02	<0.02
CHLORPYRIPHOS METHYL	µg/l	<0.02	<0.02	<0.02	<0.02	<0.02
FENPROPIMORPH	µg/l	<0.02	<0.02	<0.02	<0.02	<0.02
IPRODIONE	µg/l	<0.0200	<0.0200	<0.0200	<0.0200	<0.0200
TECNAZENE	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
1,2,3-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
1,2,4-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
1,3,5-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
ALDRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
CYPERMETHRIN	µg/l	<0.010	<0.010	<0.010	<0.010	<0.010
DDE (OP)	µg/l	<0.002	<0.002	<0.002	<0.002	<0.002
DDE (PP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
DDT (OP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
DDT (PP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
DIELDRIN	µg/l		<0.0025	<0.0025	<0.0025	<0.0025

Analyte	Units	Spring	Catchpit	Outside Tap	Header Tank	Room Tap
		<0.0025				
ENDOSULPHAN ALPHA	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
ENDOSULPHAN BETA	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
ENDRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
HCH ALPHA	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
HCH BETA	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
HCH DELTA	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
HCH GAMMA	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
HEPTACHLOR	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
HEPTACHLOR EPOXIDE	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
HEXACHLOROBENZENE	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
HEXACHLOROBUTADIENE	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
ISODRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025	<0.0025
METHOXYCHLOR	µg/l	<0.005	<0.005	<0.005	<0.005	<0.005
PERMETHRIN, CIS	µg/l	<0.001	0.0025	<0.001	<0.001	<0.001
PERMETHRIN, TRANS	µg/l	<0.001	0.0052	<0.001	<0.001	<0.001
TDE (OP)	µg/l	<0.002	<0.002	<0.002	<0.002	<0.002
TDE (PP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015	<0.0015
TRIFLURALIN	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
PCB CONGENER 028	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 052	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 101	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 105	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 118	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 138	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 153	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 156	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 180	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
ATRAZINE { }	µg/l	<0.03	<0.03	<0.03	<0.03	<0.03
AZINPHOS-ETHYL	µg/l	<0.02	<0.02	<0.02	<0.02	<0.02
AZINPHOS-METHYL	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001

Analyte	Units	Spring	Catchpit	Outside Tap	Header Tank	Room Tap
CARBOPHENOTHION	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
CHLORFENVINPHOS	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
COUMAPHOS	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
DIAZINON	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
DICHLORVOS	µg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
ETHION	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
FENCHLORPHOS {RONNEL.}	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
FENTHION	µg/l	<0.01	<0.01	<0.01	<0.01	<0.01
MALATHION	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
PARATHION-METHYL { }	µg/l	<0.015	<0.015	<0.015	<0.015	<0.015
PROPAZINE	µg/l	<0.014	<0.014	<0.014	<0.014	<0.014
PROPETAMPHOS	µg/l	<0.001	<0.001	<0.001	<0.001	<0.001
SIMAZINE	µg/l	<0.03	<0.03	<0.03	<0.03	<0.03
TRIAZOPHOS	µg/l	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
COLIFORMS, TOTAL, PRESUMPTIVE	NO/100 ml	12	<1	5	<1	<1
FAECAL COLIFORMS, CONFIRMED	NO/100 ml	<1	<1	<1	<1	<1
FAECAL COLIFORMS,PRESUMPTIVE	NO/100 ml	<1	<1	<1	<1	<1
STREPTOCOCCI FAECAL CONF-MPN	NO/100 ml	35	2	<1	<1	<1
STREPTOCOCCI FAECAL PRE-MF	NO/100 ml	35	2	<1	<1	<1
TOTAL COLIFORMS CONFIRMED -MF	NO/100 ml	12	<1	5	<1	<1

APPENDIX B: ANALYTICAL DATA – FAR END FARM

ANALYTE	UNITS	Spring	Storage Tank	Garage Tap
TEMPERATURE (FIELD)	°C	7.8	8.88	9.9
PH (FIELD)	PH UNITS	8.12	8.15	7.97
PH - AS PH UNITS	PH UNITS	7.78	7.89	7.85
ALKALINITY (FIELD)	mg/l	86.2	110.2	109.2
ALKALINITY PH 4.5 - AS CACO3	mg/l	54.7	97.9	99.5
CONDUCTIVITY (FIELD)	µS/cm	105.7	156.2	159.2
CONDUCTIVITY @25C	µS/cm	149	219	221
DISSOLVED OXYGEN (FIELD)	%	85.1	77.2	92.2
CHRMOIUM - CR	µg/l	3.03	0.56	0.50
COPPER - CU	µg/l	1.275	1.142	5.40
ALUMINIUM - AL	µg/l	121	71	58.7
IRON - FE	µg/l	775	365	330
MANGANESE - MN	µg/l	52.5	13.1	10.0
AMMONIA - AS N	mg/l	0.04	0.03	0.04
CHLORIDE ION - AS CL	mg/l	5.66	6.22	6.24
NITRITE - AS N	mg/l	0.006	0.005	0.007
NITROGEN TOTAL OXIDISED - AS N	mg/l	0.27	0.369	0.343
ORTHOPHOSPHATE - AS P	mg/l	0.10	0.040	0.115
BROMIDE ION - AS BR	mg/l	0.05	0.05	0.05
FLUORIDE - AS F	mg/l	0.05	0.058	0.061
CADMIUM - AS CD	µg/l	0.1	0.1	0.1
LEAD - AS PB	µg/l	1.50	0.51	0.54
NICKEL - AS NI	µg/l	5	5	5
ZINC - AS ZN	µg/l	6.59	6.00	6.26
ARSENIC - AS AS	µg/l	1	1	1
BARIUM - AS BA	µg/l	34.4	44.2	43.7
BORON - AS B	µg/l	100	100	100
CALCIUM - AS CA	mg/l	23.1	35.25	35.4
MAGNESIUM - AS MG	mg/l	2.62	3.94	3.95
POTASSIUM - AS K	mg/l	0.639	1.024	0.990
SODIUM - AS NA	mg/l	3.94	4.46	4.44
STRONTIUM - AS SR	µg/l	108	171	171
SULPHATE - AS SO4	mg/l	12.4	10.8	10.7
MERCURY - AS HG	µg/l	0.011	0.010	0.012
BERYLLIUM - AS BE	µg/l	1	1	1
COBALT - AS CO	µg/l	1	1	1
SILVER - AS AG	µg/l	1	1	1
VANADIUM - AS V	µg/l	1	1	1
SILICATE REACTIVE DISSOLVED - AS SIO2	mg/l	3.6	4.4	4.3
SELENIUM - AS SE	µg/l	1	1	1
NITRATE - AS N	mg/l	0.5	0.5	0.5
1,2,3-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
1,2,4-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
1,3,5-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
ALDRIN	µg/l	<0.0025	<0.0025	<0.0025
CYPERMETHRIN	µg/l	<0.010	<0.010	<0.010
DDE (OP)	µg/l	<0.002	<0.002	<0.002

ANALYTE	UNITS	Spring	Storage Tank	Garage Tap
DDE (PP)	µg/l	<0.0015	<0.0015	<0.0015
DDT (OP)	µg/l	<0.0015	<0.0015	<0.0015
DDT (PP)	µg/l	<0.0015	<0.0015	<0.0015
DIELDRIN	µg/l	<0.0025	<0.0025	<0.0025
ENDOSULPHAN ALPHA	µg/l	<0.005	<0.005	<0.005
ENDOSULPHAN BETA	µg/l	<0.005	<0.005	<0.005
ENDRIN	µg/l	<0.0025	<0.0025	<0.0025
HCH ALPHA	µg/l	<0.001	<0.001	<0.001
HCH BETA	µg/l	<0.005	<0.005	<0.005
HCH DELTA	µg/l	<0.001	<0.001	<0.001
HCH GAMMA	µg/l	0.0058	<0.001	<0.001
HEPTACHLOR	µg/l	<0.005	<0.005	<0.005
HEPTACHLOR EPOXIDE	µg/l	<0.005	<0.005	<0.005
HEXACHLOROBENZENE	µg/l	<0.001	<0.001	<0.001
HEXACHLOROBUTADIENE	µg/l	<0.005	<0.005	<0.005
ISODRIN	µg/l	<0.0025	<0.0025	<0.0025
METHOXYCHLOR	µg/l	<0.005	<0.005	<0.005
PERMETHRIN, CIS	µg/l	<0.001	<0.001	<0.001
PERMETHRIN, TRANS	µg/l	<0.001	<0.001	<0.001
TDE (OP)	µg/l	<0.002	<0.002	<0.002
TDE (PP)	µg/l	<0.0015	<0.0015	<0.0015
TRIFLURALIN	µg/l	<0.01	<0.01	<0.01
PCB CONGENER 028	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 052	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 101	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 105	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 118	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 138	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 153	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 156	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 180	µg/l	<0.001	<0.001	<0.001
ATRAZINE { }	µg/l	<0.03	0.0605	<0.03
AZINPHOS-ETHYL	µg/l	<0.02	<0.02	<0.02
AZINPHOS-METHYL	µg/l	<0.001	<0.001	<0.001
CARBOPHENOTHION	µg/l	<0.01	<0.01	<0.01
CHLORFENVINPHOS	µg/l	<0.001	0.00115	<0.001
COUMAPHOS	µg/l	<0.001	<0.001	<0.001
DIAZINON	µg/l	<0.001	<0.001	<0.001
DICHLORVOS	µg/l	<0.0005	<0.0005	<0.0005
ETHION	µg/l	<0.01	<0.01	<0.01
FENCHLORPHOS {RONNEL.}	µg/l	<0.001	<0.001	<0.001
FENTHION	µg/l	<0.01	<0.01	<0.01
MALATHION	µg/l	<0.001	<0.001	<0.001
PARATHION-METHYL { }	µg/l	<0.015	<0.015	<0.015
PROPAZINE	µg/l	<0.014	<0.014	<0.014
PROPETAMPHOS	µg/l	<0.001	0.0016	<0.001
SIMAZINE	µg/l	<0.03	0.0586	<0.03
TRIAZOPHOS	µg/l	<0.0005	<0.0005	<0.0005
COLIFORMS, TOTAL, PRESUMPTIVE	NO/100ml	171	1818	460
FAECAL COLIFORMS, CONFIRMED	NO/100ml	144	711	660

ANALYTE	UNITS	Spring	Storage Tank	Garage Tap
FAECAL COLIFORMS,PRESUMPTIVE	NO/100ml	144	790	660
STREPTOCOCCI FAECAL CONF-MPN	NO/100ml	117	126	81
STREPTOCOCCI FAECAL PRE-MF	NO/100ml	117	126	90
TOTAL COLIFORMS CONFIRMED -MF	NO/100ml	171	1454	460
1,1,1-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1
1,1,2-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1
1,2-DICHLOROETHANE {ETHYLENE	µg/l	<1	<1	<1
1,3-DICHLOROBENZENE	µg/l	<1	<1	<1
1,4-DICHLOROBENZENE	µg/l	<1	<1	<1
BENZENE	µg/l	<3	<3	<3
BROMODICHLOROMETHANE	µg/l	<0.05	<0.05	<0.05
ETHYLBENZENE	µg/l	<10	<10	<10
TETRACHLOROETHENE	µg/l	<0.1	<0.1	<0.1
TETRACHLOROMETHANE {CARBON	µg/l	<0.1	<0.1	<0.1
TOLUENE (METHYLBENZENE)	µg/l	<4	<4	<4
TRIBROMOMETHANE {BROMOFORM}	µg/l	<0.2	<0.2	<0.2
TRICHLOROETHENE	µg/l	<0.1	<0.1	<0.1
FLUMETHRIN	µg/l	<0.001	<0.001	<0.001
CHLORPYRIFOS	µg/l	<0.02	<0.02	<0.02
CHLORPYRIPHOS METHYL	µg/l	<0.02	<0.02	<0.02
FENPROPIMORPH	µg/l	<0.02	<0.02	<0.02
IPRODIONE	µg/l	<0.0200	<0.0200	<0.0200
TECNAZENE	µg/l	<0.01	<0.01	<0.01

APPENDIX C: ANALYTICAL DATA – HIGHLANDS FARM

Sample Description:	**Units**	**PV inlet**	**PV outlet**	**Tap**
TEMPERATURE (FIELD)	°C	9.6	8.9	7.7
PH (FIELD)	PH UNITS	7.31	7.29	7.7
PH - AS PH UNITS	PH UNITS	7.43	7.28	7.67
ALKALINITY (FIELD)	mg/l	294	273	318
ALKALINITY PH 4.5 - AS CACO3	mg/l	245	246	240
CONDUCTIVITY (FIELD)	µS/cm	412	404	386
CONDUCTIVITY @25C	µS/cm	582	582	569
DISSOLVED OXYGEN (FIELD)	%	88	92	96.8
COPPER - AS CU	µg/l	2.32	2.01	155
AMMONIA - AS N	mg/l	0.077	0.079	0.083
CHLORIDE ION - AS CL	mg/l	13.6	13.6	13.9
NITRITE - AS N	mg/l	0.011	0.011	0.011
NITROGEN TOTAL OXIDISED - AS N	mg/l	9.03	8.86	8.59
ORTHOPHOSPHATE - AS P	mg/l	0.043	0.042	0.045
BROMIDE ION - AS BR	mg/l	0.05	0.06	0.06
FLUORIDE - AS F	mg/l	0.08	0.08	0.087
CADMIUM - AS CD	mg/l	0.1	0.1	0.1
CHROMIUM - AS CR	µg/l	0.5	0.5	0.5
LEAD - AS PB	µg/l	0.611	0.429	1.41
NICKEL - AS NI	µg/l	5	5	5
ZINC - AS ZN	µg/l	121	132	119
ARSENIC - AS AS	µg/l	1.0	1.0	1
ALUMINIUM - AS AL	µg/l	12.1	10.0	10
BARIUM - AS BA	µg/l	13.5	13.4	13.6
BORON - AS B	µg/l	100	100	100
CALCIUM - AS CA	mg/l	112	107	102
IRON - AS FE	µg/l	37.3	38.3	30
MAGNESIUM - AS MG	mg/l	2.19	2.28	2.45
MANGANESE - AS MN	µg/l	10	10	10
POTASSIUM - AS K	mg/l	0.420	0.448	0.512
SODIUM - AS NA	mg/l	6.62	6.49	6.61
STRONTIUM - AS SR	µg/l	262	275	302
SULPHATE - AS SO4	mg/l	22.7	22.7	23
MERCURY - AS HG	µg/l	0.038	0.010	0.015
BERYLLIUM - AS BE	µg/l	1.0	1.0	1
COBALT - AS CO	µg/l	1.0	1.0	1
SILVER - AS AG	µg/l	1.0	1.0	1
VANADIUM - AS V	µg/l	1.0	1.0	1
SILICATE REACTIVE DISSOLVED - AS SIO2	mg/l	10.3	10.2	11.1
SELENIUM - AS SE	µg/l	1.0	1.0	1
NITRATE - AS N	mg/l	9.02	8.85	8.58

APPENDIX D: ANALYTICAL DATA – NEWLANDS MILL FARM

Sample Description:	**Units**	**Borehole**	**PV Outlet**	**Trough without sample 2**	**Trough with sample 2**
TEMPERATURE (FIELD)	°C	10.3	10.4	10.5	9.8
PH (FIELD)	PH UNITS	7.6	7.5	7.6	7.6
PH - AS PH UNITS	PH UNITS	7.58	7.52	7.68	7.67
ALKALINITY (FIELD)	mg/l	239	243	238	241
ALKALINITY PH 4.5 - AS CACO3	mg/l	205	206	207	206
CONDUCTIVITY (FIELD)	µS/cm	364	345	369	360
CONDUCTIVITY @25C	µS/cm	474	474	474	474
DISSOLVED OXYGEN (FIELD)	%	27.9	9.3	55.0	56.0
COPPER -AS CU	µg/l	0.883	4.180	7.686	14.355
LEAD - AS PB	µg/l	0.592	0.726	1.616	8.930
SZINC - AS ZN	µg/l	34.2	10.2	16.9	33.9
IRON - AS FE	µg/l	167.40	218.83	418.02	1925.02
AMMONIA - AS N	mg/l	0.0	0.0	0.0	0.0
CHLORIDE ION - AS CL	mg/l	10.5	10.5	10.5	10.5
NITRITE - AS N	mg/l	0.0040	0.0040	0.0040	0.0040
NITROGEN TOTAL OXIDISED - AS N	mg/l	1.19	1.19	1.19	1.19
ORTHOPHOSPHATE - AS P	mg/l	0.0203	0.02	0.0208	0.0210
BROMIDE ION - AS BR	mg/l	0.05	0.05	0.05	0.05
FLUORIDE - AS F	mg/l	0.075	0.077	0.077	0.077
CADMIUM - AS CD	µg/l	0.100	0.100	0.100	0.100
CHROMIUM - AS CR	µg/l	0.500	0.500	0.517	0.986
NICKEL - AS NI	µg/l	5.000	5.000	5.000	5.000
ARSENIC - AS AS	µg/l	1.00	1.00	1.00	1.51
ALUMINIUM - AS AL	µg/l	10.0	10.0	10.0	24.1
BARIUM - AS BA	µg/l	12.6	12.8	12.9	13.7
BORON - AS B	µg/l	100	100	100	100
CALCIUM - AS CA	mg/l	73.7	74.2	73.0	73.2
MAGNESIUM - AS MG	mg/l	13.6	13.8	13.7	13.7
MANGANESE - AS MN	µg/l	10.0	10.0	10.0	18.4
POTASSIUM - AS K	mg/l	1.14	1.15	1.13	1.14
SODIUM - AS NA	mg/l	5.4	5.5	5.4	5.4
STRONTIUM - AS SR	µg/l	266	269	265	266
SULPHATE - AS SO4	mg/l	28.4	28.9	29.2	29.1
MERCURY - AS HG	µg/l	0.0120	0.0130	0.0112	0.0110
BERYLLIUM - AS BE	µg/l	1.00	1.00	1.00	1.00
COBALT - AS CO	µg/l	1.00	1.00	1.00	1.07
SILVER - AS AG	µg/l	1.00	1.00	1.00	1.00
VANADIUM - AS V	µg/l	1.00	1.00	1.00	1.07

Sample Description:	**Units**	**Borehole**	**PV Outlet**	**Trough without sample 2**	**Trough with sample 2**
SILICATE REACTIVE DISSOLVED - AS SIO2	mg/l	4.81	4.71	4.70	4.70
SELENIUM - AS SE	µg/l	1.02	1.00	1.00	1.00
NITRATE - AS N	mg/l	1.19	1.19	1.19	1.19
1,2,3-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01	<0.01
1,2,4-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01	<0.01
1,3,5-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01	<0.01
ALDRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025
CYPERMETHRIN	µg/l	<0.010	<0.010	<0.010	<0.010
DDE (OP)	µg/l	<0.002	<0.002	<0.002	<0.002
DDE (PP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015
DDT (OP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015
DDT (PP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015
DIELDRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025
ENDOSULPHAN ALPHA	µg/l	<0.005	<0.005	<0.005	<0.005
ENDOSULPHAN BETA	µg/l	<0.005	<0.005	<0.005	<0.005
ENDRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025
HCH ALPHA	µg/l	<0.001	<0.001	<0.001	<0.001
HCH BETA	µg/l	<0.005	<0.005	<0.005	<0.005
HCH DELTA	µg/l	<0.001	<0.001	<0.001	<0.001
HCH GAMMA	µg/l	<0.001	<0.001	<0.001	<0.001
HEPTACHLOR	µg/l	<0.005	<0.005	<0.005	<0.005
HEPTACHLOR EPOXIDE	µg/l	<0.005	<0.005	<0.005	<0.005
HEXACHLOROBENZENE	µg/l	<0.001	<0.001	<0.001	<0.001
HEXACHLOROBUTADIENE	µg/l	<0.005	<0.005	<0.005	<0.005
ISODRIN	µg/l	<0.0025	<0.0025	<0.0025	<0.0025
METHOXYCHLOR	µg/l	<0.005	<0.005	<0.005	<0.005
PERMETHRIN, CIS	µg/l	<0.001	<0.001	<0.001	<0.001
PERMETHRIN, TRANS	µg/l	<0.001	<0.001	<0.001	<0.001
TDE (OP)	µg/l	<0.002	<0.002	<0.002	<0.002
TDE (PP)	µg/l	<0.0015	<0.0015	<0.0015	<0.0015
TRIFLURALIN	µg/l	<0.01	<0.01	<0.01	<0.01
PCB CONGENER 028	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 052	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 101	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 105	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 118	µg/l	<0.001	<0.001	<0.001	<0.001

Sample Description:	**Units**	**Borehole**	**PV Outlet**	**Trough without sample 2**	**Trough with sample 2**
PCB CONGENER 138	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 153	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 156	µg/l	<0.001	<0.001	<0.001	<0.001
PCB CONGENER 180	µg/l	<0.001	<0.001	<0.001	<0.001
COLIFORMS, TOTAL, PRESUMPTIVE	NO/100ml	20	16	26	26
FAECAL COLIFORMS, CONFIRMED	NO/100ml	10	12	14	14
FAECAL COLIFORMS,PRESUMPTIVE	NO/100ml	12	13	16	16
STREPTOCOCCI FAECAL CONF-MPN	NO/100ml	NoResult	NoResult	NoResult	NoResult
STREPTOCOCCI FAECAL PRE-MF	NO/100ml	7	12	4	4
TOTAL COLIFORMS CONFIRMED -MF	NO/100ml	18	11	10	10
1,1,1-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1	<0.1
1,1,2-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1	<0.1
1,2-DICHLOROETHANE {ETHYLENE	µg/l	<1	<1	<1	<1
1,3-DICHLOROBENZENE	µg/l	<1	<1	<1	<1
1,4-DICHLOROBENZENE	µg/l	<1	<1	<1	<1
BENZENE	µg/l	<3	<3	<3	<3
BROMODICHLOROMETHANE	µg/l	<0.05	<0.05	<0.05	<0.05
ETHYLBENZENE	µg/l	<10	<10	<10	<10
TETRACHLOROETHENE	µg/l	<0.1	<0.1	<0.1	<0.1
TETRACHLOROMETHANE {CARBON	µg/l	<0.1	<0.1	<0.1	<0.1
TOLUENE (METHYLBENZENE)	µg/l	<4	<4	<4	<4
TRIBROMOMETHANE {BROMOFORM}	µg/l	<0.2	<0.2	<0.2	<0.2
TRICHLOROETHENE	µg/l	<0.1	<0.1	<0.1	<0.1
FLUMETHRIN	µg/l	<0.001	<0.001	<0.001	<0.001
ATRAZINE { }	µg/l	<0.03	<0.03	<0.03	<0.03
AZINPHOS-ETHYL	µg/l	<0.02	<0.02	<0.02	<0.02
AZINPHOS-METHYL	µg/l	<0.02	<0.02	<0.02	<0.02
CARBOPHENOTHION	µg/l	<0.01	<0.01	<0.01	<0.01
CHLORFENVINPHOS	µg/l	<0.02	<0.02	<0.02	<0.02
COUMAPHOS	µg/l	<0.01	<0.01	<0.01	<0.01
DIAZINON	µg/l	<0.01	<0.01	<0.01	<0.01
DICHLORVOS	µg/l	<0.03	<0.03	<0.03	<0.03
ETHION	µg/l	<0.01	<0.01	<0.01	<0.01
FENCHLORPHOS {RONNEL.}	µg/l	<0.02	<0.02	<0.02	<0.02
FENTHION	µg/l	<0.02	<0.02	<0.02	<0.02

Sample Description:	Units	Borehole	PV Outlet	Trough without sample 2	Trough with sample 2
MALATHION	µg/l	<0.015	<0.015	<0.015	<0.015
PARATHION-METHYL { }	µg/l	<0.015	<0.015	<0.015	<0.015
PROPAZINE	µg/l	<0.03	<0.03	<0.03	<0.03
PROPETAMPHOS	µg/l	<0.01	<0.01	<0.01	<0.01
SIMAZINE	µg/l	<0.03	<0.03	<0.03	<0.03
TRIAZOPHOS	µg/l	<0.01	<0.01	<0.01	<0.01
CHLORPYRIFOS	µg/l	<0.02	<0.02	<0.02	<0.02
CHLORPYRIPHOS METHYL	µg/l	<0.02	<0.02	<0.02	<0.02
FENPROPIMORPH	µg/l	<0.02	<0.02	<0.02	<0.02
IPRODIONE	µg/l	<0.0200	<0.0200	<0.0200	<0.0200
TECNAZENE	µg/l	<0.01	<0.01	<0.01	<0.01

APPENDIX E: ANALYTICAL DATA – PIRELLI TYRES

Analyte	Units	Borehole	Tank inlet	Tank
TEMPERATURE (FIELD)	°C	11	14	14
PH (FIELD)	PH UNITS	7.6	7.9	7.9
PH - AS PH UNITS	PH UNITS	7.62	7.87	7.80
ALKALINITY (FIELD)	mg/l	270	286	286
ALKALINITY PH 4.5 - AS CACO3	mg/l	253	252	249
CONDUCTIVITY (FIELD)	µS/cm	453	487	486
CONDUCTIVITY @25C	µS/cm	641	638	637
DISSOLVED OXYGEN (FIELD)	%	36.2	61.3	65.3
AMMONIA - AS N	mg/l	0.0300	0.0300	0.0320
CHLORIDE ION - AS CL	mg/l	29.6	29.0	28.2
NITRITE - AS N	mg/l	0.013	0.009	0.004
NITROGEN TOTAL OXIDISED - AS N	mg/l	1.73	1.66	1.51
ORTHOPHOSPHATE - AS P	mg/l	0.037	0.035	0.035
BROMIDE ION - AS BR	mg/l	0.086	0.090	0.077
FLUORIDE - AS F	mg/l	0.067	0.069	0.067
CADMIUM - AS CD	µg/l	0.130	0.215	0.100
CHROMIUM - AS CR	µg/l	0.514	0.500	0.959
COPPER - AS CU	µg/l	2.8	0.5	2.0
LEAD - AS PB	µg/l	0.412	0.400	0.583
NICKEL - AS NI	µg/l	5.00	5.00	5.00
ZINC - AS ZN	µg/l	10.69	5.34	14.32
ARSENIC - AS AS	µg/l	4.31	5.64	6.05
ALUMINIUM - AS AL	µg/l	10.0	10.0	14.0
BARIUM - AS BA	µg/l	64.2	66.4	63.4
BORON - AS B	µg/l	100	100	100
CALCIUM - AS CA	mg/l	63.0	63.8	60.4
IRON - AS FE	µg/l	30.6	30.0	34.2
MAGNESIUM - AS MG	mg/l	35.5	35.4	34.5
MANGANESE - AS MN	µg/l	10.0	10.0	10.0
POTASSIUM - AS K	mg/l	1.93	1.96	1.89
SODIUM - AS NA	mg/l	23.1	23.0	22.2
STRONTIUM - AS SR	µg/l	627	616	606
SULPHATE - AS SO4	mg/l	59	59	59
MERCURY - AS HG	µg/l	0.010	0.010	0.010
BERYLLIUM - AS BE	µg/l	1.000	1.000	1.000
COBALT - AS CO	µg/l	1.000	1.000	1.000
SILVER - AS AG	µg/l	1.000	1.000	1.000
VANADIUM - AS V	µg/l	1.08	1.13	1.20
SILICATE REACTIVE DISSOLVED - AS SIO2	mg/l	16	16	16
SELENIUM - AS SE	µg/l	1.00	1.00	1.00
NITRATE - AS N	mg/l	1.72	1.65	1.51
1,1,1-TRICHLOROETHANE	µg/l	0.121	<0.1	<0.1
1,1,2-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1
1,2-DICHLOROETHANE {ETHYLENE	µg/l	<1	<1	<1
1,3-DICHLOROBENZENE	µg/l	<1	<1	<1
1,4-DICHLOROBENZENE	µg/l	<1	<1	<1
BENZENE	µg/l	<3	<3	<3
BROMODICHLOROMETHANE	µg/l	<0.05	<0.05	<0.05
ETHYLBENZENE	µg/l	<10	<10	<10
TETRACHLOROETHENE	µg/l	<0.1	<0.1	<0.1

Analyte	Units	Borehole	Tank inlet	Tank
TETRACHLOROMETHANE {CARBON	µg/l	<0.1	<0.1	<0.1
TOLUENE (METHYLBENZENE)	µg/l	<4	<4	<4
TRIBROMOMETHANE {BROMOFORM}	µg/l	<0.2	<0.2	<0.2
TRICHLOROETHENE	µg/l	<0.1	<0.1	<0.1
CHLORPYRIFOS	µg/l	<0.02	<0.02	<0.02
CHLORPYRIPHOS METHYL	µg/l	<0.02	<0.02	<0.02
FENPROPIMORPH	µg/l	<0.02	<0.02	<0.02
IPRODIONE	µg/l	<0.0200	<0.0200	<0.0200
TECNAZENE	µg/l	<0.01	<0.01	<0.01
1,2,3-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
1,2,4-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
1,3,5-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
ALDRIN	µg/l	<0.0025	<0.0025	<0.0025
CYPERMETHRIN	µg/l	<0.010	<0.010	<0.010
DDE (OP)	µg/l	<0.002	<0.002	<0.002
DDE (PP)	µg/l	<0.0015	<0.0015	<0.0015
DDT (OP)	µg/l	<0.0015	<0.0015	<0.0015
DDT (PP)	µg/l	<0.0015	<0.0015	<0.0015
DIELDRIN	µg/l	<0.0025	<0.0025	<0.0025
ENDOSULPHAN ALPHA	µg/l	<0.005	<0.005	<0.005
ENDOSULPHAN BETA	µg/l	<0.005	<0.005	<0.005
ENDRIN	µg/l	<0.0025	<0.0025	<0.0025
HCH ALPHA	µg/l	<0.001	<0.001	<0.001
HCH BETA	µg/l	<0.005	<0.005	<0.005
HCH DELTA	µg/l	<0.001	<0.001	<0.001
HCH GAMMA	µg/l	<0.001	<0.001	<0.001
HEPTACHLOR	µg/l	<0.005	<0.005	<0.005
HEPTACHLOR EPOXIDE	µg/l	<0.005	<0.005	<0.005
HEXACHLOROBENZENE	µg/l	<0.001	<0.001	<0.001
HEXACHLOROBUTADIENE	µg/l	<0.005	<0.005	<0.005
ISODRIN	µg/l	<0.0025	<0.0025	<0.0025
METHOXYCHLOR	µg/l	<0.005	<0.005	<0.005
PERMETHRIN, CIS	µg/l	<0.001	<0.001	<0.001
PERMETHRIN, TRANS	µg/l	<0.001	<0.001	<0.001
TDE (OP)	µg/l	<0.002	<0.002	<0.002
TDE (PP)	µg/l	<0.0015	<0.0015	<0.0015
TRIFLURALIN	µg/l	<0.01	<0.01	<0.01
PCB CONGENER 028	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 052	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 101	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 105	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 118	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 138	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 153	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 156	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 180	µg/l	<0.001	<0.001	<0.001
ATRAZINE { }	µg/l	<0.03	<0.03	<0.03
AZINPHOS-ETHYL	µg/l	<0.02	<0.02	<0.02
AZINPHOS-METHYL	µg/l	<0.001	<0.001	<0.001
CARBOPHENOTHION	µg/l	<0.01	<0.01	<0.01
CHLORFENVINPHOS	µg/l	<0.001	<0.001	<0.001

Analyte	**Units**	**Borehole**	**Tank inlet**	**Tank**
COUMAPHOS	µg/l	<0.001	<0.001	<0.001
DIAZINON	µg/l	<0.001	<0.001	<0.001
DICHLORVOS	µg/l	<0.0005	<0.0005	<0.0005
ETHION	µg/l	<0.01	<0.01	<0.01
FENCHLORPHOS {RONNEL.}	µg/l	<0.001	<0.001	<0.001
FENTHION	µg/l	<0.01	<0.01	<0.01
MALATHION	µg/l	<0.001	<0.001	<0.001
PARATHION-METHYL { }	µg/l	<0.015	<0.015	<0.015
PROPAZINE	µg/l	<0.014	<0.014	<0.014
PROPETAMPHOS	µg/l	<0.001	<0.001	<0.001
SIMAZINE	µg/l	<0.03	<0.03	<0.03
TRIAZOPHOS	µg/l	<0.0005	<0.0005	<0.0005
COLIFORMS, TOTAL, PRESUMPTIVE	NO/100ml	NoResult	NoResult	NoResult
FAECAL COLIFORMS, CONFIRMED	NO/100ml	NoResult	NoResult	NoResult
FAECAL COLIFORMS,PRESUMPTIVE	NO/100ml	NoResult	NoResult	NoResult
STREPTOCOCCI FAECAL CONF-MPN	NO/100ml	NoResult	NoResult	NoResult
STREPTOCOCCI FAECAL PRE-MF	NO/100ml	NoResult	NoResult	NoResult
TOTAL COLIFORMS CONFIRMED -MF	NO/100ml	NoResult	NoResult	NoResult

APPENDIX F: ANALYTICAL DATA – FRANK BIRD POULTRY

Sample Description:	Units	Borehole	Tank	Tap
TEMPERATURE (FIELD)	°C	12.5	11.54	12.16
PH (FIELD)	PH UNITS	7.78	7.90	8.04
PH - AS PH UNITS	PH UNITS	7.78	7.83	7.93
ALKALINITY (FIELD)	mg/l	205	211	218
ALKALINITY PH 4.5 - AS CACO3	mg/l	165	166	166
CONDUCTIVITY (FIELD)	µS/cm	339	298	328.6
CONDUCTIVITY @25C	µS/cm	432	433	433
DISSOLVED OXYGEN (FIELD)	%	73.2	59.3	72.6
COPPER - AS CU	µg/l	5.3	0.5	1.2
IRON - AS FE	µg/l	30	60	56
ZINC - AS ZN	µg/l	53.4	34.7	60.6
LEAD - AS PB	µg/l	0.57	0.48	0.49
AMMONIA - AS N	mg/l	0.03	0.03	0.03
CHLORIDE ION - AS CL	mg/l	9.9	9.9	10.0
NITRITE - AS N	mg/l	0.004	0.004	0.004
NITROGEN TOTAL OXIDISED - AS N	mg/l	0.828	0.816	0.814
ORTHOPHOSPHATE - AS P	mg/l	0.02	0.02	0.02
BROMIDE ION - AS BR	mg/l	0.05	0.05	0.05
FLUORIDE - AS F	mg/l	0.05	0.05	0.05
CADMIUM - AS CD	µg/l	0.1	0.1	0.1
CHROMIUM - AS CR	µg/l	0.5	0.5	0.5
NICKEL - AS NI	µg/l	5.1	5.0	5.0
ARSENIC - AS AS	µg/l	1.94	1.91	1.60
ALUMINIUM - AS AL	µg/l	10.0	10.0	10.0
BARIUM - AS BA	µg/l	81.7	79.4	78.2
BORON - AS B	µg/l	100	100	100
CALCIUM - AS CA	mg/l	58.3	55.5	56.2
MAGNESIUM - AS MG	mg/l	20.5	19.5	19.7
MANGANESE - AS MN	µg/l	10.0	10.0	10.5
POTASSIUM - AS K	mg/l	2.00	1.94	1.97
SODIUM - AS NA	mg/l	5.78	5.62	5.70
STRONTIUM - AS SR	µg/l	402	385	390
SULPHATE - AS SO4	mg/l	47.5	44.2	44.2
MERCURY - AS HG	µg/l	0.01	0.02	0.01
BERYLLIUM - AS BE	µg/l	1	1	1
COBALT - AS CO	µg/l	1	1	1
SILVER - AS AG	µg/l	1	1	1
VANADIUM - AS V	µg/l	1	1	1
SILICATE REACTIVE DISSOLVED - AS SIO2	mg/l	9.5	9.5	9.3
SELENIUM - AS SE	µg/l	1	1	1
NITRATE - AS N	mg/l	0.82	0.81	0.81
1,2,3-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
1,2,4-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
1,3,5-TRICHLOROBENZENE	µg/l	<0.01	<0.01	<0.01
ALDRIN	µg/l	<0.0025	<0.0025	<0.0025
CYPERMETHRIN	µg/l	<0.010	<0.010	<0.010

Sample Description:	**Units**	**Borehole**	**Tank**	**Tap**
DDE (OP)	µg/l	<0.002	<0.002	<0.002
DDE (PP)	µg/l	<0.0015	<0.0015	<0.0015
DDT (OP)	µg/l	<0.0015	<0.0015	<0.0015
DDT (PP)	µg/l	<0.0015	<0.0015	<0.0015
DIELDRIN	µg/l	<0.0025	<0.0025	<0.0025
ENDOSULPHAN ALPHA	µg/l	<0.005	<0.005	<0.005
ENDOSULPHAN BETA	µg/l	<0.005	<0.005	<0.005
ENDRIN	µg/l	<0.0025	<0.0025	<0.0025
HCH ALPHA	µg/l	<0.001	<0.001	<0.001
HCH BETA	µg/l	<0.005	<0.005	<0.005
HCH DELTA	µg/l	<0.001	<0.001	<0.001
HCH GAMMA	µg/l	<0.001	<0.001	<0.001
HEPTACHLOR	µg/l	<0.005	<0.005	<0.005
HEPTACHLOR EPOXIDE	µg/l	<0.005	<0.005	<0.005
HEXACHLOROBENZENE	µg/l	<0.001	<0.001	<0.001
HEXACHLOROBUTADIENE	µg/l	<0.005	<0.005	<0.005
ISODRIN	µg/l	<0.0025	<0.0025	<0.0025
METHOXYCHLOR	µg/l	<0.005	<0.005	<0.005
PERMETHRIN, CIS	µg/l	0.0171	<0.001	<0.001
PERMETHRIN, TRANS	µg/l	0.0215	<0.001	<0.001
TDE (OP)	µg/l	<0.002	<0.002	<0.002
TDE (PP)	µg/l	<0.0015	<0.0015	<0.0015
TRIFLURALIN	µg/l	<0.01	<0.01	<0.01
PCB CONGENER 028	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 052	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 101	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 105	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 118	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 138	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 153	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 156	µg/l	<0.001	<0.001	<0.001
PCB CONGENER 180	µg/l	<0.001	<0.001	<0.001
COLIFORMS, TOTAL, PRESUMPTIVE	NO/100ml	<1	<1	<1
FAECAL COLIFORMS, CONFIRMED	NO/100ml	<1	<1	<1
FAECAL COLIFORMS,PRESUMPTIVE	NO/100ml	<1	<1	<1
STREPTOCOCCI FAECAL CONF-MPN	NO/100ml	<1	<1	<1
STREPTOCOCCI FAECAL PRE-MF	NO/100ml	<1	<1	<1
TOTAL COLIFORMS CONFIRMED -MF	NO/100ml	<1	<1	<1
1,1,1-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1
1,1,2-TRICHLOROETHANE	µg/l	<0.1	<0.1	<0.1
1,2-DICHLOROETHANE {ETHYLENE	µg/l	<1	<1	<1
1,3-DICHLOROBENZENE	µg/l	<1	<1	<1
1,4-DICHLOROBENZENE	µg/l	<1	<1	<1
BENZENE	µg/l	<3	<3	<3

Sample Description:	Units	Borehole	Tank	Tap
BROMODICHLOROMETHANE	µg/l	<0.05	<0.05	<0.05
ETHYLBENZENE	µg/l	<10	<10	<10
TETRACHLOROETHENE	µg/l	<0.1	<0.1	<0.1
TETRACHLOROMETHANE {CARBON	µg/l	<0.1	<0.1	<0.1
TOLUENE (METHYLBENZENE)	µg/l	<4	<4	<4
TRIBROMOMETHANE {BROMOFORM}	µg/l	<0.2	<0.2	<0.2
TRICHLOROETHENE	µg/l	<0.1	<0.1	<0.1
FLUMETHRIN	µg/l	<0.001	<0.001	<0.001
ATRAZINE { }	µg/l	<0.03	<0.03	<0.03
AZINPHOS-ETHYL	µg/l	<0.02	<0.02	<0.02
AZINPHOS-METHYL	µg/l	<0.02	<0.02	<0.02
CARBOPHENOTHION	µg/l	<0.01	<0.01	<0.01
CHLORFENVINPHOS	µg/l	<0.02	<0.02	<0.02
COUMAPHOS	µg/l	<0.01	<0.01	<0.01
DIAZINON	µg/l	<0.01	<0.01	<0.01
DICHLORVOS	µg/l	<0.03	<0.03	<0.03
ETHION	µg/l	<0.01	<0.01	<0.01
FENCHLORPHOS {RONNEL.}	µg/l	<0.02	<0.02	<0.02
FENTHION	µg/l	<0.02	<0.02	<0.02
MALATHION	µg/l	<0.015	<0.015	<0.015
PARATHION-METHYL { }	µg/l	<0.015	<0.015	<0.015
PROPAZINE	µg/l	<0.03	<0.03	<0.03
PROPETAMPHOS	µg/l	<0.01	<0.01	<0.01
SIMAZINE	µg/l	<0.03	<0.03	<0.03
TRIAZOPHOS	µg/l	<0.01	<0.01	<0.01
CHLORPYRIFOS	µg/l	<0.02	<0.02	<0.02
CHLORPYRIPHOS METHYL	µg/l	<0.02	<0.02	<0.02
FENPROPIMORPH	µg/l	<0.02	<0.02	<0.02
IPRODIONE	µg/l	<0.0200	<0.0200	<0.0200
TECNAZENE	µg/l	<0.01	<0.01	<0.01