Widescreen Groundwater Quality Monitoring Programme – Analysis of Historical Data Sets

ENVIRONMENTAL PROTECTION DEPARTMENT
MINISTRY OF ENERGY AND THE ENVIRONMENT
JEMMOTTS LANE,
ST. MICHAEL
BARBADOS

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Abstract

Wide Screen water quality monitoring has been conducted for general groundwater quality monitoring as well as under several other programmes in recognition of its ability to assess the state of groundwater resources in a more holistic fashion. In addition to allowing the Government to honour its obligations to the Stockholm Convention on Persistent Organic Pollutants it has afforded the relevant agencies the opportunity to evaluated parameters with regards to water quality of concern to public health that are not considered under existing programmes. Analysis has shown elevated levels of nitrates, sodium and chlorides which have all closely approach or exceed WHO recommended guideline values. In 2007 samples taken at the Belle P.S gave readings of 9.7mg/L which closely approached the WHO guideline value of 10mg/L. Additionally the presence of arsenic within the water system was found at the Molyneux and Arch Hall sites in 2003. What has been emphasised is the need to and importance of investigating the effects of emerging parameters such as Pharmaceuticals and Personal Care Products (PPCP) and Methylene Blue Active Surfactants (MBAS). This study has highlighted the need for a more structured broad based programme capable of informing current water quality monitoring programmes with regards to the need for continuous monitoring of parameters not frequently assessed or the addition of parameters not currently monitored.

Table of Contents

List of Tables

Table of Figures

1. Introduction

1.1. Current Groundwater Quality Monitoring Programmes

The current groundwater quality monitoring programme undertaken by the Environmental Protection Department (EPD) and the Barbados Water Authority (BWA) evolved from the British Geological Survey Risk Assessment Study of the Belle and Hampton groundwater catchments (Environmental Protection Department In prep). The monitoring regime that is used was adopted from that which was undertaken in the study of these catchment areas. The overall aim of the of the programme is "*to provide water quality data upon which informed public decisions can be based through the continuous surveillance of physico-chemical, chemical and biological parameters at water abstraction and distribution locations*."

Water abstraction and distribution sources of potable water were selected by the Barbados Water Authority through detailed analysis of hydrogeological conditions and water availability (Environmental Protection Department In prep). These sites are all located within the Zone 1 areas with the exception of the Ionic desalination plant which is the only abstraction site to be located outside of this zone. This water supply system is comprised of twenty three well sources. Contributions to the distribution system are also made from seven boreholes and two spring sources. These systems feed into a larger distribution system which consists of twenty nine reservoirs and twelve re-pumping stations. Additionally, wells for agricultural purposes have been implemented in response to irrigation needs in various areas around the island. Water is disinfected through the process of chlorination by means of chlorine gas which is applied prior to distribution. A full list of groundwater abstraction wells for potable and agricultural use, as well as the springs from which samples are taken for monitoring, are outlined in Table 2. Sampling at each site is a collaborative effort between EPD and the BWA. There are currently no national guidelines for drinking water quality in Barbados. Standards are informed by the World Health Organisation (WHO) recommendations for selected parameters.

Table 1: Groundwater abstraction wells and springs

Supply Well	Catchment	Well Depth (m)	Abstraction Rate (m^3/day)	Chlorination Method
Alleynedale (PS)	West Coast	53.3	3745.868	In well
Applewaithes (PS)	Belle	75.9	6214.322	In pipe
Applewaithes Well Field (PS)	Belle	-	-	None
Ashton Hall (PS)	West Coast	53	2463.908	In well
Bath	Springs	N/A	N/A	-
Belle (PS)	Belle	35.7	52733.090	In well
Benn Spring (PS)	Spring	N/A	N/A	-
Bowmanstan (PS)	Hampton	64	9969.282	In well
Brighton (AS)	Hampton	-	-	-
Carlton (PS)	West Coast	55.2	2836.677	In well
Carrington (PS)	Hampton	-	872.824	In well

Supply Well	Catchment	Well Depth (m)	Abstraction Rate (m^3/day)	Chlorination Method
Codrington (PS)	Belle	50.5	4545.956	In pipe
Codrington College (PS)	Springs	N/A	N/A	In stilling well
Constant (PS)	Belle	>30.5	1250.138	In well
Corbin's Farm (AS)	Hampton	-	-	-
Edgecumbe (AS)	Hampton	-	-	-
Fortesque	Springs	N/A	N/A	-
Hampton (PS)	Hampton	36.4	28636.523	In well
Haymans (PS)	West Coast	39	4545.956	In well
Hope (PS)	West Coast	29.8	368.222	In well
Kendal Factory (AS)	Hampton	-	-	-
Marchfield (AS)	Belle	46.9	15633.543	In well
Molyneux (PS)	West Coast	60.6	1454.706	In well
National Hatcheries (AS)	Hampton	-	-	-
New Market (PS)	Belle	46.9	15633.543	In well
Packers (AS)	Hampton	-	-	-
Engine Field (AS)	Belle	-	-	-
Pool Plantation (AS)	Hampton	-	-	-
Porey	Springs	N/A	N/A	-
Pot House	Springs	N/A	N/A	-
Kings Road (AS)	Belle	-	-	-
St Joseph Hospital / Villa Maria	West Coast	-	-	-
Sweet vale #1 (PS)	Belle	43.5	6091.581	-
Sweet vale #2 (PS)	Belle	44.8	-	In well
The Whim (PS)	West Coast	-	3804.965	In well
Three Houses	Springs	N/A	N/A	-
Trents (PS)	West Coast	-	1982.037	In well
Waterford (PS)	Belle	-	6364.338	-

Source: Environmental Protection Department, in prep

Presently this programme seeks to assess the microbiological and chemical composition of the water supply with the primary intention of securing public health. Collection is done once weekly on a rotation system where samples are taken from water supply sources in each sample area once a month so that a different catchment area is assessed every week. The parameters used under this monitoring regime, the justification for assessment as well as the WHO guidelines for their concentrations have been outlined in Table 3.

Table 2: Sampling parameters used in water quality assessment in Barbados

Parameter	WHO Recommendation	Rationale
pH	6.5-8.5	Extreme pH values may cause corrosion of distribution pipes. pH levels < 8 increases potency of chlorine disinfection
Residual Chlorine (ppm)	>0.5	Used to assess the extent and effectiveness of chlorination.
Electrical conductivity (us/cm)	1500	Measure of the amount of natural inorganic material present in groundwater
Chlorine (mg/L)	250	No health guideline for drinking water but values greater than the recommended will have an effect on taste
Sulphate (mg/L)	500	No health based guidelines derived. High levels of sulphates may affect taste and my have a laxative effect in unaccustomed consumers
Nitrate (mg/L)	10	By product of organic material. May be derived from agrochemicals as well as s domestic sewage, treated wastewater. High levels of nitrates may result in methaemoglobineamia (Blue Baby Syndrome) in babies and small children.
Total Dissolved Solids (mg/L)	1000	No health based guideline derived for TDS. High concentrations may affect appearance and taste of drinking water. However it may be used as aggregate indicator of the presence of a broad array of chemical contaminants
Total Coliform (CFU)	0	While posing no threat itself, it is used as an indicator of the presence of other potentially harmful bacteria
Faecal Coliform (CFU)	0	Found in the intestinal tract of warm blooded animals, they are the preferred indicators of faecal pollution
Faecal Streptococci	0	Found in the intestinal tract of warm blooded animals, they are the preferred indicators of faecal pollution

Source: WHO 2004

1.2. Widescreen Groundwater Monitoring Programme

The chemical and microbiological parameters for groundwater abstracted for public use that are monitored and regulated by relevant government agencies, represent but a small fraction of the universe of chemicals that occur in the environment as a result of natural and human influence (Daughton 2004). Many substances outside of those that are identified as contaminants of concern have the potential to foul fresh water reserves. If present in high enough concentrations, these substances pose serious threats to human health. Often times there is an implicit assumption that a selective list of substances that have been targeted for frequent monitoring, are those that are responsible for the most significant share of hazards with respect to human and environmental well being (Petrovic 2003). The reality is that many other substances that may not be included for assessment in government run programmes may be just as prolific and as harmful as those which are. The move towards a widescreen analysis of groundwater, which has evolved out of the current water quality monitoring programme, represents the realisation of the limited scope of the current assessment regime and the urgent need for a more broad based picture of the threats to a highly valued resource. In this way agencies can more adequately access and be better able to cope with probable contaminants to groundwater systems and improve or implement mechanisms for the protection or remediation of such systems.

Additionally this programme was launched in recognition of the legal obligation that the Barbadian government has to uphold, by becoming signatory to international conventions and treaties. This obligation extends to the Stockholm Convention on Persistent Organic Pollutants (POP). The convention calls for global action to be taken on the eradication of on these compounds. These substances persist in the environment; resulting in bioaccumulation through the food web resulting in potentially deleterious effects to human health. The Intergovernmental Forum on Chemical Safety (IFCS) and the International Programme for Chemical Safety (IPCS) has drafted a list of twelve of the worst known offenders which are referred to as the "dirty dozen." This list includes eight organo-chlorine pesticides, two industrial chemicals and two groups of industrial by-products. These have been outlined in Table 3.

Table 3: Substances addressed under the Stockholm Convention on Persistent Organic Pollutants

Parameter	WHO recommendation	Rationale
Organo-chlorine pesticides		
Aldrin	0.00003mg/L	Used against soil dwelling pest; used for wood protection. Highly toxic. Targets liver and central nervous system
Dieldrin	0.00003mg/L	Used against insects of public health importance. Highly toxic. Targets liver and central nervous system. Similar to Aldrin in toxicology and mode of action. Aldin converted to Dieldrin under most environmental conditions and in the body.
DDT	0.01mg/L	Moderately toxic, possible carcinogen. Could impair reproduction and development in several species.
Chlorodane	-	Affects functions of the liver; nervous and digestive system. No guideline value given.
Endrin	0.0006mg/L	Acute poisoning affects primarily the nervous system. Highly toxic to aquatic organisms.
Heptachlor	-	Liver damage and central nervous system toxicity. Currently occurs at concentrations below those at which toxic effects are seen; no guideline value allocated.
Mirex	-	No human effect identified currently. Listed as unlikely to occur in drinking water but is highly toxic to aquatic organisms, especially aquatic crustaceans. No guideline value given.
Toxaphene	-	When ingested in sufficient amounts can damage nervous system and kidneys. No guideline value given as it is listed as unlikely to occur in drinking water.
Industrial Chemicals		
Hexachlorobenzene	0.05ug/L	Possibly carcinogenic. Currently occurs at concentrations below those at which deleterious effects are seen.

Parameter	WHO recommendation	Rationale
Polychlorinated biphenyl (PCB) group	-	Highly toxic. Results in skin conditions such as chloracne and rashes and may cause liver damage. May also be associated with endocrine and developmental effects.
Industrial by- products		
Dioxins	-	Highly toxic. Causes reproductive difficulties in humans. Possibly carcinogenic.
Furans	-	Highly toxic. Causes reproductive difficulties in humans. Possibly carcinogenic

Source: WHO 2004

The Government of Barbados signed and ratified this convention on June 7th, 2004. As such it must honour all stipulations of this agreement which include those that speak to a discontinuance of the manufacture, importation and use of these chemicals or to guidelines for usage under the convention. Additionally it also addresses programmes which facilitate monitoring and impact assessments of these substances. Monitoring and research of the above items have been addressed under Article 11 of this convention.

Currently widescreen analysis has been undertaken for general groundwater quality monitoring as well as for project specific monitoring. In each case samples were sent overseas for analysis to assess the concentrations of inorganics, volatile organics, pesticides and PCB chemicals, trihalomethanes and secondary chemicals. The chemicals listed in the table above have all been incorporated into current widescreen analyses. In recent times this rigorous assessment regime has been used in the 2003 Belle feasibility study as well as leachate studies done for the Mangrove Landfill in 2003 and then again in 2004 and under the general groundwater quality screening programme. Additionally such studies were also conducted for the Barbados Agricultural Development and Marketing Cooperation (BADMC) analysis of groundwater in various agricultural wells and boreholes in the Gibbons Bogg area and in a recent study conducted on the effect of agrochemicals on water quality at the abstraction site at St. Joseph's Hospital also known as Villa Maria.

1.2.1. Leachate Monitoring Programme

This project sought to assess the impacts of the leaching of contaminants from the Mangrove Landfill on the ground water resources of the West Coast catchment area and the nearshore marine environment. Scheduled to run for a period not exceeding two years, it aimed at establishing whether or not long term monitoring would be necessary and what parameters should be assessed if such a decision was found to be warranted. Additionally it attempted to identify leachate migration patterns as well as characterize the leachate that was generated. The plan called for sampling to be done for at least one established well as well as four proposed boreholes in order to capture the spatial variation in groundwater quality in the vicinity of the landfill (Environmental Engineering Division 1999). Subsequent to this programme further monitoring was done at Mangrove where raw leachate was taken from within the landfill and groundwater samples were taken at strategically selected sample sites within the catchment area.

It should be noted that the Belle borehole, Newmarket, Applewaithes and Ashton Hall pumping stations that were sampled during this period were not done as part of the leachate programme. These sites were incorporated during the sampling exercise as there was time and opportunity to do so. Data for the sites reported in this document will be used to highlight trends as added value to the analysis.

1.2.2. Belle Feasibility Study

This study was undertaken in an effort to address elevated nitrate and bacteria levels in raw water at the Belle, Codrington and Waterford wells. Its main aim was to provide a technical basis upon which the problems in these areas could be quantified and so provide information from which alternatives for evaluation could be developed. It sought to provide a review of the sources of contamination within this catchment area as well as their build up. An evaluation of the aquifer characteristics was also undertaken (Stantec 2004).

1.2.3. BADMC Analysis of the Gibbons Boggs Area

This analysis was undertaken to determine the level of hydrocarbon contamination caused by leaks in the Shell pipeline transporting airline fuel from holding tanks in Oistins to the airport. It sought to determine the impact of these leaks on the groundwater system within this area and the extent to which these impacts had affected local populations economically as well as from a public health perspective. Leaks had been detected in this pipeline from as early as 1995 and though this line has now been decommissioned the effects of these spills on the groundwater systems and on agricultural land and the remediation methods that would be necessary are still of great concern. The analysis highlights the main trends seen in the sample collected at various locations within pipelines area of influence.

1.2.4. Widescreen analysis of Villa Maria (St. Joseph Hospital)

Due to saline intrusion in the Colleton and Hope public supply wells production at these sites was discontinued. The Joseph Hospital (Villa Maria) facility was brought online to meet the needs of persons in the northern section of the island. To determine its suitability as a source of potable water for public consumption and to determine the influence of agrochemicals on this site a widescreen analysis was undertaken.

1.2.5. Widescreen analysis of Effluent Quality from Ionic Desalination Plant

The increased demand for fresh water supplies in Barbados has necessitated the augmentation of groundwater supplies. This has recently been undertaken through the development of the island's only desalination plant. Ionics Freshwater Limited currently operates at half of its production capability; producing 30,000m3 of fresh water daily which accounts for 17% of fresh water supplies. In order to determine the quality of the waste generated as a result of the desalination process and in depth analysis of the effluent has been undertaken.

1.3. Future of Widescreen Analysis in Barbados

It is the intention of the Environmental Protection Department that widescreen analysis of groundwater be undertaken for all abstraction sites and springs that are addressed under the current monitoring regime (Table 1). These include all public supply and agricultural wells as well as all spring sources. Collection and testing of these samples will be conducted twice yearly, once during the dry season and then again in the wet season on a rotation system until all sample sites have been visited. The wet season in Barbados extends from June to November with the dry season spanning from December to May.

Recognising the significant contribution of the Belle and Hampton sites to the public supply and distribution system, these sites will be the only ones that will be targeted each time samples are collected, being tested both in the dry and wet season for all years. In addition to these two sites eight additional sites will be tested each year, four different locations in each season. These locations will be rotated on a catchment by catchment basis beginning with the Belle, followed by Hampton, West Coast and concluding with the springs. Each season will constitute one sampling phase and will extend for a period of six months. Sample collection, laboratory analysis, data compilation and analysis as well as interim report generation will be conducted for each sample period. Below is a draft sampling schedule for the proposed widescreen monitoring programme.

Table 4: Draft sampling schedule for proposed Long Term Widescreen Sampling Programme

Year	Wet Season		Dry Season	
	Sample Site	**Catchment**	**Sample Site**	**Catchment**
2008	Belle PS	Belle		
	Hampton PS	Hampton		
	Applewaithes PS	Belle		
	Applewaithes PS	Belle		
	Codrington PS	Belle		
	Constant PS	Belle		
2009	Belle PS	Belle	Belle PS	Belle
	Hampton PS	Hampton	Hampton PS	Hampton
	MarchField AS	Belle	Sweetvale #1 PS	Belle
	Newmarket PS	Belle	Sweetvale #2 PS	Belle
	Engine Field AS	Belle	Waterford PS	Belle
	King's Road AS	Belle	Bowmanstan PS	Hampton
2010	Belle PS	Belle	Belle PS	Belle
	Hampton PS	Hampton	Hampton PS	Hampton
	Brighton (AS)	Hampton	National Hatcheries	Hampton
	Carrington (PS)	Hampton	Packers	Hampton
	Corbin's Farm	Hampton	Pool Plantation	Hampton
	Edgecumbe (AS)	Hampton	Kendal Factory (AS)	Hampton
2011	Belle PS	Belle	Belle PS	Belle
	Hampton PS	Hampton	Hampton PS	Hampton
	Alleynedale	West Coast	St Joseph Hospital	West Coast
	Ashton Hall	West Coast	Molyneux	West Coast
	Carlton	West Coast	The Whim	West Coast
	Haymans	West Coast	Trents	West Coast
2012	Belle PS	Belle	Belle PS	Belle
	Hampton PS	Hampton	Hampton PS	Hampton
	Bath	Springs	Pot House	Springs
	Benn Spring	Springs	Three Houses	Springs
	Codrington College	Springs		
	Fortesque	Springs		
	Porey	Springs		

2. Assessment of the Widescreen Groundwater Quality Monitoring Programme

2.1. Methodology

A number of documents were used in the analysis of the widescreen groundwater quality programmes that have been implemented to date. These include the results of groundwater sampling conducted for all programmes listed in the previous section. The programmes under which these samples were taken, their corresponding sampling sites and the type of sampling sites that was used is outlined in Table 5. In each case samples were sent to Severn Trent Laboratories in Florida who provided sample bottles for collection. All samples were collected in duplicate for each subset of parameters (i.e. nutrients, microbiological etc.) and kept refrigerated until they were shipped to the laboratory on the same day that they were collected.

Table 5: Widescreen Groundwater Quality Monitoring Programmes completed to date

Programme	Year	Sample sites	Sample site type
Groundwater Quality Analysis	2007	Belle	Pumping Station
		New market	Pumping Supply
		Ashton Hall	Pumping Supply
		Alleyndale	Pumping Supply
		Hampton	Pumping Supply
		Bowmanstan	Pumping Supply
Mangrove Leachate Monitoring Programme	2004	** Belle	Bore Hole
		**New market	Pumping Supply
		Molyneux	Pumping Supply
		Arch Hall	Pumping Supply
Mangrove Leachate Monitoring Programme	2003	**Ashton Hall	Pumping Supply
		**Molyneux	Pumping Supply
		**Belle BH	Bore Hole
		Arch Hall	Agricultural well
Belle Catchment Study	2003	Sweet Water II	Pumping Supply
		Applewaithes	Pumping Supply
BADMC Gibbons Boggs Assessment		Jessamy	Bore Hole
		Ford	Bore Hole
		Atherley#1	Bore Hole
		Atherley#2	Bore Hole
		Sayes Court	Agricultural well
		Moore	Agricultural well
		Eastmond	Bore Hole
St. Joseph Hospital	2007	St. Joesph Hospital	Pumping Supply

Programme	Year	Sample sites	Sample site type
Ionics Desalination Plant	2007	Effluent	Pumping Supply

****** Sites that were not a part of the Leachate Monitoring Programme

2.2. Results

In this analysis, parameters have been divided into sub groups based on chemical structure and origin. These groups have been designated by the laboratory responsible for testing water quality samples. Results of the analysis have been presented for parameters within each of these subgroups whose concentrations exceed the minimum detection limit and have been displayed graphically for many of the parameters tested within their respective programmes. In each case these recorded values have been displayed relative to the guideline value, denoted by a red line on each graph. A full list of the parameters investigated as well as their corresponding groups has been outlined in Appendix 1 extracted from the widescreen analysis done in 2007 for the Belle PS (Site 1).

2.2.1. Inorganics

Most of parameters within this subgroup were found to be below their respective minimum detection limits (MDLs) as well below the maximum concentrations recommended under the WHO guidelines for drinking water. Barium exceeded the MDL when tested under the groundwater quality assessment carried out in 2007. However barium concentrations at all sites was found to be below the WHO recommended guideline value of 0.2mg/L with the highest values reading at 0.021 mg/L from samples taken at the Belle PS and Alleynedale PS sites.

At the majority of the sample sites in all programmes, readings for chromium and lead were recorded at values that were below their respective MDLs. On no occasion did these values exceed the WHO guideline values. The highest reading for lead was 0.003, taken at the Belle which was well below the WHO value of 0.01mg/L in 2004. For chromium the highest value seen was recorded in 2004 and only exceeded the MDL at Newmarket with a reading of 0.005mg/L, far below the WHO value of 0.05mg/L. This pattern continued with nickel, where the highest value was recorded under leachate study of 2004 at the Arch Hall site at 0.012 lower than the recommended value of 0.02mg/L.

Values for fluoride within the majority of the programmes followed a similar trend as the parameters previously mentioned. However even though most values fell below the WHO guideline value of 1.5mg/L, it was found that highest value of 1.05mg/L, which was seen at the Ionics Desalination in 2002, closely approached the concentration recommended under WHO guidelines. High values were also seen in 2003 in the sample taken from the Belle borehole where a value of 1mg/L was recorded. These trends are illustrated in Figure 1 which shows the concentration of fluorides found in samples from all sites in the 2003 leachate study as well as additional samples taken during this period, relative to the recommended guideline value.

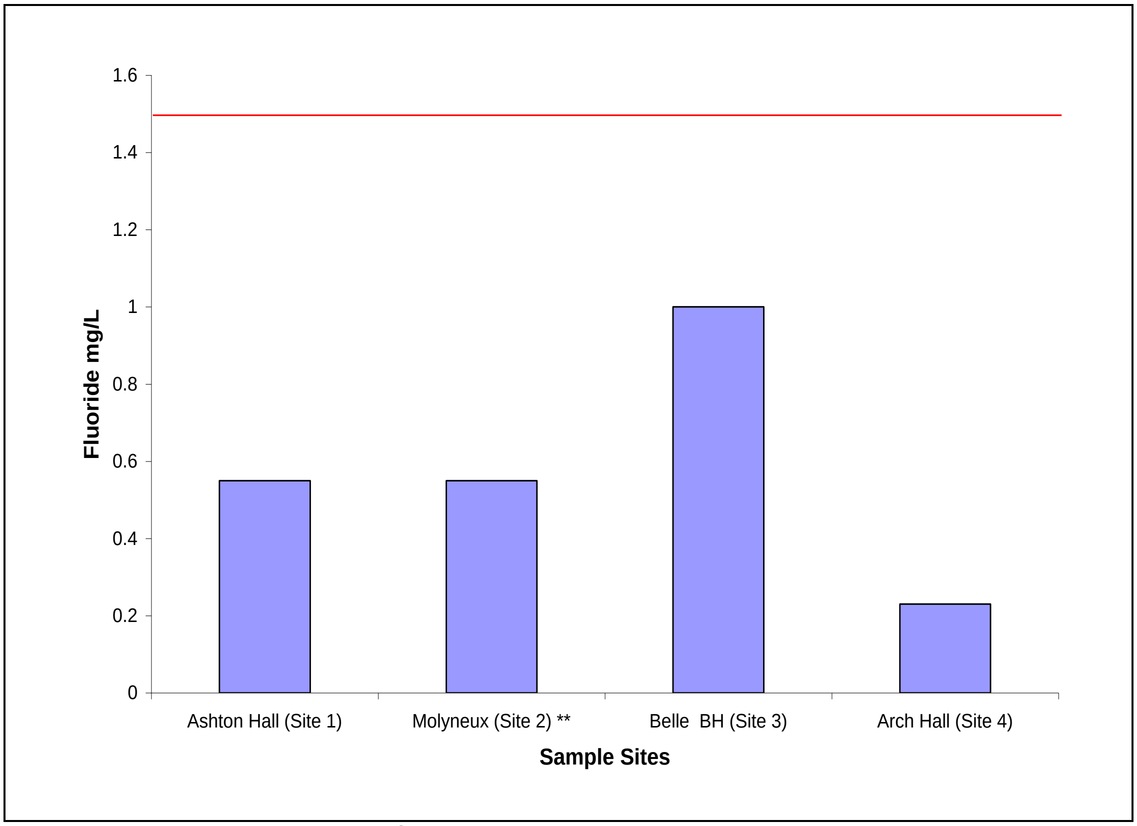

Figure 1: Fluoride concentrations for the Mangrove Leachate Study 2003

This trend was also found in the case of nitrates, nitrites and sodium. For sodium, in most cases values have begun to approach WHO value of 200mg/L. Some of the highest readings where recorded for Molyneux and Belle in 2003 with values of 193mg/L and 146mg/L respectively. This trend has been highlighted in Figure 2 which shows concentrations for all sites under the 2003 leachate monitoring programme, as well as the additional site that were tested during this period, relative to the recommended guideline value. However samples collected at Ionics in 2002 showed readings that far exceeded the WHO guideline value with sodium concentrations reaching as high as 512mg/L.

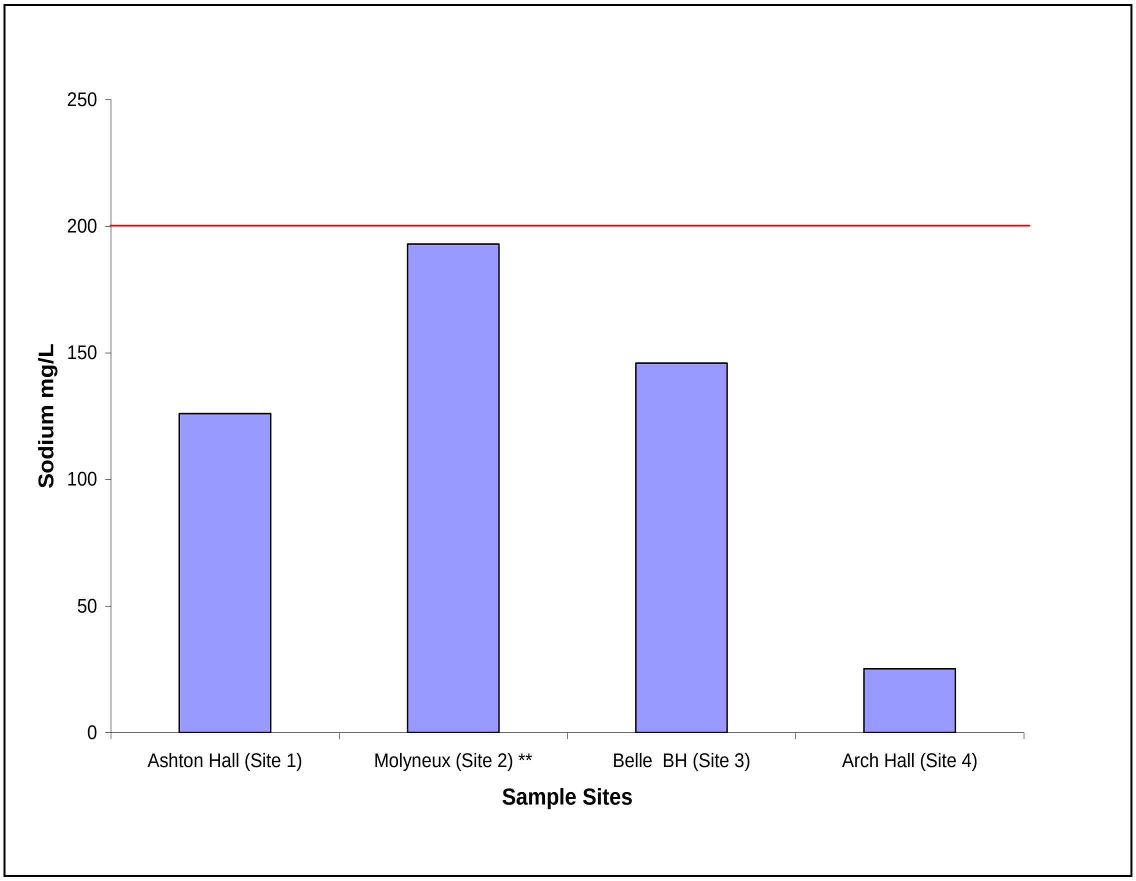

Figure 2: Sodium concentration for Mangrove Leachate Study 2003

Nitrates, of all the parameters of this subgroup used in any of the programmes under which the widescreen analyses done is the only one which consistently produced values that exceeded its MDL. Additionally some of these values closely approached the WHO guideline value of 10mg/L. Under the groundwater screening programme among the highest value seen, was 9.7mg/L at the Belle PS during groundwater screening in 2007 followed by 8.6 mg/L at Ashton Hall PS in 2003. Values of 7.83mg/L and 6.08 mg/L were seen in the 2004 and Belle catchment programme respectively. However, in 2002 the nitrate values exceeded guideline values with a reading of 33.7mg/L at the desalination plant. These trends for nitrate concentrations are illustrated in Figures 3 through 5. In each the concentration of the parameter at each site is shown relative to the guideline value.

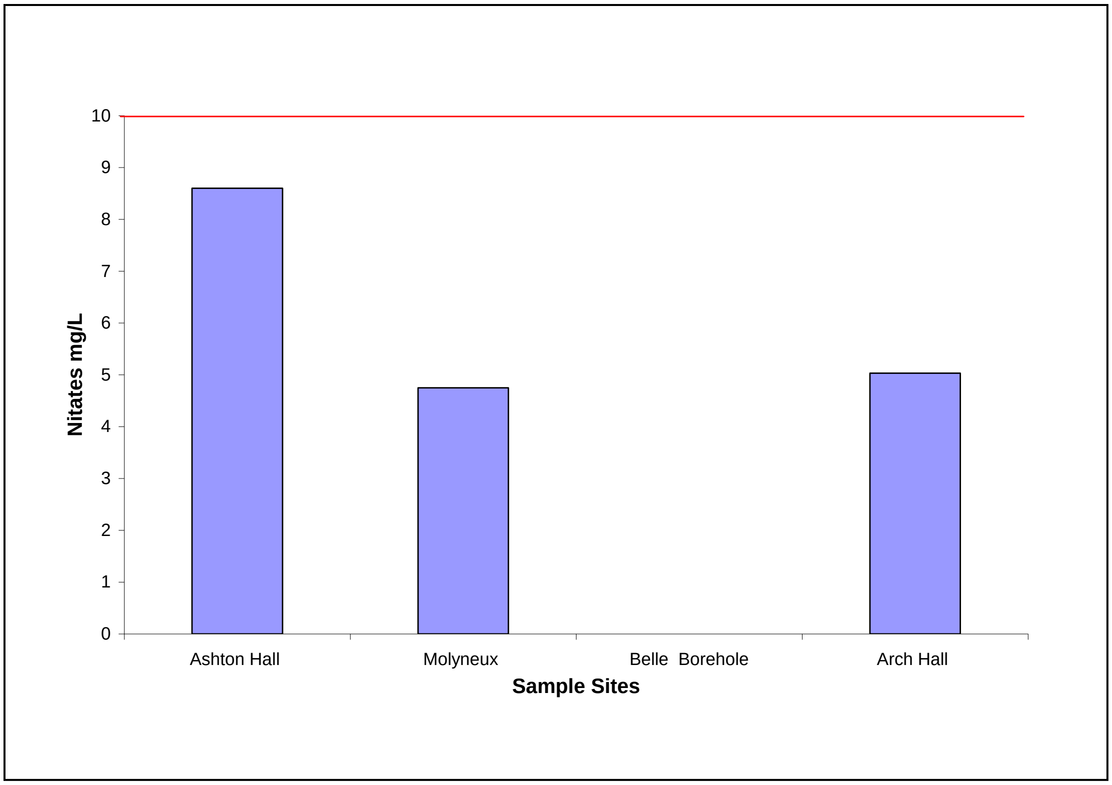

Figure 3: Nitrate concentration for Mangrove Leachate Study 2003

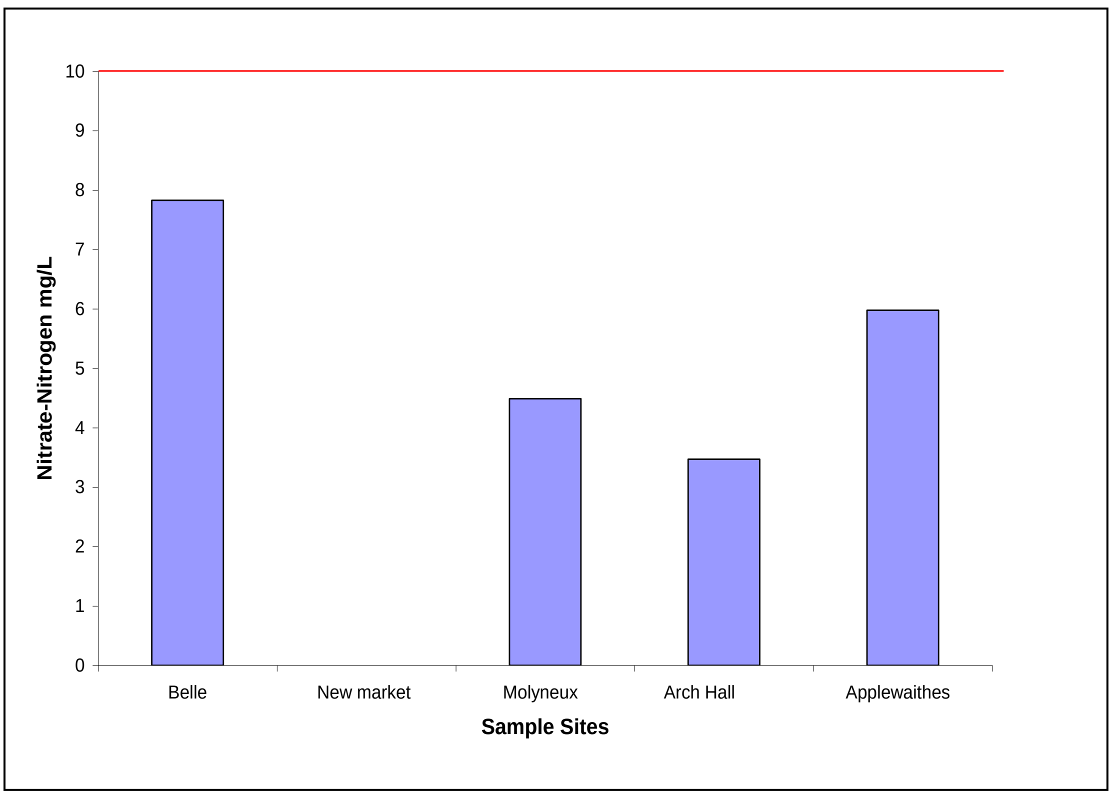

Figure 4: Nitrate concentration for Mangrove Leachate Study 2004

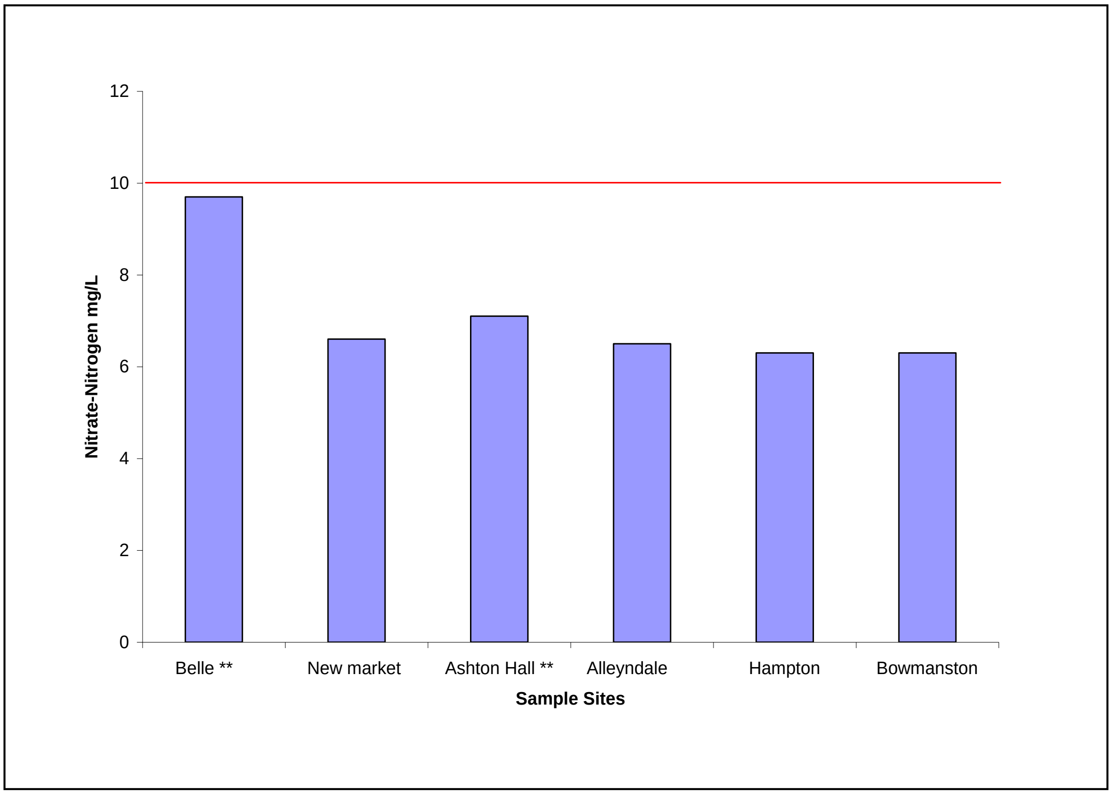

Figure 5: Nitrate concentration for Groundwater Screening Programme 2007

In the case of nitrites a guideline value of 3mg/L has been given. In most of the programmes when this parameter was evaluated it was not detected in the water quality samples. Where it was found values fell below the recommended guideline concentration.

2.2.2. Pesticide and PCBs

Under all the widescreen water quality programmes values for the majority of pesticides and PCBs had concentrations that were recorded below their respective MDLs and WHO guideline values. This is with the exception of atrazine which was found to exceed its MDL with the highest value being that of 0.067µg/L which was recorded for Hampton and Bowmanstan sample sites in the groundwater screening programme of 2007. However these values fall far below the WHO guideline value of 0.002mg/L.

2.2.3. Turbidity

Though there is no health based guideline value for this parameter, high turbidity is indicative of large amounts of suspended particulate matter in drinking water. Though it is thought by the WHO that a turbidity reading below 5 is acceptable to most consumers, it is generally recommended that levels are kept below 0.1NTU to allow for effective disinfection. This was not a test parameter under the general groundwater quality screening of 2007. However at all of the sites where samples were taken, under the Leachate programmes of 2003 and 2004, additional sites sampled during this period, under the Belle catchment study and then again at Ionics Desalination Plant, readings exceeded both the MDL and the recommended guideline value. The highest values seen were at the Arch hall location with a 2003 value of 15.3NTU and a 2004 value of 25NTU. These values have been illustrated in Figures 6 and 7.

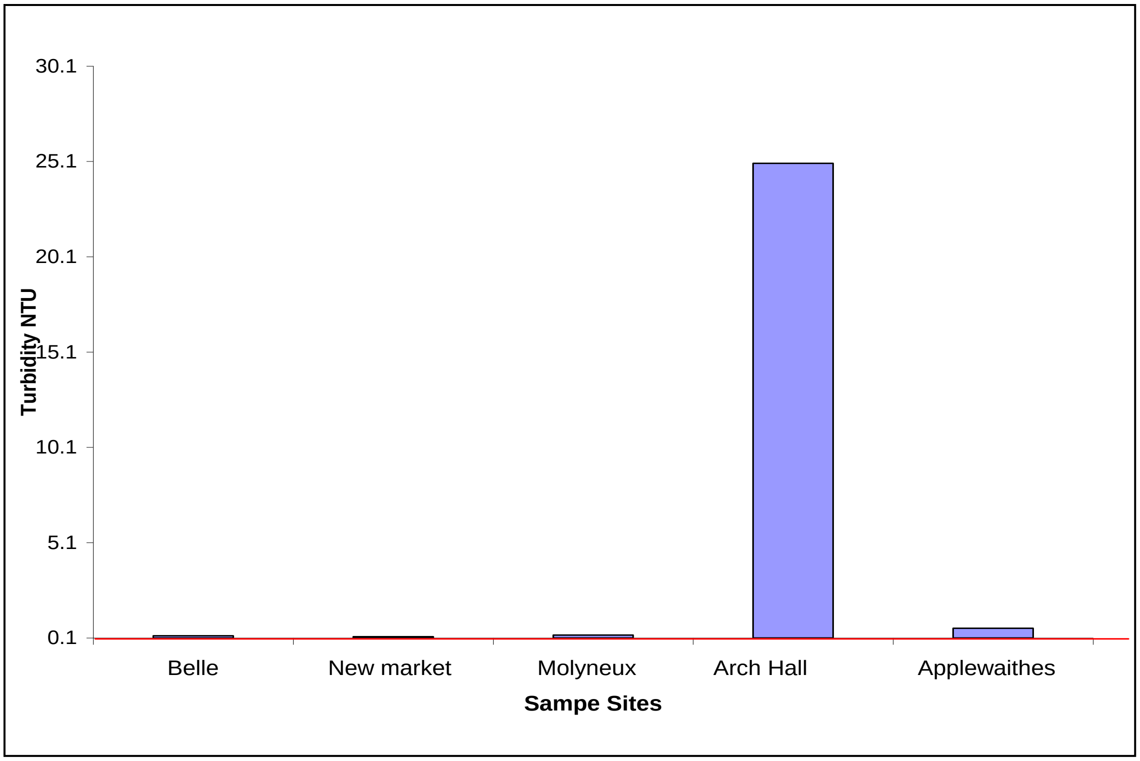

Figure 6: Turbidity readings for Mangrove Leachate Programme 2004

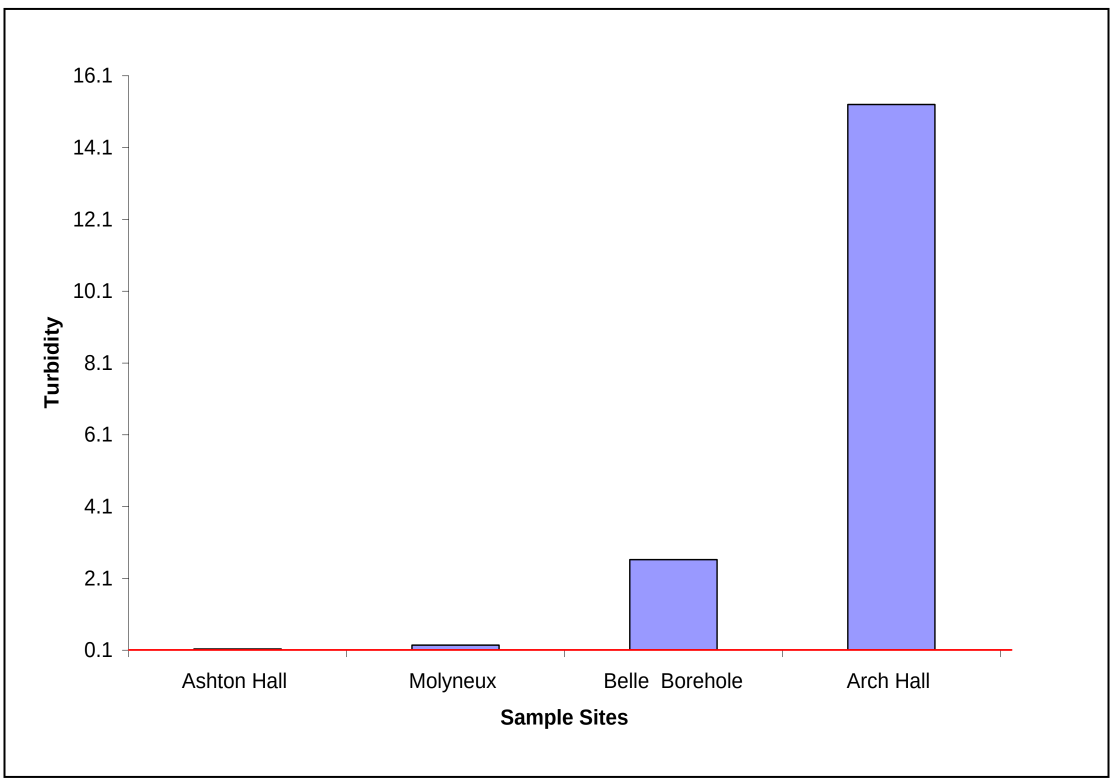

Figure 7: Turbidity readings from Mangrove Leachate Programme 2003

2.2.4. Secondary Chemicals

In most cases the values for Aluminum fell below its MDL and the guideline value of 0.2mg/L. However in the leachate programmes of 2003 and 2004 this parameter was found to be above the recommended value at the Arch hall sample site with the highest recorded value being that of 0.39mg/L. At all sites under all programmes, chlorides were detected in water quality samples. Values were found to be very high during testing at the Aston Hall and Belle sites in 2004 with values of 234mg/L and 213mg/L respectively. Readings exceeded the recommended value of 250mg/L in 2003, in 2004 with values of 291 mg/L and 331 respectively at Molyneaux and then again in 2002 at Ionics with a reading of 760mg/L. These results are represented graphically in Figures 8 and 9.

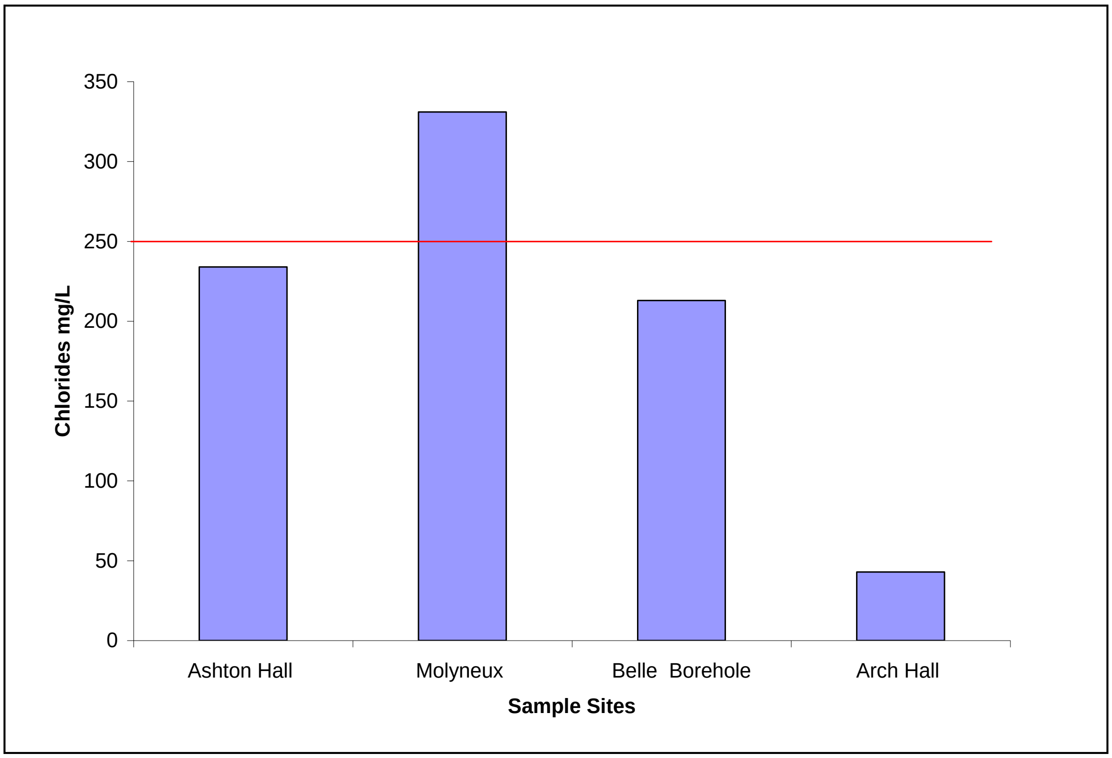

Figure 8: Chloride concentrations for Mangrove Leachate Programme 2003

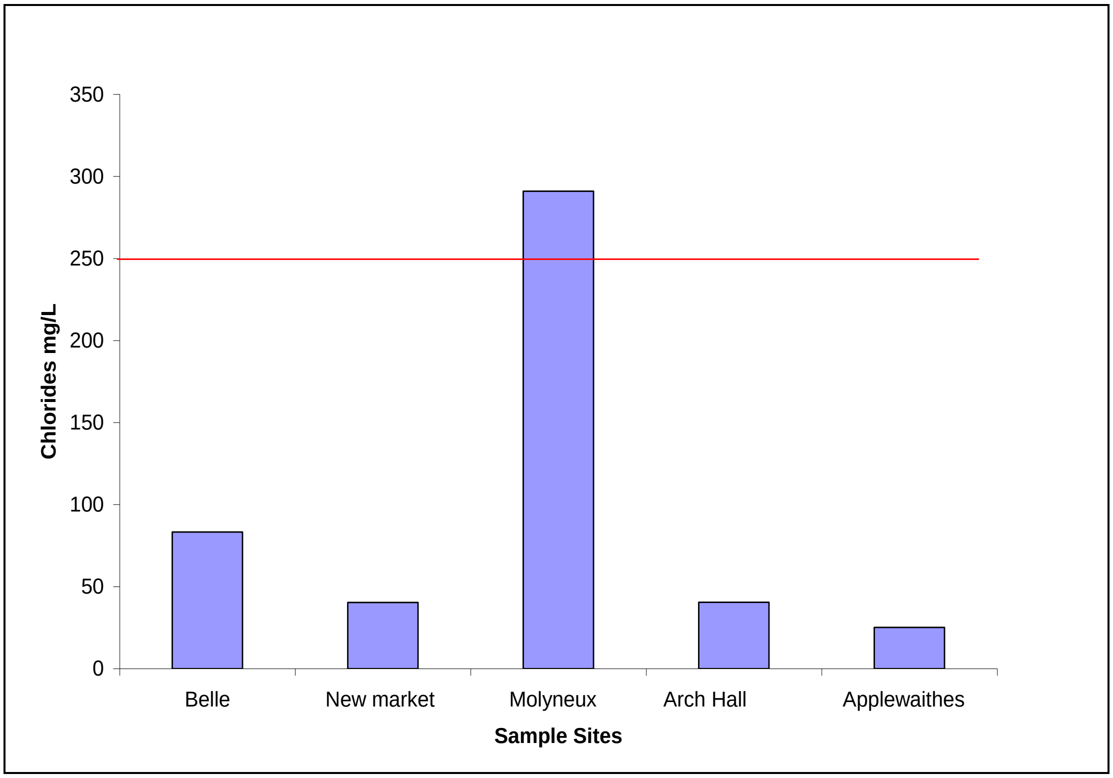

Figure 9: Chloride concentrations for Mangrove Leachate Programme 2004

Manganese, silver, sulfates, iron, fluorides and zinc were all detected during testing of samples under various programmes, however although these substances had values that exceeded their respective MDL's none of these recorded results surpassed the recommended guideline values for drinking water. In all cases readings fell considerably below their WHO guideline values. Additionally pH for all sites fell within the recommended range of 6.5-8.5. It must be noted however that these values are not field pH values and are likely to vary from what would had been seen had these tests been conducted in situ. Colour was also deemed to be acceptable at all sites under each of the widescreen programmes. All values fell below the recommended value of 15TCU.

Copper levels followed a similar trend where most of the values under all programmes fell below the recommended values. However in 2004 levels of this metal far exceeded the WHO value of 2mg/L where levels had risen to 7.28mg/L at the Applewaithes sampling site. Total Dissolved Solids (TDS) readings were also found to be acceptable under all monitoring initiatives. In most cases although it was detected it did not exceed the WHO value of 1000 mg/L. However levels rose above recommended standards in the 2004 where a value of 1050 mg/L was recorded at Molyneux and illustrated in Figure 10.

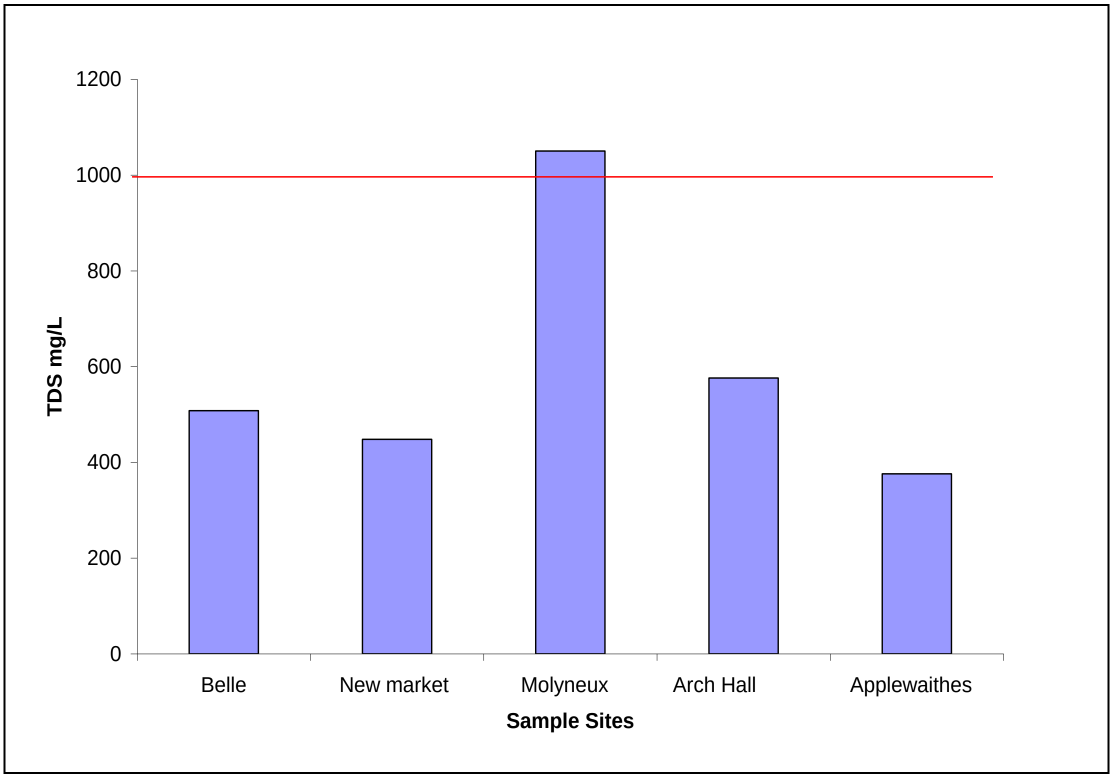

Figure 10: Concentration of Total Dissolved Solids from Mangrove Leachate Programme 2004

2.2.5. Total Coliform

For the most accurate test results, analysis of water samples should be conducted within a six hour period after the sample was collected. In all cases analysis was conducted outside of this time period.

This parameter was used only in the evaluation of the water quality samples that were taken for the Mangrove Leachete studies of 2003 and 2004 and all additional sites that were sampled during these periods. Total coliform was not assessed under the general widescreen groundwater monitoring programme conducted in 2007. In 2004 all values fell below the MDL as well as the WHO standard of zero. However 2003 values for total coliform were exceedingly high and far surpassed the recommended guideline value. It must be noted however that

most of these samples were taken from unchlorinated ground water from agricultural wells with the exception of Molyneux PS and Ashton Hall PS which are public supply wells. At these sites the water is disinfected through the process of chlorination before the point of sampling. This parameter is regularly evaluated under the general water quality monitoring programme where samples are taken from this location on a monthly basis. For comparative purposes, a graphical representation of the results of the 2003 survey as well as results of all monthly monitoring for this parameter at Molyneux PS and Ashton Hall PS sites from 2003 to June 2007 are presented in Figures 11 through 13.

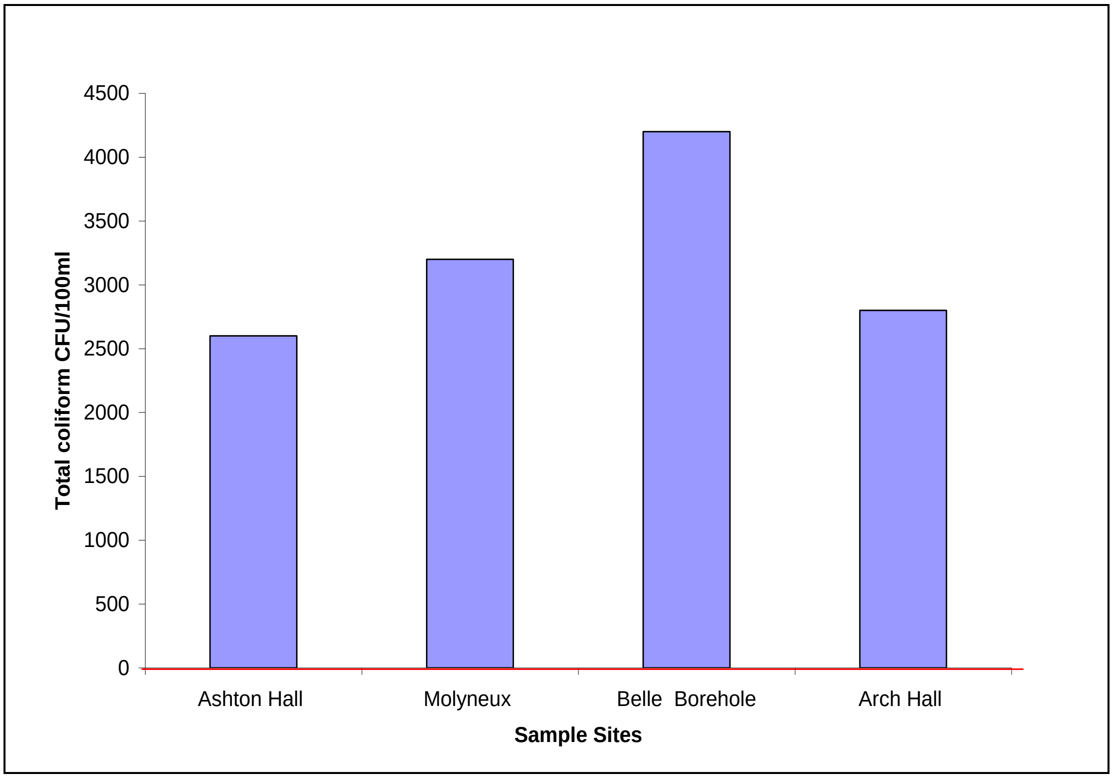

Figure 11: Total Coliform counts for Mangrove Leachate Programme 2003

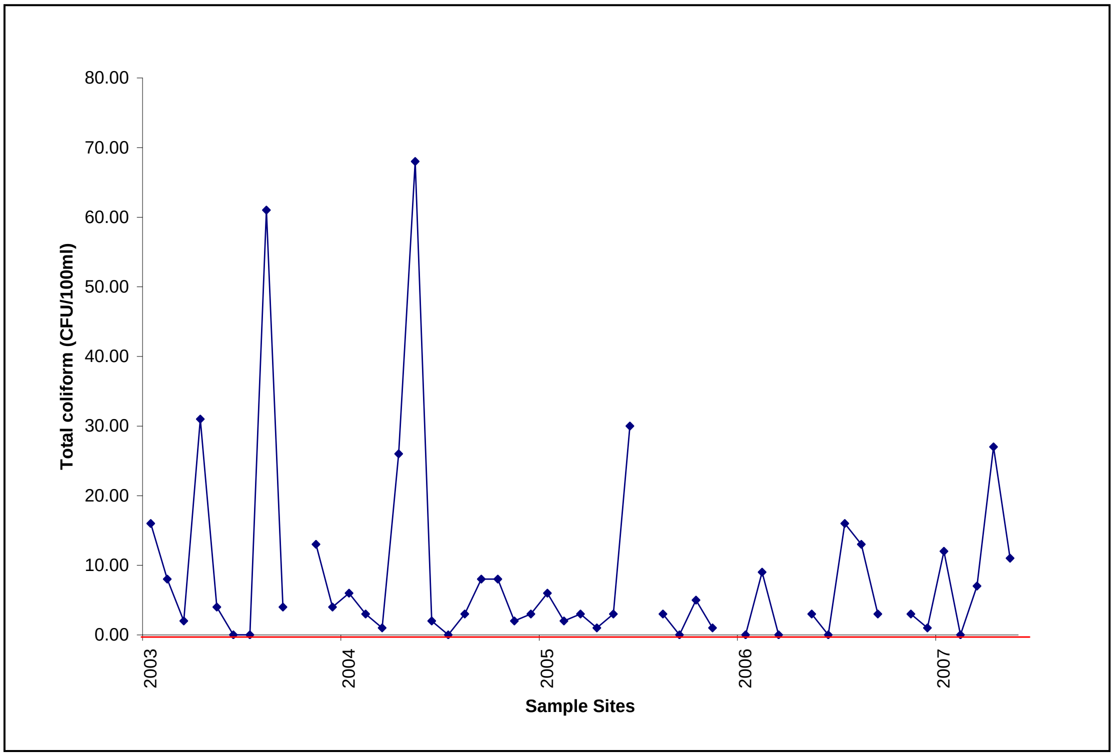

Figure 12: Total Coliform counts for Molyneux 2003-2007

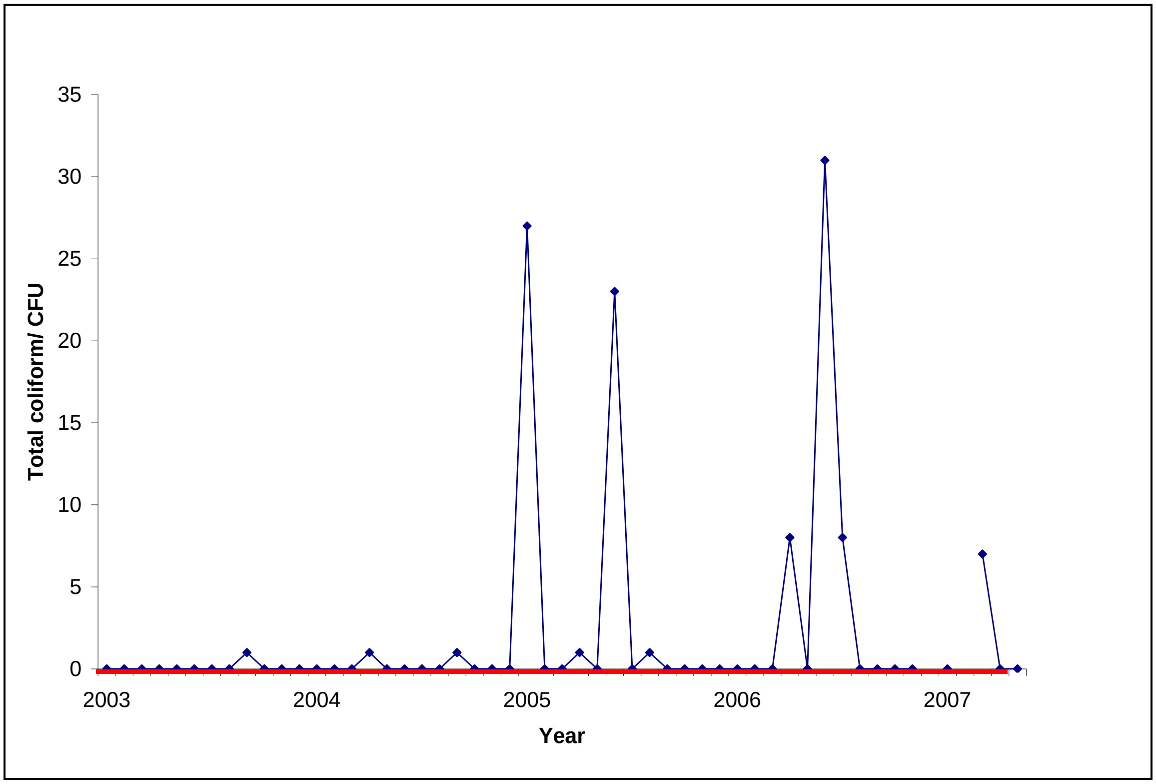

Figure 13: Total Coliform counts for Ashton Hall 2003 -2007

2.2.6. Thallium and Selenium

In all cases these substances had been found to occur below their MDL. Though no guideline value is given for Thallium the WHO recommends a concentration of no greater than 0.01mg/L for Selenium.

2.2.7. Arsenic

This chemical was detected at two locations in the 2003. Samples were taken from the Molyneux PS and Arch Hall PS sites. In both instances values came close to the guideline value of 0.01mg/L with readings of 0.009mg/L.

2.2.8. Methylene Blue Active Surfactants (MBAS)

Commonly found in anionic detergents they are used to lower the surface tension of water so that dirt, grease and other substances may easily be removed from the surfaces to which they are attached. There is currently no WHO guideline value for these substances. However foam or suds that result when these chemicals are mixed with water may be rich in nutrients such as nitrates and phosphates. Additionally this group of substances have the ability to alter the hydraulic characteristics of soils thereby affecting the movement of contaminants through the soil strata to groundwater. Persistent in nature MBAS are often slow to degrade. However their by-products are characteristically carcinogenic and reproductively toxic. An example of this is nonylphenol which a highly effective endocrine disrupter (Donnelly 2004).However there are mainly tagged for their effect on the aesthetic quality of drinking water where they have the potential to influence taste. In a 1998 study done in Colorado if twenty wells, four were found to contain MBAS. It was found that the substances soluble nature allowed for it to be transported from septic tank effluent into the groundwater (USGS 1998). This has serious implications locally. The highest level of sewage treatment offered for properties on the island other than those that are connected to sewage treatment facilities are septic tanks. Developments within Zone 1 areas are required to be equipped with these systems. However they may not be effective enough to reduce the impacts of these substances on groundwater supplies in areas where calculated contaminant transport times are lowest. In light of continuous development of residential areas on the island, many of which will have high housing densities relative to land area, the potential effects of the cumulative contribution of MBAS may be of major importance to the quality of groundwater and certainly to public health. Future monitoring of this group may be necessary.

These substances have been detected only during the groundwater screening programme of 2007 and were found at all sites. The highest recorded value came from the evaluation of water samples, from Newmarket at 0.077mg/L

2.2.9. Hydrocarbons, Hydrocarbon Derivatives and By-products

During the BADMC survey of the Gibbons Boggs areas to determine the impact of leaks in the pipeline on groundwater, it was found that a hydrocarbon plume existed within the aquifer and that many areas within the groundwater system had been affected. The boundaries of this plume have yet to be delineated and true effects of this contamination on fresh water supplies have not been quantified. Table 4 below outlines the sample sites which were found to be contaminated by these substances. Additionally Figures 14 through 16 (Environmental Protection Department In Prep) highlight the areas in which irrigation water was tested and the range of substances which were detected above their respective MDLs.

Table 6: Well sources affected by hydrocarbon leaks

Contaminated Wells	Period
Jackmans Well (BADMC)	March 2004
Atherley Well (BADMC)	November 1995
Atherley Borehole 2	
Atherley Borehole 3	
Forde Well (BADMC)	March 1996
Moore Well	First Quarter 2004
Eastmond borehole	2004
Jessamy borehole	2004
Moseley Well	First Quarter 2004
Sayes Court Well	First Quarter 2004

Source: Environmental Protection Department, In Prep

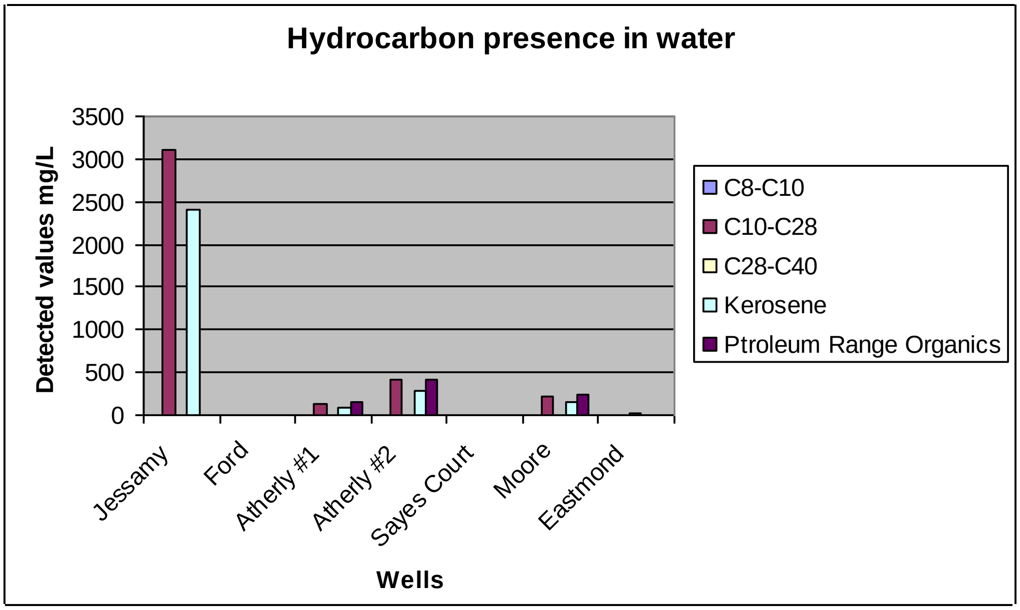

Figure 14: Hydrocarbon concentrations for BADMC analysis of Gibbons Bogg area

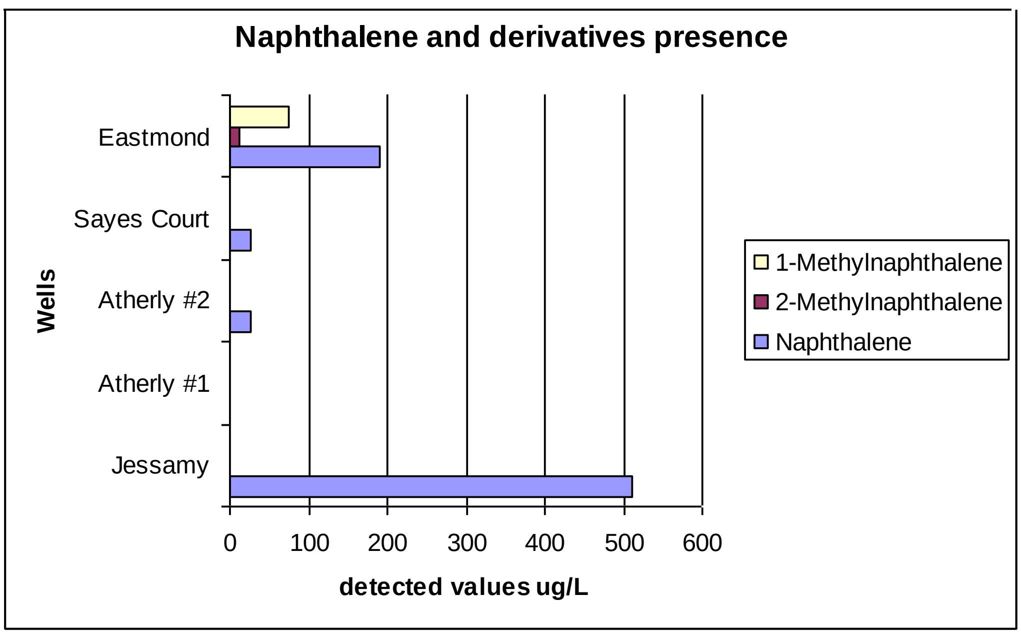

Figure 15: Concentrations of Naphthalene and its derivatives in BADMC analysis of Gibbons Boggs

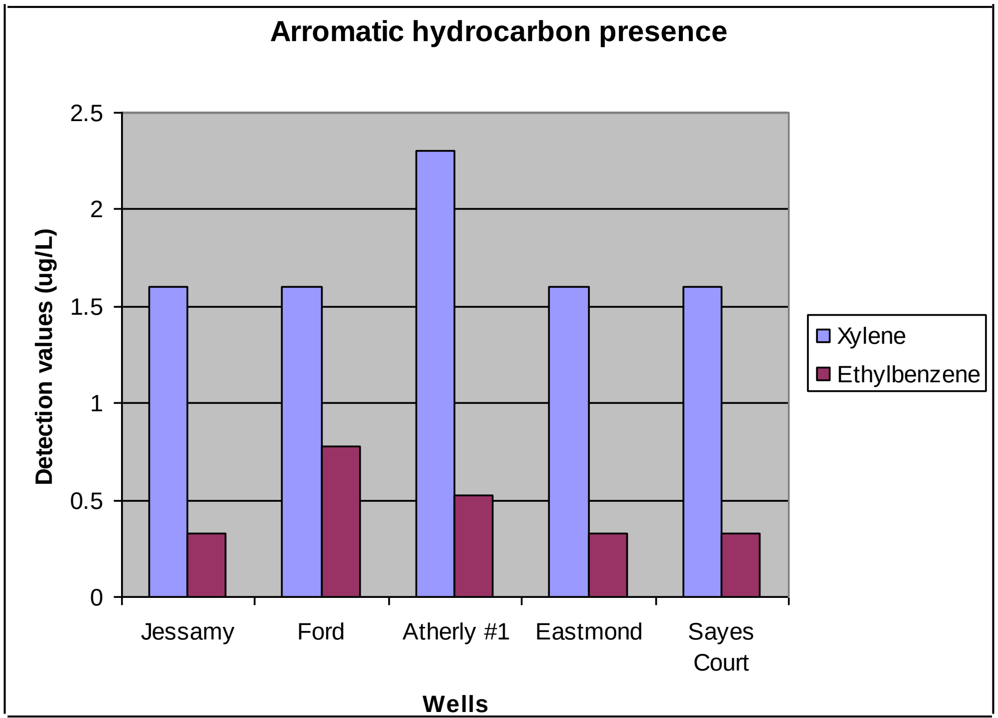

Figure 16: Concentrations of Aromatic Hydrocarbons in BADMC analysis of Gibbons Boggs area

2.2.10. Required Parameters under the Stockholm Convention

The parameters listed in Table 3 of this document were not detected at any of the sites under the widescreen monitoring programmes conducted to date. All readings were below the MDL for each of these substances.

3. General Discussion and Conclusions

3.1. Limitations to data analysis

Some limitations were seen in the assessment of the data presented. Firstly, there was no time series data available for an analysis of trends over any substantial time periods. As a result each data set represents just a snapshot of conditions within a particular time period and will not accurately represent prevailing conditions at any site. Though this does not allow for conclusive statements on the state of groundwater conditions on the island it may suggest parameters that require further assessment, sites that require more frequent monitoring or serve as a comparative tool with other data sets where trends may be more apparent. Secondly, the sample sites under each programme were not consistent either in location or in type. Each programme was carried out with a different objective and over various timeframes. This is characteristic for project specific monitoring programmes. The variation seen created some difficulties in the analysis of trends both within and across sample sites. However these results may be indicative of the variations in concentrations of each parameter both within groundwater and at the pumping station and may be able to suggest the implications of the presence of substances within the groundwater on drinking water quality and by extension public health.

3.2. Parameters of Concern

Although fluoride concentrations never actually exceeded their guideline values, assessments carried out under the 2003 Mangrove Leachate Monitoring programme and at the Ionics desalination plant have suggested that levels have begun to approach this standard. Fluoride may exist in a number of minerals and in many cases the most important sources of fluorides in drinking water occur naturally. Its concentration may therefore depend upon geographical area where variations in rock type may determine levels that are seen in groundwater (Chilton 1996). However the geology of Barbados and in particular the geology of the areas in which the samples were taken, should not give rise to any significant levels of naturally occurring fluorides. Levels seen in the evaluation of these samples therefore suggest that this substance has been introduced and is a pollutant. A recommended value of 1.5mg/L has been given for this substance given that excess concentrations may lead to the increased risk of dental and skeletal fluorosis. Removal of fluorides may be done through the use of a resin filtration system where fluoride salts are eliminated through catalytic exchange.

Unlike fluorides the WHO has given no health derived guideline for sodium. In addition elevated levels of sodium have only been seen within the 2003 Mangrove Leachate Monitoring programme. Sodium salts is a naturally occurring substance in most drinking water with a guideline value of 200mg/L given its effect on taste. High sodium levels are generally associated with high pumping rates and may be indicative of some saline intrusion they may also be associated with sample site location. Concentrations close to or exceeding this value may lead to the distribution of a product that is not acceptable for consumption. It should be noted that the highest concentrations have been seen at the Molyneux Pumping station.

Nitrates are of particular concern to groundwater sources. Derived from many sources they are extremely mobile and highly persistent. They are introduced via numerous pathways such as through onsite sanitation treatment facilities, in particular when soak away systems are used, and as a result of agricultural activity. This activity has been regarded as a major contributor to increased nitrate loading. The primary concern associated with elevated concentration of nitrates in groundwater is the incidence of methaemoglobinaemia or “blue baby syndrome.” Characteristic of its name it is manifested in infants who are exposed to drinking water with higher than recommended concentrations of nitrates and results in the oxidization of haemoglobin to methaeglobin which is unable to transport oxygen around the body (WHO 2004). One of the highest concentrations of nitrates seen across all programmes is in the Belle area. High concentrations were seen from samples taken both at the borehole and the pumping station that distributes groundwater for public consumption. Ironically the Belle sites are afforded the highest level of protection under current legislation by being designated a Zone 1 area. These concentrations, acquired both under the leachate programme and general water quality screening suggest both leachate from the Mangrove landfill, housing developments and agricultural activity may have contributed to some extent for the presence of nitrates at these sites. However values exceeded WHO guidelines in 2002 at the Ionics. Its presence speaks to the persistent nature of the substance and the effective nature of the transport systems by which it is mobilised. The sources of the pollutant need to be qualified and their volumes quantified so that effective measures can be implemented to address these increasing values in order to ensure public health.

In addition to being associated with rising levels of nitrates in groundwater systems on the island agricultural activity has also been responsible for the presence of agrochemicals, in particular atrazine. This herbicide was widely used in sugar cane cultivation and to a smaller extent in horticulture. Whereas most insecticides are foliar, atrazine is applied to the soil ands is therefore more likely to be leached into groundwater. This herbicide had been the center of much controversy in the recent past when an article was published in a national newspaper which posited that atrazine levels were not only ubiquitous in Barbadian ground water but that that they had exceeded the USEPA standard of 3ppb. In doing so it would have serious implications on human health resulting in possible genetic defects as well as reproductive difficulties. The BWA subsequently released a statement refuting these claims and publishing detailed results of atrazine levels at various sites around the island as well as the average concentrations for 1996 after an extensive and rigorous study of pesticides. A review of their records highlighted that that average levels were 0.35ppb with a maximum and modal levels of 0.86ppb and 0.36ppb respectively. The results of the widescreen monitoring have highlighted the fact that atrazine levels continue to be well within the guideline values of the WHO and the standards of the USEPA. At most sites, under each programme, levels were below their MDL with atrazine only being detected at Alleyndale, Hampton and Bowmanstan. However continuous monitoring will be necessary to determine if this trend continues for all sites across the island.

Unlike atrazine there is no health derived guideline value for turbidity. It may occur as a result of the presence of inorganic particulate matter in some groundwater. High concentrations of particulate matter may create a barrier of protection for microorganisms in the water supply from during disinfection thus reducing the effectiveness of the process. High values such as those that are seen in at the sample sites evaluated may indicate high levels of inorganic material which may affect the disinfection process.

Chlorides like turbidity present no known direct health threats. However high levels not only affect taste but may result in increased rates of corrosion in the lines of the distribution system. Depending on the alkalinity of the source water, increased chloride concentration may be correlated with an increased concentration of metals in water within the distribution system.

Additionally, total coliform was only detected in the Mangrove leachate programme of 2003. Recorded values far exceeded the WHO standard of zero. It must be noted that sampling all the sites except Molyneux which is a public supply well, were taken directly from groundwater. Therefore only samples taken from this site were subject to disinfection by chlorination. Despite this however, coliform counts were exceedingly high. Although there have been other occasions where total coliform had been detected at this public supply well, these high numbers, compared with average values per month seen over the four year period extending from January 2003 to June 2007 suggest that these results may not be completely accurate. Contamination during sample collection, transportation to the overseas laboratory or laboratory error may have resulted in the spurious results that have emerged from these analyses.

Of additional concern was the presence of arsenic seen in 2003 at Molyneux P.S and then again in the leachate programme at the Arch Hall AS site in the same year. On both occasions the recorded value fell short of the guideline value by 0.001mg/L. Though not detected on any other occasion or at any other site during subsequent widescreen analyses, the presence of this substance in such high quantities warrants some attention. It is one of the few substances which have been shown to cause cancer in humans through consumption of potable water (WHO 2004). The development of cancer due to the presence of this chemical has been reported to affect the bladder, skin and lungs (WHO 2004).

It must be noted however, that even though values for several parameters exceeded the recommended WHO guideline value at the Ionics Plant that these readings reflect the quality of the effluent and not of the product. Though these readings may not have any direct impact on public health in the context of potable water supplies the method of disposal may determine if these parameters will have any bearing on environmental well being in the future.

Hydrocarbons, their derivatives and by products were only found above their respective MDL in the Gibbons Boggs areas during the BADMC widescreen analyses. Of great concern is the presence of Jet fuel in water samples tested taken from water which used for the irrigation of agricultural lands. The major constituents of Jet fuel with serious implications on human health are listed below (Environmental Protection Department In Prep). Typical Constituents of Concern (COC) from jet fuel are:

a. Benzene, Toluene, Ethylbenzene and Xylene (BTEX);
b. Naphthalene (a PAH)
c. Volatile Petroleum Hydrocarbons (VPH) - (Aliphatics C_5-C_8, C_9-C_{12} & Aromatics C_9-C_{10})
d. Extractable Petroleum Hydrocarbons (EPH) (Aliphatics C_9-C_{18}, C_{19}-C_{36} & Aromatics C_{11}-C_{22})

Various health concerns are associated with the ingestion or close contact with these substance many of which are highly toxic and in some cases carcinogenic in nature. Benzene in particular has been shown to have such properties. Correlations have been made with the contact time with this and higher incidences of leukemia (Environmental Protection Department In Prep). Table 5 highlights some of the substances that were detected in the analysis of the water samples, their respective standards and possible health implications. The concerns seen here should be considered within the broader context where attention is placed on other areas within the island where the potential for the ingress of these substances into groundwater sources is possible. These include petrol service stations where fuel is dispensed and stored, as well as areas where oil and gas exploration is ongoing. Table 5 highlights the health implications associated with the various hydrocarbon compounds.

Table 7: USEPA Standards and associated health effect related to hydrocarbons in water

Parameter	**Standard Value**	**Health Impacts**
Benzene	0.005 mg/L	Anaemia, decreases in Blood Platelets and increased risk of cancer
Toluene	1 mg/L	Nervous system, kidney, or liver problems
Ethyl Benzene	0.7 mg/L	Liver or kidney problems
Xylenes (Total)	10 mg/L	Nervous system damage
Polynuclear Aromatic Hydrocarbons	0.7 mg/L	Cancer and reproductive problems
Tetrachloroethene	0.005 mg/L	Neurological, liver, and kidney effects
Gasoline Range Organics (GRO)	0.047 mg/L	Dermatitis, skin cancer
Diesel Range Organics (DRO)	0.047 mg/L	Dermatitis, skin cancer

3.3. Emerging Parameters

Emerging groundwater contaminants may be defined as substances which are currently unregulated but due to their structure and chemical nature, and based on recent research on the possible health risks, may be candidates for future regulation. The rigor with which they will be monitored would largely depend on the data accrued on their effect on public and environmental health, quantities they are found in, proximity to potable water sources and the frequency with which they occur. In many cases most of the chemical contaminants may be derived from products used in everyday life. For many of them no ecotoxicological data is available which creates great difficulty in predicting what public health effects may occur as well as the impact that they may have on aquatic organisms and general ecosystem integrity (Petrovic et al 2003).

Many of these "emerging pollutants" have not been recently manufactured or newly discovered. Instead this terminology may apply to a number of scenarios. For example this group may include chemical structure (chemicals with a completely new structure are introduced), types of use (new uses in industry or with the general consumer), types of effects (recently discovered effects that existed previously or new effects that have recently occurred) as well as exposure routes (new pathways for dispersion that were discounted or that were not anticipated) (Daughton 2004). Although many of these contaminants are anthropogenic by nature, several of them may be naturally occurring chemicals or pathogens where the magnitude of their effects had never been fully appreciated. Though the universe of substances of a chemical or microbiological nature, that may ingress into groundwater systems and have an effect on public and environmental health, seems large, the universe of potential contaminants is unimaginably so (Daughton 2004). Pharmaceuticals and Personal Care Products (PPCP) has been recognized as having the potential to have severe deleterious effects on human well being and where much attention and research has been focused. Research has shown that in high enough concentrations that they have affected the lives of many species namely aquatic organisms. Although the impact that they many have on man has not been fully understood, the results of research on other species has not been encouraging. A subset of this group of particular concern is known as Endocrine Disruptors (ED) (Daughton 2004).

PPCPs include a wide array of items that range from human and veterinary medicines to sunscreen, soaps and cosmetics. Particular substances within this wide ranging group may be deleterious even in small doses and some of them have been shown to be highly persistent. Additionally, many of these substances are used with such frequency and in such high amounts that although they are not persistent and not known to attenuate, their concentrations in the environment may still increase noticeably. Of even greater concern are their potential cumulative and synergistic effects (McBride and Wyckoff 2002). The concern of accumulation in the environment is further compounded by the range of PPCPs that share specific modes of action that could lead to significant impact through additive exposures (Daughton and Ternes 1999).

Greater attention has been given to this group for two main reasons; the advent of analytical methods that are sensitive enough to detect substances at extremely low concentrations and an explosion in their use due to population growth, an increase in affluence within many populations, greater access to many of these substances and new chemical discoveries. Particular attention has been given to EDs, where research has revealed that at very low levels these compounds may disrupt the normal functioning of hormones that regulate development and control (McBride and Wyckoff 2002). Although EDs are only a subset of PPCPs they have been given special focus in light of the evidence presented on their adverse effects on development and reproduction in aquatic organisms. One example of this may be seen in the effects of selective serotonium reuptake inhibitors (SSRIs) and widely used antidepressants such as fluoxetine on certain shell fish. Deleterious effects were seen at concentrations as low as 30 parts per trillion. Additionally nitro and amino nitro musks, used frequently in personal care products, are highly toxic to aquatic animals. Similarly studies in the USA have highlighted the androgenic effects of anabolic steroids, used to promote weight gain in cattle, on fresh water minnows (McBride and Wyckoff 2002).

What is troubling is that PPCPs are such a wide group and encompassed a great variety of chemicals and medicines that are ubiquitous in nature. The pathways of dispersion vary so much that pinpointing their point of origin may not be possible. Additionally treating waste that contains them or regulating their discharge will be a logistical challenge of monumental proportions and great expense. The ease with which they may enter groundwater systems and the current inability of regulatory agencies to predict long term environmental effects or the effects on humans from low levels of these substances creates a situation of great uncertainty.

Given the geographical dispersion of the sources and receptors of these substances, the true impact of these substances will not be immediately apparent and will emerge over time. Limited resources and budgets in Barbados and many developing countries are currently used to focus on priority pollutants and suggested contaminants to be added to this list whose effects on groundwater resources, and by extension public health, are already known. It is unlikely that any attempts at formulating regulations or focusing management efforts in this direction will occur in the near future. Additionally research in this regard is only in its initial stages. Certainly more information and case studies that more closely relate to the Caribbean scenario will be needed in order that monitoring and regulatory regimes can be structured around them.

3.4. Recommended Parameters

Based on the data collected from the various programmes which employed widescreen water quality analysis, parameters have been suggested for addition to the current water quality monitoring programme conducted on a weekly basis by the EPD. Currently none of these contaminants are evaluated with any regularity. However, during widescreen monitoring they have been found in concentrations closely approaching WHO guideline values. Additionally if present in high enough concentrations, they have the potential to adversely affect human health and the environment. Additionally laboratories on the island have the capability to test for these substances. These parameters, their recommended guideline values as well as potential sources and possible health effects are outlined in Table 6.

Table 8: Recommended parameters for current water quality monitoring programme

Parameters	Potential Sources	WHO guideline value	Human and Environmental Impacts
Arsenic	Derived from industrial sources. It is used in semiconductor manufacturing, petroleum refining, wood preservatives, animal feed additives, and herbicides.	0.01mg/L	Highly toxic and a proven carcinogen. Areas of the body primarily affected are the bladder, skin and lungs. May also result in nausea, thickening and discoloration of the skin as well as partial paralysis and blindness.
Turbidity	Presence of inorganic particulate matter in some groundwater The re-suspension of sediment within the distribution system The sloughing of biofilm within the	0.1 NTU	Measure of the cloudiness of the water. Higher turbidity levels are often associated with higher levels of disease causing microorganisms such as viruses, parasites and some bacteria. E.g. *Cryptosporidium*

Parameters	Potential Sources	WHO guideline value	Human and Environmental Impacts
	distribution system		whose oocyts are highly resistant to disinfection. High turbidity also decreases the efficiency of the disinfection process. Particulate matter may act as a shield for microorganisms against disinfection.
Fluoride	Runoff and infiltration of chemical fertilizers in agricultural areas Liquid waste from industrial sources	1.5 mg/L	May result in dental florosis which is manifested in the pitting and alteration of tooth enamel. Higher concentrations or greater exposure may result in skeletal fluorosis which may cause joint pain, decreased mobility and an increase in bone fractures

3.5. Conclusion

The ability of any regulatory agency to ensure that each consumer receives a high quality supply of potable water, while adequately safeguarding public health, is determined by the availability of relevant information. This will allow them to effectively respond to situations that may have the potential to undermine the integrity of highly valued and limited groundwater resources. Current monitoring strategies evaluate the quality of water produced from public supply wells in each catchment once monthly. These results will inform both supply and regulatory agencies of trends in water quality on a catchment by catchment basis. This should allow for regular evaluation with regard to selected parameters in order to determine if these sources are still suitable for use for public distribution or if additional management strategies or regulations need to be implemented. However the scope of the monitoring regime currently employed is very limited.

Wide screen water quality monitoring is an expensive but necessary undertaking. Not only does it allow the Barbadian government to live up to the obligations that it undertook when becoming signatory to relevant multilateral environmental agreements but it greatly broadens the scope of the water quality assessment. The prohibitive nature of its cost may not allow for them to be conducted as frequently as monitoring by the EPD and BWA may be done, and indeed such regularity may not be necessary.

Additionally the ad hoc nature in which they have been done previously has not allowed for trend data to be compiled. However it is extremely valuable at this time, as an indicator of areas where more frequent evaluation is needed and highlighting parameters that may require regular analysis. Management structures therefore need to be adaptive and flexible enough to allow the detailed analysis to inform the more structured programme which is currently conducted with greater frequency. In doing so sampling regimes may be altered and parameters added as necessary to ensure that any monitoring programme addresses all areas of immediate concern. However although it may not be necessary or feasible to conduct widescreen analysis more than once every year, some structure must still be given to when these will done so that all sites can be evaluated within a reasonable timeframe.

Additionally there is a need for a comprehensive categorisation of pollutant loading in order to adequately assess pollution potential of known contaminants within all catchment areas. This categorisation will ultimately determine the urgency of the responses that will be necessary to protect public health. This system should be based on evidence from existing groundwater quality data which is able to validate any assessment of pollution potential. However it must be noted that for this potential to be translated into an immediate impact depends largely on the mobility and persistence of the contaminant as well as the scope for further dilution within the groundwater regime. This categorisation should also incorporate an economic assessment which addresses the value of the resources that may be affected, the cost of sourcing and deriving potable water from other supplies as well as the socio economic impact of persons who may be affected by increased cost or reduced supply such as those involved in the agricultural sector.

This quantification and catagorisation of threats to groundwater resources in probability terms will provide a more reliable basis for consideration of actions that may need to be taken to enhance groundwater protection. Additionally, it may act to focus monitoring effort on sources of pollutants or activities that may lead to their production or dispersal that have been determined to of be of immediate concern. This is especially useful given that testing is done within the constraints of limited budget and resources. A more focus and better informed programme maximizes available capacity and allows for better planning and sourcing of additional resources or training in areas that may be needed in the future.

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5. Appendices

Appendix 1: Parameters for Widescreen analysis extracted from 2007 report for the Belle (Site 1)

ANALYTICAL REPORT

Sample ID:	Site 1	Project:	GW Supply Wells/Drinking Water
Lab #:	Q002171-01	Work Order #:	Q002171
Sampled:	03/26/07 9:47	Matrix:	Drinking Water

Primary DW Volatiles by EPA 524.2

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
1,1,1-Trichloroethane	0.22 ug/L	U	1	0.22	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,1,2-Trichloroethane	0.30 ug/L	U	1	0.30	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,1-Dichloroethene	0.25 ug/L	U	1	0.25	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,2,4-Trichlorobenzene	0.29 ug/L	U	1	0.29	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,2-Dichlorobenzene	0.28 ug/L	U	1	0.28	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,2-Dichloroethane	0.23 ug/L	U	1	0.23	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,2-Dichloropropane	0.25 ug/L	U	1	0.25	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
1,4-Dichlorobenzene	0.28 ug/L	U	1	0.28	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Benzene	0.30 ug/L	U	1	0.30	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Carbon Tetrachloride	0.24 ug/L	U	1	0.24	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Chlorobenzene	0.27 ug/L	U	1	0.27	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
cis-1,2-Dichloroethene	0.24 ug/L	U	1	0.24	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Ethylbenzene	0.32 ug/L	U	1	0.32	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Methylene chloride	0.42 ug/L	U	1	0.42	1.0	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Styrene	0.27 ug/L	U	1	0.27	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Tetrachloroethene	0.37 ug/L	U	1	0.37	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Toluene	0.41 ug/L	U	1	0.41	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
trans-1,2-Dichloroethene	0.31 ug/L	U	1	0.31	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Trichloroethene	0.24 ug/L	U	1	0.24	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Vinyl chloride	0.38 ug/L	U	1	0.38	0.50	524.2	04/06/07 8:58	04/06/07 11:45	7040179
Xylenes, Total	0.98 ug/L	U	1	0.98	1.5	524.2	04/06/07 8:58	04/06/07 11:45	7040179

Surrogate Recovery	% Recovery	% Recovery Limits	
1,2-Dichlorobenzene-d4	96.0 %	0-200	7040179
4-Bromofluorobenzene	96.5 %	80-120	7040179

Semivolatiles by GC

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
1,2-Dibromo-3-chloropropane	0.0036 ug/L	U	1	0.0036	0.040	504.1	04/02/07 8:44	04/02/07 11:02	7040006
1,2-Dibromoethane (EDB)	0.0053 ug/L	U	1	0.0053	0.020	504.1	04/02/07 8:44	04/02/07 11:02	7040006

Surrogate Recovery	% Recovery	% Recovery Limits	
1,1,1,2-Tetrachloroethane	86.7 %	64-125	7040006

Metals

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Aluminum, Total	0.035 mg/L	U	1	0.035	0.20	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Barium, Total	0.021 mg/L	I	1	0.00098	0.050	200.7	03/27/07 16:53	03/28/07 16:18	7030744

ANALYTICAL REPORT

Sample ID:	Site 1		Project:	GW Supply Wells/Drinking Water
Lab #:	Q002171-01		Work Order #:	Q002171
Sampled:	03/26/07 9:47		Matrix:	Drinking Water

Metals

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Beryllium, Total	0.0018 mg/L	U	1	0.0018	0.0040	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Cadmium, Total	0.0021 mg/L	U	1	0.0021	0.0050	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Chromium, Total	0.0025 mg/L	U	1	0.0025	0.0050	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Copper, Total	0.0088 mg/L	I	1	0.0060	0.010	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Iron, Total	0.029 mg/L	U	1	0.029	0.050	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Manganese, Total	0.0034 mg/L	U	1	0.0034	0.0050	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Mercury, Total	0.000084 mg/L	J, I	1	0.000060	0.00020	245.1	03/28/07 16:56	03/31/07 15:58	7030745
Nickel, Total	0.0059 mg/L	U	1	0.0059	0.010	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Silver, Total	0.00099 mg/L	I, V	1	0.00088	0.0050	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Sodium, Total	50 mg/L		1	0.35	1.0	200.7	03/27/07 16:53	03/28/07 16:18	7030744
Zinc, Total	0.020 mg/L		1	0.0042	0.020	200.7	03/27/07 16:53	03/28/07 16:18	7030744

Wet Chemistry

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Chloride	66 mg/L		1	0.20	0.40	300.0	03/28/07 9:30	03/28/07 9:30	7030803
Color	5.0 cu	Q	1	2.5	2.5	2120B	03/29/07 8:00	03/29/07 8:00	7030808
Cyanide	0.0040 mg/L	U	1	0.0040	0.0050	335.4	03/30/07 16:00	03/30/07 16:42	7030892
Fluoride	0.26 mg/L		1	0.054	0.20	300.0	03/28/07 9:30	03/28/07 9:30	7030803
MBAS	0.045 mg/L	I	1	0.043	0.075	425.1	03/28/07 9:30	03/28/07 9:30	7030787
Nitrogen, Nitrate (as N)	9.7 mg/L		1	0.062	0.50	300.0	03/28/07 9:30	03/28/07 9:30	7030803
Nitrogen, Nitrite (as N)	0.021 mg/L	U	1	0.021	0.50	300.0	03/28/07 9:30	03/28/07 9:30	7030803
Odor	0.0 t.o.n.	U	1	0.0	0.0	2150B	03/29/07 8:00	03/29/07 8:00	7030807
pH	7.29 s.u.		1	0.00	0.00	150.1	03/28/07 12:45	03/28/07 12:45	7030772
Solids, Total Dissolved	400 mg/L		1	8.9	10	160.1	03/28/07 16:30	03/28/07 16:30	7030819
Sulfate	25 mg/L		1	0.14	1.0	300.0	03/28/07 9:30	03/28/07 9:30	7030803

Subcontract Data - 200.9

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Thallium	0.001 mg/L	U	1	0.001		200.9		04/05/07 17:08	

Subcontract Data - 3113B

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Antimony	0.001 mg/L	U	1	0.001		3113B		04/02/07 16:47	
Arsenic	0.001 mg/L	U	1	0.001		3113B		04/13/07 12:40	
Lead	0.001 mg/L	U	1	0.001		3113B		04/16/07 17:51	

ANALYTICAL REPORT

Sample ID:	Site 1		Project:	GW Supply Wells/Drinking Water
Lab #:	Q002171-01		Work Order #:	Q002171
Sampled:	03/26/07 9:47		Matrix:	Drinking Water

Subcontract Data - 3113B

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Selenium	0.001 mg/L	U	1	0.001		3113B		04/17/07 12:14	

Subcontract Data - 508.1

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Chlordane	0.05 ug/L	U	1	0.05	0.2	508.1		04/03/07 17:03	
PCB 1016	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
PCB 1221	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
PCB 1232	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
PCB 1242	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
PCB 1248	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
PCB 1254	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
PCB 1260	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
Total PCBs	0.2 ug/L	U	1	0.2	0.1	508.1		04/03/07 17:03	
Toxaphene	0.5 ug/L	U	1	0.5	1	508.1		04/03/07 17:03	

Subcontract Data - 515.3

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
2,4,5-TP (Silvex)	0.25 ug/L	U	1	0.25	0.2	515.3		04/03/07 15:57	
2,4-D	1 ug/L	U	1	1	0.1	515.3		04/03/07 15:57	
Dalapon	1 ug/L	U	1	1	1	515.3		04/03/07 15:57	
Dinoseb	0.5 ug/L	U	1	0.5	0.2	515.3		04/03/07 15:57	
Pentachlorophenol	0.1 ug/L	U	1	0.1	0.04	515.3		04/03/07 15:57	
Picloram	0.75 ug/L	U	1	0.75	0.1	515.3		04/03/07 15:57	

Subcontract Data - 525.2

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Alachlor	0.2 ug/L	U	1	0.2	0.2	525.2		04/02/07 19:09	
Atrazine	0.06 ug/L	U	1	0.06	0.1	525.2		04/02/07 19:09	
Benzo (a) pyrene	0.1 ug/L	U	1	0.1	0.02	525.2		04/02/07 19:09	
Di(2-ethylhexyl)adipate	0.3 ug/L	U	1	0.3	0.6	525.2		04/02/07 19:09	
Di(2-ethylhexyl)phthalate	0.6 ug/L	U	1	ND	0.6	525.2		04/02/07 19:09	
Endrin	0.1 ug/L	U	1	0.1	0.01	525.2		04/02/07 19:09	
gamma-BHC	0.06 ug/L	U	1	0.06	0.02	525.2		04/02/07 19:09	
Heptachlor	0.08 ug/L	U	1	0.08	0.04	525.2		04/02/07 19:09	
Heptachlor epoxide	0.1 ug/L	U	1	0.1	0.02	525.2		04/02/07 19:09	
Hexachlorobenzene	0.05 ug/L	U	1	0.05	0.1	525.2		04/02/07 19:09	

ANALYTICAL REPORT

Sample ID:	Site 1		Project:	GW Supply Wells/Drinking Water
Lab #:	Q002171-01		Work Order #:	Q002171
Sampled:	03/26/07 9:47		Matrix:	Drinking Water

Subcontract Data - 525.2

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Hexachlorocyclopentadiene	0.2 ug/L	U	1	0.2	0.1	525.2		04/02/07 19:09	
Methoxychlor	0.05 ug/L	U	1	0.05	0.1	525.2		04/02/07 19:09	
Simazine	0.07 ug/L	U	1	0.07	0.07	525.2		04/02/07 19:09	

Subcontract Data - 531.1

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Carbofuran	0.5 ug/L	U	1	0.5	0.9	531.1		04/06/07 0:36	
Oxamyl	0.5 ug/L	U	1	0.5	2	531.1		04/06/07 0:36	

Subcontract Data - 547

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Glyphosate	48 ug/L	U	1	48	240	547	04/02/07 0:00	04/02/07 0:00	

Subcontract Data - 548.1

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Endothall	20.3 ug/L	U	1	20.3	50	548.1	03/28/07 0:00	03/29/07 0:00	

Subcontract Data - 549.2

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
Diquat	2 ug/L	U	1	2	10	549.2	03/29/07 0:00	03/30/07 0:00	

Subcontract Data

Parameter	Analytical Results	Q	DF	MDL	PQL	Analysis Method	Prep Date/Time	Analysis Date/Time	Analytical Batch
4,4' -DDT	0.095 ug/L	U	1	0.095	0.1	8081	04/03/07 0:00	04/10/07 0:00	
Mirex	0.11 ug/L	U	1	0.11	0.11	8081	04/03/07 0:00	04/10/07 0:00	

Appendix II: Results used in the comparative analysis of widescreen water quality programmes done to date

Date	Site	Barium (mg/L)	Copper (mg/L)	Iron (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Silver (mg/L)	Sodium (mg/L)	Zinc (mg/L)	Chloride (mg/L)	Color (cu)	Fluoride (mg/L)	MBAS (mg/L)
Wide Screen Ground Water Quality													
WHO guidelines for drinking water		**0.2mg/L**	**2mg/L**	**2mg/L**	**0.4mg/L**	**0.001**	**0.1mg/L**	**200mg/L**	**3mg/L**	**250mg/L**	**~15 TCU**	**1.5mg/L**	
Mar-07	Belle **	0.021	0.0088	BDL	BDL	0.000084	0.00099	50	0.02	66	5	0.26	0.045
Mar-07	New market	0.017	0.0062	BDL	BDL	0.000089	BDL	28	0.21	45	BDL	0.2	0.077
Mar-07	Ashton Hall **	0.016	BDL	BDL	BDL	BDL	BDL	98	0.098	160	BDL	0.15	0.05
Mar-07	Alleyndale	0.021	0.007	0.061	0.012	BDL	BDL	26	0.047	47	5	0.15	0.045
Mar-07	Hampton	0.019	BDL	BDL	BDL	BDL	BDL	97	0.03	160	BDL	0.24	0.045
Mar-07	Bowmanston	0.012	BDL	BDL	BDL	BDL	BDL	22	0.015	29	BDL	0.11	0.045
Leachate Study													
Jun-04	Belle	BDL	BDL	BDL	BDL	BDL	BDL	45.5	0.02	83.3	2.5	0.22	BDL
Jun-04	New market	BDL	BDL	BDL	BDL	0.2	BDL	24.1	0.05	40.3	Q	0.23	BDL
Jun-04	Molyneux	BDL	BDL	BDL	BDL	BDL	BDL	149	0.042	291	BDL	BDL	BDL
Jun-04	Arch Hall	BDL	BDL	BDL	0.1	BDL	BDL	21.9	BDL	40.5	BDL	BDL	BDL
Jun-04	Applewaithes	BDL	7.28	BDL	BDL	BDL	BDL	14	BDL	25.1	2.5	BDL	BDL
Dec-03	Ashton Hall	BDL	0.003	BDL	BDL	BDL	BDL	126	0.029	234	5	0.55	BDL
Dec-03	Molyneux	BDL	BDL	BDL	BDL	BDL	BDL	193	0.053	331	5	0.55	BDL
Dec-03	Belle Borehole	BDL	BDL	BDL	BDL	BDL	BDL	146	0.011	213	5	1	BDL
Dec-03	Arch Hall	BDL	BDL	BDL	0.036	BDL	BDL	25.2	BDL	42.9	7.5	0.23	BDL
Oct-04	Molyneux (W 860)												
Oct-04	Sandy Lane BH (W861)												
Oct-04	Arch Hall BH (W 856)												
Oct-04	Raw Leachate												
Belle Catchment Study													
Jun-03	Sweet Water II	BDL	BDL	BDL	BDL	BDL	BDL	14.9	0.06	25.6	2.5	BDL	BDL
Jun-03	Applewaithes	BDL	BDL	BDL	BDL	BDL	BDL	12.3	BDL	22.6	2.5	BDL	BDL

Key	
	Exceeds WHO value
	Approaching WHO values
Q	Sample was held beyond recc. time
**	Public supply wells
BDL	Below Detection Limit
NTP	Not a test parameter

Appendix II Cont'd

Date	Site	Nitrate- Nitrogen (mg/L)	Nitrite- Nitrogen (mg/L)	pH	TDS (mg/L)	Sulfate (mg/L)	Thallium (mg/L)	Lead (mg/L)	Selenium (mg/L)	Atrazine (ug/L)	Turbidity (NTPU)	Chromium (mg/L)	Aluminium (mg/L)	Nickel (mg/L)	Sub EPA 900 Gross Alpha	Arsenic (mg/L)	Total coliform (CFU100ml)
Wide Screen Ground Water Quality																	
WHO guidelines for drinking water		**10mg/L**	**3 mg/L**	**6.5 - 9.2**	**1000mg/L**	**500mg/L**		**0.01mg/L**	**0.01mg/L**	**0.002mg/L**	**0.1**	**0.05mg/L**	**0.2mg/L**	**0.02mg/L**		**0.01**	
Mar-07	Belle **	9.7	BDL	7.29	400	25	0.001	BDL	BDL	BDL	NTP	BDL	BDL	BDL		BDL	NTP
Mar-07	New market	6.6	BDL	7.29	360	24	BDL	0.0021	0.0021	BDL	NTP	BDL	BDL	BDL		BDL	NTP
Mar-07	Ashton Hall **	7.1	BDL	7.47	600	35	BDL	BDL	0.0015	BDL	NTP	BDL	BDL	BDL		BDL	NTP
Mar-07	Alleyndale	6.5	BDL	7.28	380	22	0.001	BDL	BDL	0.064	NTP	BDL	BDL	BDL		BDL	NTP
Mar-07	Hampton	6.3	BDL	7.27	560	33	BDL	BDL	BDL	0.067	NTP	BDL	BDL	BDL		BDL	NTP
Mar-07	Bowmanston	6.3	BDL	7.56	240	23	BDL	BDL	0.0014	0.067	NTP	BDL	BDL	BDL		BDL	NTP
Leachate Study																	
Jun-04	Belle	7.83	BDL	7.97	508	28.5	BDL	BDL	BDL	BDL	0.213	BDL	BDL	BDL	3		BDL
Jun-04	New market	0	7	Q	448	23.5	BDL	BDL	BDL	BDL	0.163	0.0005	BDL	BDL	BDL		BDL
Jun-04	Molyneux	4.49	4.49	7.89	1050	42.7	BDL	BDL	BDL	BDL	0.247	BDL	BDL	BDL	BDL		BDL
Jun-04	Arch Hall	3.47	BDL	7.65	576	30.5	BDL	BDL	BDL	BDL	25	BDL	0.21	0.012	17.4		BDL
Jun-04	Applewaithes	5.98	BDL	7.28	376	21.4	BDL	BDL	BDL	BDL	0.606	BDL	BDL	BDL	BDL		BDL
Dec-03	Ashton Hall	8.6	8.6	7.9	770	37.7	BDL	BDL	BDL	BDL	0.133	BDL	BDL	BDL	BDL	BDL	2600
Dec-03	Molyneux	4.75	4.75	7.13	940	50	BDL	0.002	BDL	BDL	0.24	BDL	BDL	BDL	BDL	0.009	3200
Dec-03	Belle Borehole	BDL	BDL	7.8	708	54.5	BDL	0.003	BDL	BDL	2.62	BDL	BDL	BDL	BDL	BDL	4200
Dec-03	Arch Hall	5.03	5.03	7.69	384	22.9	BDL	BDL	BDL	BDL	15.3	BDL	0.39	0.009	BDL	0.009	2800
Oct-04	Molyneux (W 860)																
Oct-04	Sandy Lane BH (W861)																
Oct-04	Arch Hall BH (W 856)																
Oct-04	Raw Leachate																
Belle Catchment Study																	
Jun-03	Sweet Water II	4.77		7.43	328	19.4	BDL	BDL	BDL	BDL	0.45	BDL	BDL	BDL		BDL	
Jun-03	Applewaithes	6.08		7.85	276	19.9	BDL	BDL	BDL	0.55	0.25	BDL	BDL	BDL		BDL	

Key	
	Exceeds WHO value
	Approaching WHO values
Q	Sample was held beyond recc. time
**	Public supply wells
BDL	Below Detection Limit
NTP	Not a test parameter