A Comprehensive Review of Nitrate Pollution in Groundwater in Barbados

ENVIRONMENTAL PROTECTION DEPARTMENT

May 2009

Executive Summary

The issue of increasing nitrate concentration in potable water sources in Barbados is a point of great concern for government agencies charged with the distribution of drinking water and the protection of groundwater resources. Recent studies have cast doubts on the efficacy of the current Groundwater Zoning Policy and how effective it would be in continuing to safeguard the quality of local water supplies. Statistical analysis of three of the major wells on the island, Belle, Hampton and Ashton wells, have suggested that nitrate concentration at these points are increasing. Over 46% of the wells had some probability of exceeding the WHO guideline value of 10mg/L. Forecasts for these sites also indicate that this trend is likely to continue.

Although leaching and run off from agricultural land; and inadequately treated domestic and industrial sewage have been implicated as the major contributors to this trend, there is insufficient data to pinpoint the major sources of this problem and to quantify and categorise contributions from any particular sector. Also of note is the considerable impact that elevated levels of nitrate in the groundwater will have on the nearshore marine environment.

Although the Zoning Policy has provided protection against bacteriological contamination, its ability to minimise the ingress of chemical contaminants is questionable. Suggestions to address these issues include a revision of the current zoning policy, the sewering of residential districts in Zone 1 areas and an in-depth study and reform of current agricultural practices.

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

1 INTRODUCTION

The human impact on the nitrogen cycle over the last half century has resulted in a steady accumulation of nitrates in both terrestrial and marine water resources on a global scale. It has been suggested that the anthropogenic production of nitrogen has outstripped that fixed by natural sources by approximately 30% (Ward et al 2005). The largest contributor to the current trend is that of fertiliser followed closely by other major sources which include animal and human excreta. Transformation of these organic forms of nitrogen is done through the processes of mineralisation, hydrolysis and bacterial nitrification. The result has been the production of nitrates; one of the most prolific chemical contaminants of the world's groundwater aquifers (Ward et al 2005).

In Barbados all potable water supplies are derived from groundwater sources. Currently there are twenty-three well sources, with contributions from seven boreholes and two spring sources, which supply a local population of approximately 273,428 persons. With annual renewable fresh water resources estimated at 225 410m^3 per day (less then 1000m^3 per capita), water resources may be considered both scarce and highly valued. Additionally the demand for fresh water resources extends to the agricultural and industrial sectors as well as to the large transient tourist population all of which place additional stress on the limited resource. The severe constraints associated with potable water supplies on the island not only highlight the complexities that are intrinsic in meeting the growing demand, but also those that would be associated with ensuring the provision of a high quality product as well as ensuring the health and safety of its users.

The Barbadian scenario presents several challenges for the agencies charged with meeting this demand and safeguarding public health. These include the complex land use patterns that are characteristic of the local landscape as well as the vulnerability of the aquifer due to the karstic geology of the island. Although the coral limestone forms a highly productive aquifer, the overlying soils provide very little protective cover (Chilton at al 2006). Even though locally these soils are more developed than is characteristic of this geological type, the surface of the aquifer may still be considered highly vulnerable. As is typical of many developing countries, there are concentrated areas of commercial and industrial activity. However much of these activities may also be widely scattered throughout the urban and periurban areas in the form of smaller, informal or unregistered businesses. These are all potential sources of nitrate contaminants through the ineffective management of the waste produced by these entities (Chilton et al 2006).

The highly variable spatial distribution of much of the land use activity creates a scenario where there are a number of small, widely dispersed or superimposed sources of nitrate contamination (Chilton et al 2006). This presents a challenge in the quantifying and characterising pollutants generated from these different sources whose individual contribution to the nitrate loading may not be easily identified or defined.

These challenges do not negate the fact that groundwater data is critical if the relevant agencies are to be able adaptively and effectively manage the resource. Currently groundwater is assessed on a weekly basis under the Groundwater Monitoring Programme which is a collaborative effort between the Environmental Protection Department (EPD) and the Barbados Water Authority (BWA). Twenty eight parameters are monitored under this programme. Due to lack of national guidelines for drinking water, the WHO standards are used for these parameters with a guideline value of 10mg/L given for nitrate- nitrogen.

Due to the highly mobile and persistent nature of nitrates, particularly in aerobic limestone, this chemical has been observed to approach and on occasion surpass recommended guideline values on a number of occasions at particular abstraction sites (Chilton et al 2006). This is cause for concern as elevated levels of nitrates have been linked to chronic health effects and if released into the marine environment, adversely impact marine life and ecosystem shifts.

This report aims to provide a comprehensive assessment of the trends in nitrate concentration through the analysis of data gathered from the inception of the groundwater monitoring programme to present.

2 AIM

To determine the current status of groundwater quality with regards to nitrate concentration through the analysis of time series data collected from the inception of the Groundwater Monitoring Programme, in and effort to highlight trends and offer recommendations for the management of potable water resources.

3 OBJECTIVES

- To determine current trends and predict future trends in nitrate concentrations in groundwater in Barbados through the statistical analysis of available data
- To highlight the various sources which may impact on groundwater resources
- To highlight the implications of current nitrate loading in the island on the marine environment and by extension the Marine Pollution Control Act 1998-40 (MPCA)
- To present various measures for the mitigation and reduction of nitrate pollution of groundwater sources

4 METHODOLOGY

Data collected from various groundwater wells monitored under the Groundwater Monitoring Programme was extracted from the Environmental Protection Department database to be statistically analysed. The sample period for this data for most wells extended from 1987 to September 2008. During the course of this monitoring programme many wells were decommissioned due to saline intrusion or consistently elevated levels of nitrates. On those occasions other wells were brought online to augment water supply. Where this has been a recent event and less than twenty data points were documented, analysis was not conducted as the small size of the data set was deemed inadequate for the purpose of providing results that were statistically robust. Even though all wells were not analysed for the same length of time it was assumed that the number of data points were equal in each case in order for comparisons between wells to be conducted. Descriptive statistics for nitrates concentration was calculated for each site, a full report of which can be found in Appendix A. All statistical analyses were conducted using Minitab version 15 and Microsoft Excel 2003. A complete table of sites from which water samples have been taken and for which data has been analysed may be seen in Appendix B of this report.

4.1 Variations by Season

A two sample T-Test was used to determine whether the variation in nitrate readings was statistically different in the wet season as opposed to the dry season. In this instance all data was coded by season where samples collected between November to June were categorised as that dry season data and samples collected between July and October as wet season data. The differences between seasons was deemed to be statistically significant if $p<0.05$.

4.2 Variations by well category

A one way ANOVA was used to determine if the differences in values between well categories were significant. Three categories were analysed in this report; public supply wells used for potable water, agricultural wells used for irrigation and natural springs used for recreational purposes and potable supplies. Differences between categories was deemed to be significant if $p<0.05$.

4.3 Variations between well source and consumer

The differences in nitrate concentrations between samples taken at the well source and those taken at the consumer end were analysed using a two sample T- test. Samples were collected by members of the Barbados Water Authority from the Belle pumping station and then again at the Government Analytical laboratory, which receives its supplies from that station, on the same day. These differences were deemed to be statistically significant if $p<0.05$.

4.4 Variation in Nitrate Concentration over the Sample Period

Pearsons Correlation was used to determine the relationship between nitrate concentrations and time, at each well that was assessed. This was done to determine the trend in nitrate concentration from the inception of the Groundwater Monitoring Programme to present. The relationship was deemed to be significant if $p<0.05$

4.5 Trend Analysis and Forecasting

Due to the great variability in the time series data collected over the sample period, a simple forecasting and smoothing method was employed to better identify trends within the data set that may have otherwise been masked and to extrapolate these trends to provide a forecast of future trends. The Single Exponential Smoothing method was used for this analysis, which smoothes the data by calculating exponentially weighted averages, in addition to a one step ARIMA forecasting formula. Forecasts were done within a 95% confidence range and are indicated in green on each graph between two confidence bands.

A linear trend analysis was applied to the smoothed data to visually illustrate the direction in which the trend was going; whether decreasing or increasing over time. A simple correlation was done to identify the relationship between nitrate concentration and time to determine whether the direction of the trend illustrated by the linear trend analysis was statistically significant. Statistical significance was determined if $p<0.05$.

4.6 Probability of Exceeding WHO Guidelines for Drinking Water

A cumulative probability function was used to determine the likelihood of the nitrate concentration exceeding 10mg/L which is the guideline value given by the WHO for drinking water. This function is used to determine the probability of a random variable being within a certain range for a particular distribution.

5 NATIONAL OVERVIEW OF NITRATES

5.1 General

During the sample period which extended from 1987 to 2008, the average nitrate concentration in Barbados was found to be 7.4mg/L. This fell 0.2mg/L below the 1988 – 2000 average of 7.6mg/L (Ifill 2000); and 3.6mg/L below the WHO guideline standard of 10mg/L. Statistical analysis has suggested that the overall nitrate concentration in groundwater on the island has shown a significant ($p<0.05$) but relatively small decrease within the 1987-2008 time period.

The island is divided into 21 water catchments. For sampling purposes these catchments have been grouped into three larger catchment categories; Belle, Hampton and West Coast. These categories are further broken down into four sampling groups which include the previous three classifications and selected natural spring sources.

Of these categories, springs had the highest average nitrate values with 8.37mg/L followed by Hampton with a mean concentration of 7.66mg/L. It should be noted that the average nitrate results for each sampling category was below the WHO guideline value. Figure 1 highlights the nitrate results by sampling group.

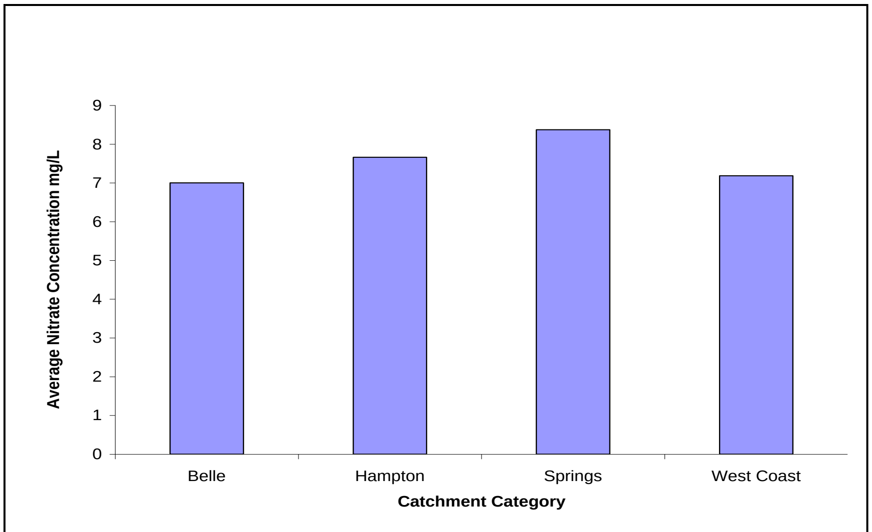

Figure 1: Average Nitrate Concentration for each sampling group

However, the Nitrate Vulnerability Assessment, Risk and Exposure Mapping Study done in 2000 indicated that the highest nitrate loadings occurred with in the Belle catchment category and in the south- western portion of the West Coast catchment category. These estimations correspond with areas of high population density and predominating residential land use activities. Exceedence probabilities for the island done during this study concluded that the areas most likely to surpass the WHO guideline standard of 10mg/L were that of Hampton with a probability of 16.4% followed by Belle with a probability of 8.9% (Ifill 2000). It must be noted that the natural springs that are currently monitored are scattered throughout the Scotland District as well as the Hampton and West Coast catchment categories. Figures 2 through 4 highlight the land use, population density and nitrate loading per catchment respectively.

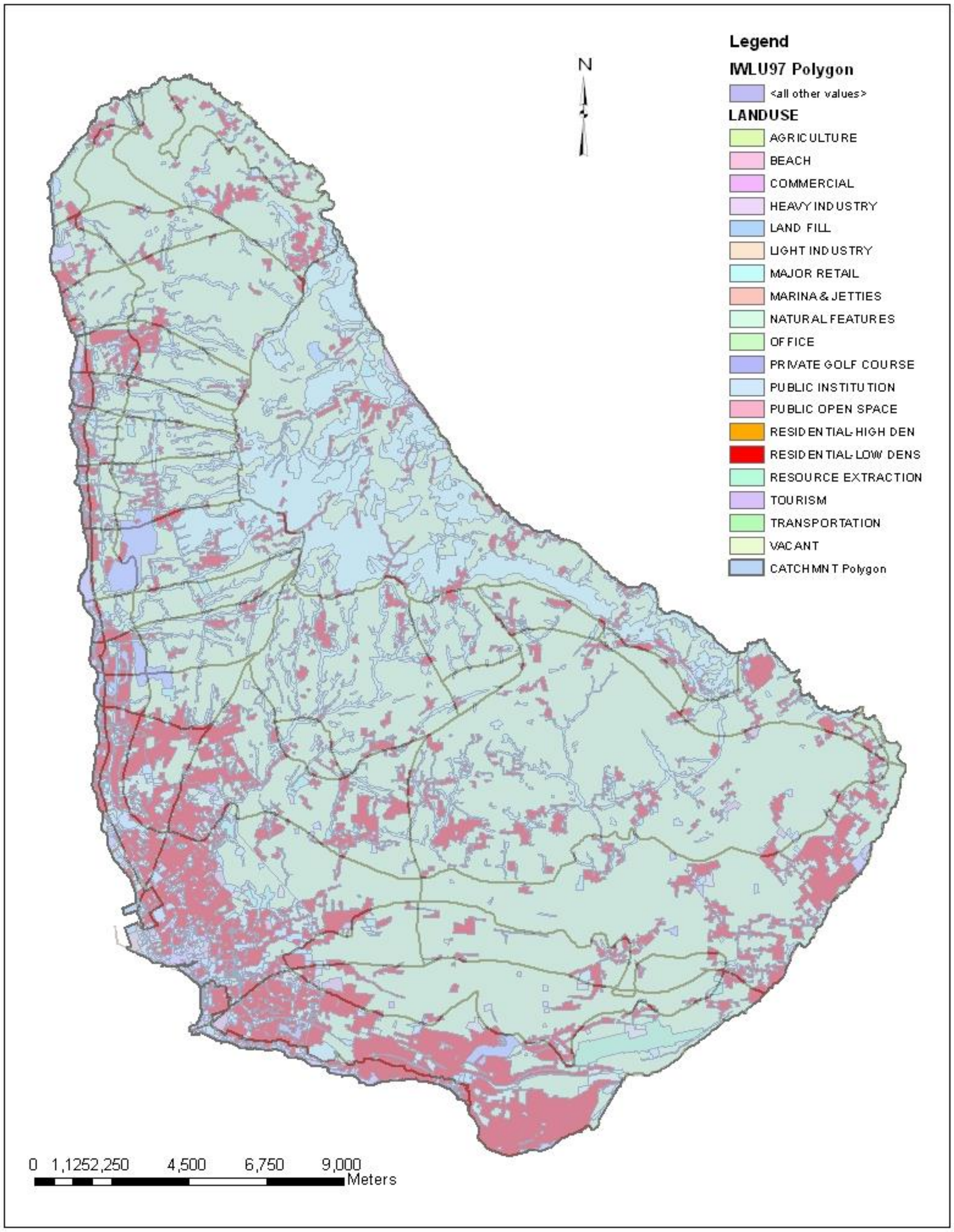

Figure 2: Land Use Map of Barbados

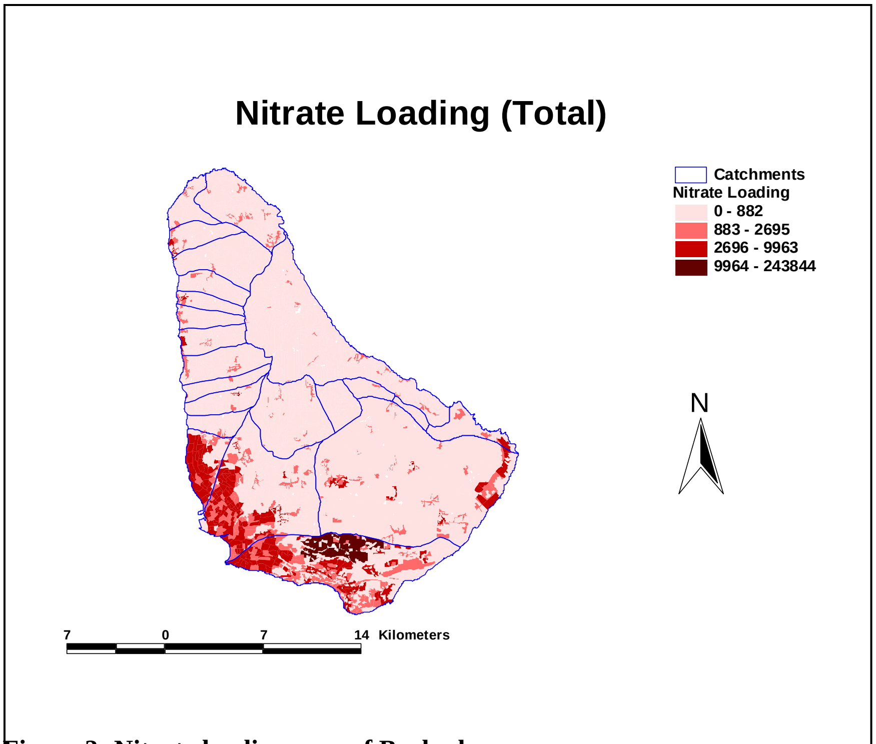

Figure 3: Nitrate loading map of Barbados

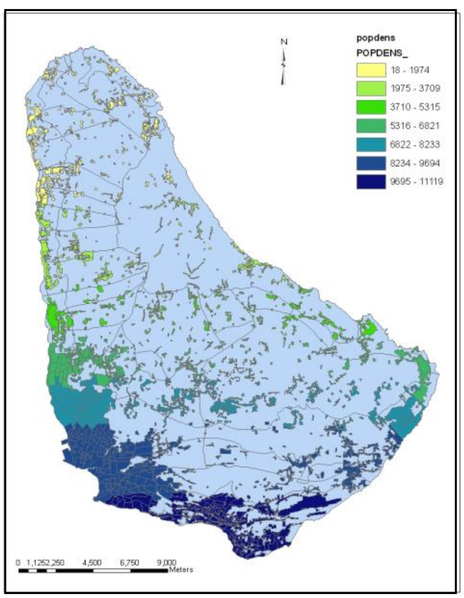

Figure 4: Population Density Map of Barbados

Vulnerability mapping done in the 2000 report highlighted several areas where groundwater sources were susceptible to contamination. This modelling was done using the DRASTIC model for assessing groundwater sensitivity. This programme requires seven criteria; Depth to water table, Recharge rates, Aquifer permeability, Soil type, Topography, Impact of the Vadose Zone, and Conductivity of the Vadose Zone (DRASTIC) (Aller 1985). It uses a groundwater quality index for evaluating the pollution potential of large areas using the hydrogeological settings of a region (Ifill 2000). Figure 5 shows the results of applying this model locally.

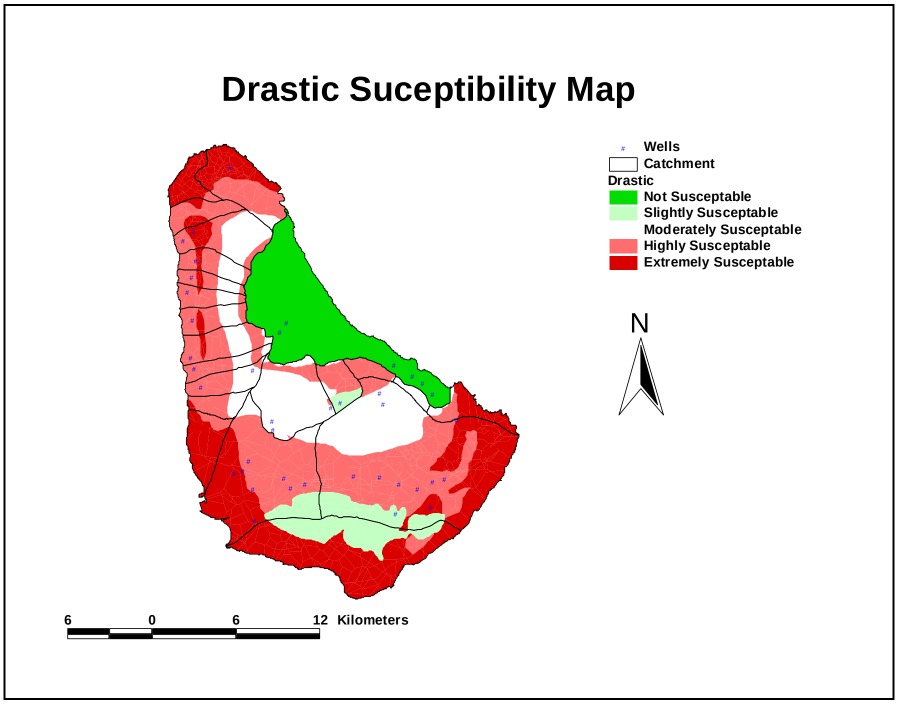

Figure 5: Drastic Model applied to Barbados

A visual assessment of this figure highlights that some of these areas of extremely high susceptibility correspond with areas of high population density and residential land use activity. However areas within the south and north eastern sections of the Hampton as well as the northern sections of the West Coast catchment categories also show sections that are highly predisposed to the ingress of pollutants into the groundwater system. Figure 1 highlights these areas as those in which significant agricultural activity occurs.

5.2 Seasonal Variation in Nitrate Concentration

Barbados experiences a subtropical climate with a distinct wet and dry season (Government of Barbados 2002). The dry season extends from December to May and the wet season from June to November. However, nitrate levels have shown very little seasonal variation with the highest average readings recorded in December with a value of 8.26mg/L, March at 7.52mg/L, and June with an average of 7.46mg/L. Additionally, there appears to be no significant difference between

($p>0.05$) the nitrate readings within each season. Figure 6 highlights the average nitrate values over the sample period.

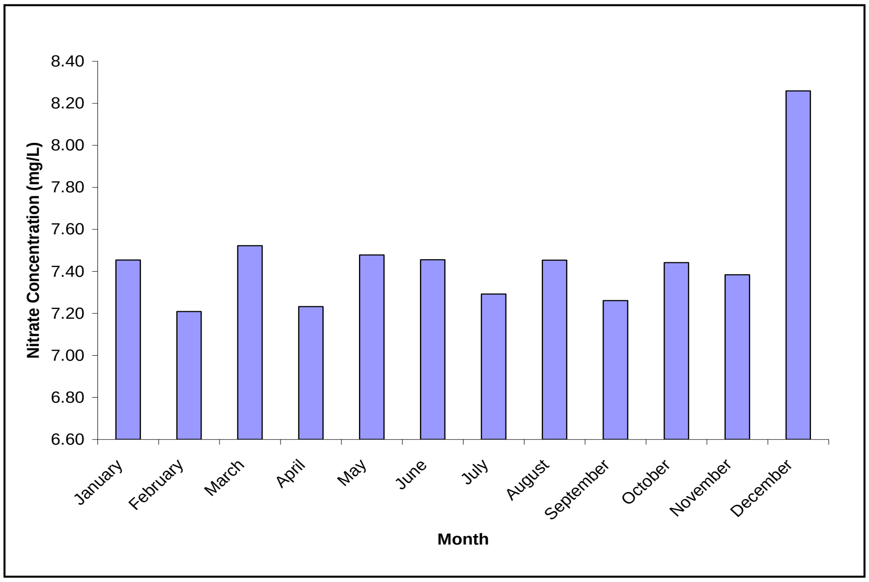

Figure 6: Nitrate Concentration per month

6 OVERVIEW OF NITRATES BY CATCHMENT

6.1 Belle Catchment

6.1.1 General

The Belle catchment area encompasses three smaller water catchment zones. These include the St. Michael, Sweetvale and Applewhaites catchments. Currently there are ten potable water wells within this zone, all of which are monitored once monthly with the exception of the Belle pumping station where samples are taken weekly. Additionally samples are collected from two agricultural wells. Monitoring was done at the Pine Central and Salters pumping stations which where decommissioned in September 2007 and replaced with wells at King's Road and Engine Field. Monitoring for these new sites began in November 2007. As a result the data was not used for this report as it was insufficient for statistical analysis.

The highest rate of abstraction for any well in this catchment is seen at the Belle pumping station which supplies 30% of the nation's drinking water (Ifill 2000). Table 1 highlights the wells monitored along with their respective water catchment zones and abstraction rates.

From the land use map it can be seen that the south western section of the catchment appears to have the highest population densities as well as most of the residential land use activities while much of the north eastern sections are used for agricultural purposes.

Table 1: well information for Belle Catchment

Catchment Zone	Well Name	Well Type	Abstraction rate (m^3/day)	Status
St. Michael	Codrington	Public Supply	4545.96	Active
	Belle	Public Supply	52733.1	Active
	Salters	Agriculture	-	Decommissioned
	Newmarket	Public Supply	15633.5	Active
	Constant	Public Supply	1250.1	Active
	Waterford	Public Supply	6364.3	Active
	Pine Central	Agriculture	-	Decommissioned
	Kings Road	Agriculture	-	Active
	Engine Field	Agriculture	-	Active
	Ionics Desal Product	Public Supply	-	Active
Applewhaites	Applewhaites	Public Supply	6214.3	Active
	Applewhaites Well Field	Public Supply	-	Active
Sweetvale	Sweetvale #1	Public Supply	6091.3	Active
	Sweetvale #2	Public Supply	-	Active

6.1.2 Wells of Interest

Statistical analysis of the wells within this catchment area has suggested that the nitrate values at most sites are decreasing and that this decline is significant ($p<0.05$). Codrington pumping station is the only monitoring site where this decline was shown not to be statistically significant. The average nitrate concentration for the Codrington was 8.28±1.2115 mg/L.

Of these wells an increase in nitrate concentration has only been seen at the Belle pumping station. Results from this site have suggested that the nitrate concentration continues to increase with forecast projections indicating that this upward trend is likely to continue. The forecasted value for this site has been calculated at 8.71mg/L with an upper limit of 10.9mg/L and a lower limit of 6.6mg/L. within a 95% confidence range. The average nitrate concentration for this site over the sample period was 8.42±1.4388 mg/L with a minimum value of 2.46mg/L and a maximum value of 17.3mg/L. With an abstraction rate of 52,733.09m^3/day a calculated 162,064.61 kg/year of nitrates is received at the abstraction point from the catchment.

During the sample period, the nitrate values exceeded the WHO guideline value on twenty occasions out of the 230 times that monthly samples were taken from this site. Using the cumulative frequency distribution function it has been estimated that the probability of nitrates concentrations exceeding these guideline standards is 13.6%. Figures 7 and 8 highlight the trends over the monitoring period for the Belle station.

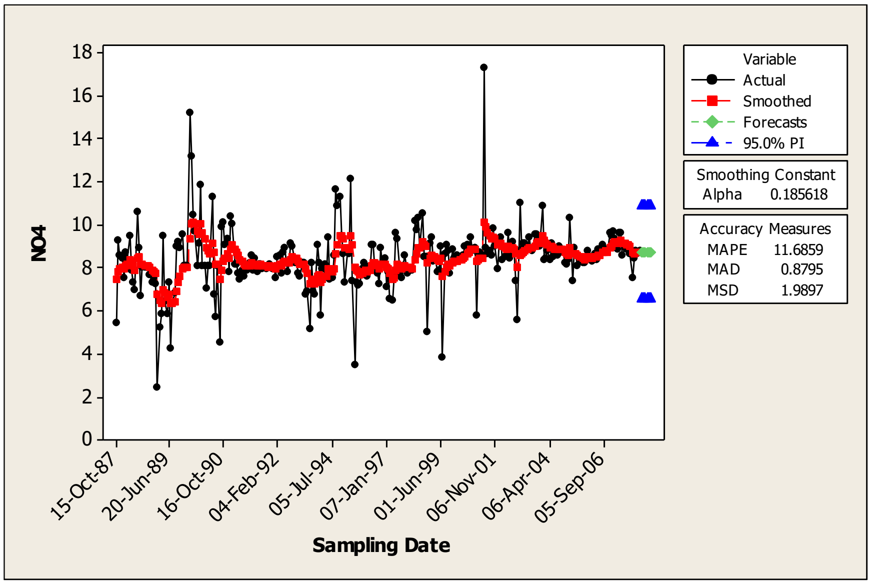

Figure 7: Time Series Analysis and Forecast for Belle P.S

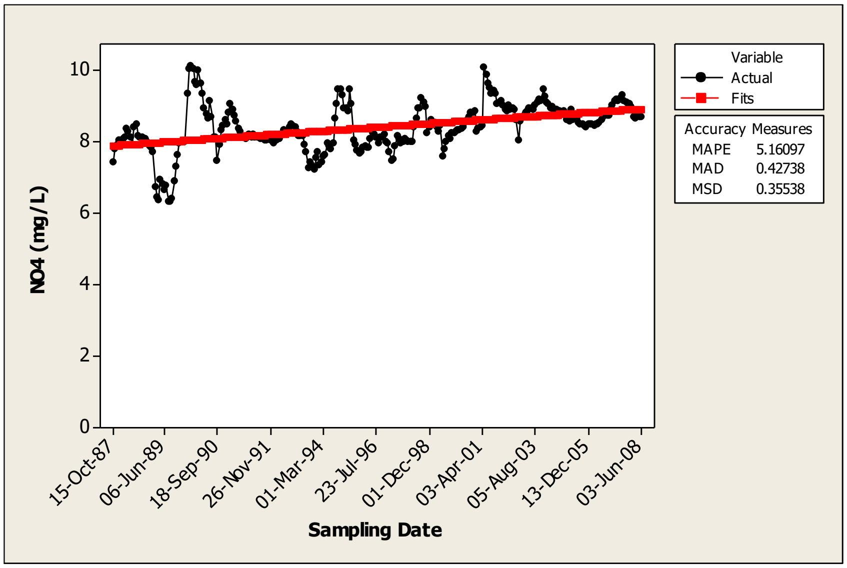

Figure 8: Linear Trend Analysis for Belle P.S

6.2 Hampton Catchment

6.2.1 General

The Hampton catchment area is comprised of four smaller water catchment zones which include Newcastle, Ragged Point, Codrington and St. Philip. Currently there are eleven wells that are monitored monthly all of which may be found in the St. Philip water catchment zone. These include three potable water wells and eight agricultural wells. The highest rate of abstraction is seen at the Hampton pumping station which is the second highest contributor to domestic potable water supply on the island. Table 2 highlights the wells monitored along with their respective water catchment zones and abstraction rates.

Table 2: Well information for Hampton catchment

Catchment Zone	Well Name	Well Type	Abstraction rate (m^3/day)	Status
St. Philip	Bowmanston	Public Supply	9969.28	Active
	Brighton	Agriculture	-	Active
	Carrington	Public Supply	4545.96	Active
	Corbin’s Farm	Agriculture	-	Decommissioned
	Edgecumbe	Agriculture	-	Active
	Hampton	Public Supply	28639.52	Active
	Kendal	Agriculture	-	Active
	Marchfield	Agriculture	-	Active
	National Hatcheries	Agriculture	-	Active
	Packers	Agriculture	-	Active
	Pool Plantation	Agriculture	-	Active

The population distribution appears to be more widely dispersed in this catchment area than seen in the Belle. Pockets of high population density are scattered widely through out the catchment with the largest of these situated on the south eastern section. Much of the land use activity in the Hampton catchment is concerned with agriculture.

6.2.2 Wells of Interest

Much like the Belle catchment area, analysis has suggested that for most wells in the Hampton area nitrate concentration has significantly decreased ($p<0.05$). However there was some increase in concentration at the Hampton and Edgecumbe pumping stations. The small rise in nitrates recorded at Edgecumbe over the sample period proves not to be statistically significant indicating that in this instance that any correlation between time and nitrate concentration was most likely due to chance and did not indicate an upward trend.

Unlike the results seen for the Edgecumbe site, those for Hampton have significantly increased ($p<0.05$) with a stronger correlation between time and nitrate concentration than seen at the Belle pumping station. The average nitrate value for this site over the sample period was 6.0963±1.1938 mg/L with minimum value of 0mg/L and a maximum value of 15.09mg/L. The minimum value recorded for this site, which indicates a total absence of nitrates, may be attributed to laboratory error. With an abstraction rate of 28,636.52m^3/day this indicates that the amount of nitrates received at this abstraction point from the catchment is approximately 63,717.40kg/year. Forecasts have indicated that this upward trend is likely to continue where the average forecast value was 6.53mg/L with an upper limit of 8.08mg/L and a lower limit of 4.97mg/L within a 95% confidence range.

During the sample period nitrate concentration exceeded the WHO guideline standard on two occasions out of the 252 times that monthly samples were taken. The probability of exceeding this guideline value based on current data has been calculated at 0.05%. Figures 9 and 10 highlight the trends over the monitoring period for the Hampton station

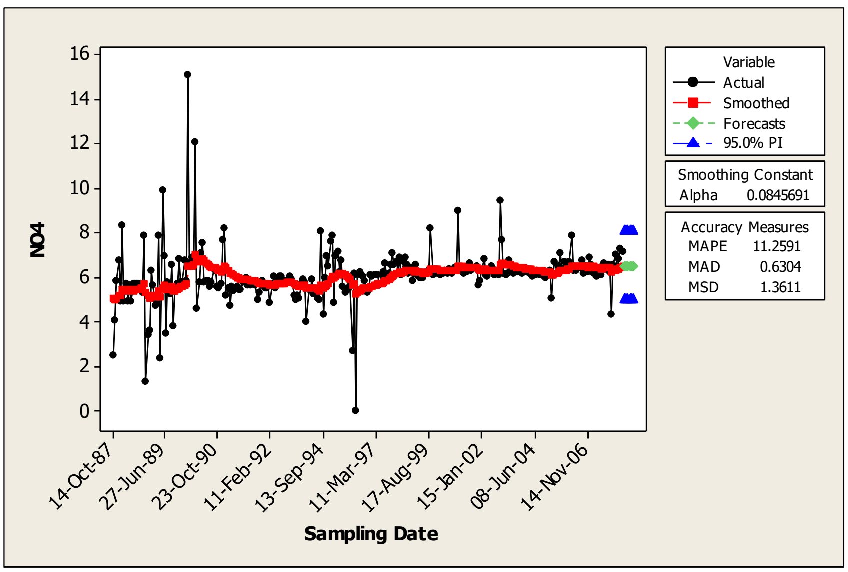

Figure 9: Time Series Analysis and Forecast for Hampton P.S

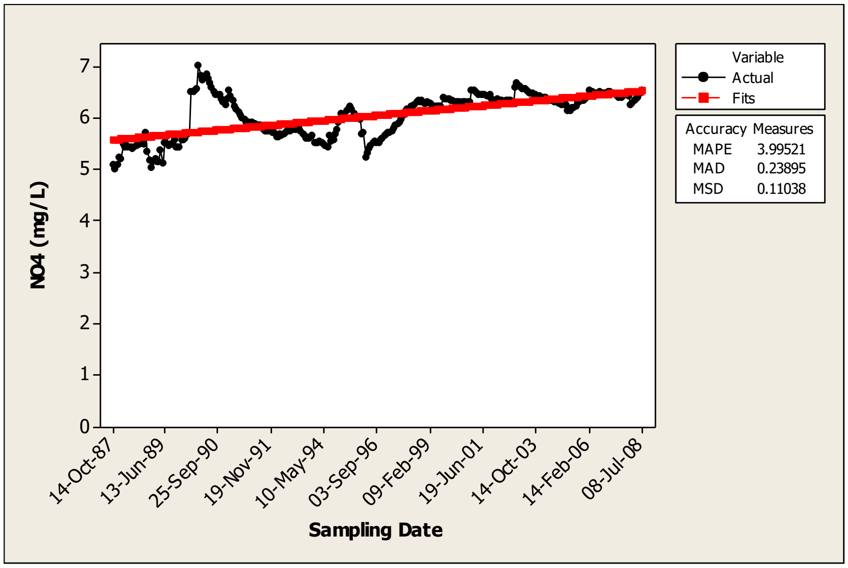

Figure 10: Linear Trend Analysis for Hampton P.S

6.3 West Coast Catchment

6.3.1 General

This catchment area encompasses the largest number of water catchment zones. Wells that are currently monitored may be found in each of these water catchments zones with the exception of Norwood, Bourbon and Content. The wells sampled are all potable water wells. Table 3 highlights the wells monitored along with their respective water catchment zones and abstraction rates.

Of these wells, two have been decommissioned; the Hope and Colleton pumping stations. Samples were last taken from these sites in February 2004 and June 2005 respectively. The Villa Maria pumping station located on the old St. Joseph Hospital compound was brought online to replace the two decommissioned stations. Monitoring for this site commenced in January 2008. As a result the data set is insufficient for statistical analysis.

Table 3: Well information for West Coast catchment

Catchment Zone	Well Name	Well Type	Abstraction rate (m^3/day)	Status
Molyneux	Molyneaux	Public Supply	1454.71	Active
Trents	Trents	Public Supply	1982.04	Active
Porters	Royal Westmoreland	Public Supply	-	Active
Carlton	Carlton	Public Supply	2236.68	Active
Haymans	Haymans	Public Supply	4545.96	Active

Catchment Zone	Well Name	Well Type	Abstraction rate (m^3/day)	Status
The Whim	Whim	Public Supply	3804.97	Active
Alleyndale	Colleton	Public Supply	1577.45	Decommissioned
	Alleynedale	Public Supply	3745.87	Active
St. Lucy	Hope	Public Supply	368.22	Decommissioned
Clermont	Ionics Desalination Plant	Public Supply	-	Active
Ashton Hall	Ashton	Public Supply	2463.91	Active
	Villa Maria	Public Supply	-	Active

Figure 1 appears to indicate that the highest density of residential land use activity is concentrated within the coastal areas. The remainder of the catchment is a mixture of residential, agricultural and some industrial activity.

6.3.2 Wells of Interest

Of all the wells within this catchment area only Ashton Hall showed any increase in nitrate concentration over the sample period. All other wells noted a significant decrease ($p<0.05$). Ashton hall pumping station had a calculated average nitrate concentration of 7.98mg/L ±1.03mg/L with a minimum value of 1.06mg/L and a maximum value of 10.7mg/L. With an average abstraction rate of 2463.91m^3/day this translates to a nitrate load of 7183.35kg/year. When the data was extrapolated, calculated forecast values have indicated that this upward trend is likely to continue. The average forecast value was calculated at 7.98mg/L with an upper limit of 9.26mg/L and a lower limit of 6.56mg/L

During the sample period nitrate concentration exceeded the WHO guideline standards on 2 occasions out of the 180 times that monthly samples were taken from this location. The calculated probability for nitrate to exceed the guideline value based on current data is 2.5%. Figures 11 and 12 highlight the trends over the monitoring period for the Ashton Hall pumping station

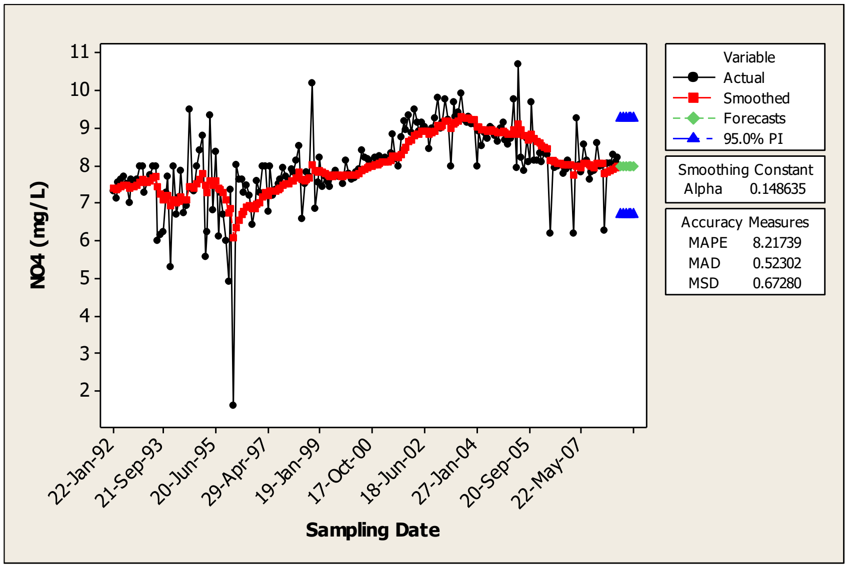

Figure 11: Time Series Analysis and Forecast for Ashton Hall P.S

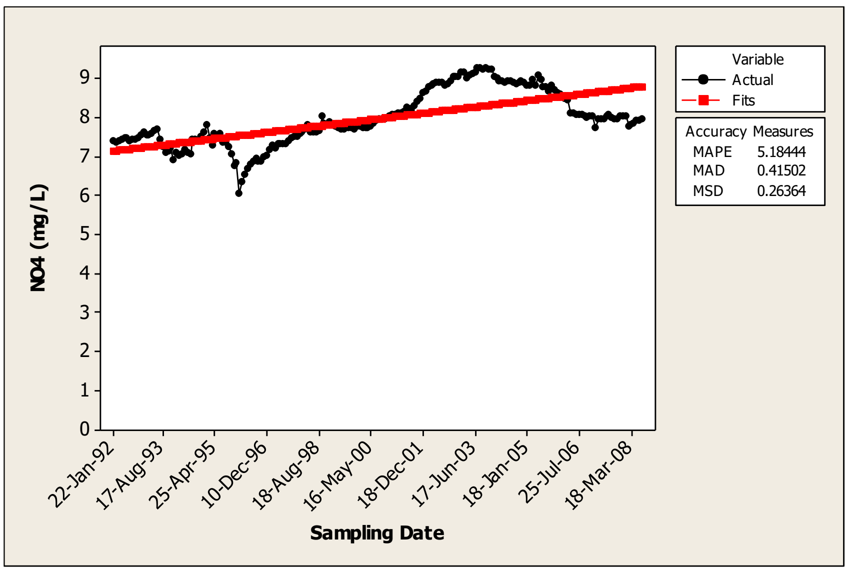

Figure 12: Linear Trend analysis for Ashton Hall P.S

6.4 Natural Springs

6.4.1 General

Under the current groundwater quality monitoring programme there are seven spring sources from which monthly samples are taken. These sources are located across the island and fall within a number of the larger catchment categories previously outlined in this report. Of all the springs found around the island, only these seven provide high enough flows to be viable sources of potable water. Two of these springs, Codrington College and Newcastle (Benn Spring) have been developed to provide safe drinking water. A full list of springs from which samples are taken and their respective catchments is highlighted in Table 4.

Table 4: Information for natural spring sources

Catchment Zone	Well Name	Use
Molyneux	Bath	Sample Point
Trents	Benn Spring	Public Supply
Porters	Codrington College	Public Supply
Carlton	Fortesque	Sample Point
Haymans	Porey Spring	Sample Point
The Whim	Pot House	Sample Point
Alleynedale	Three Houses	Sample Point

Like many of the agricultural wells that are monitored throughout the island, most of these spring sources may not highlight any immediate threat to potable water sources. They serve however to provide complimentary sampling locations to aid in the assessment of the overall condition of groundwater quality in the island.

6.4.2 Sites of Interest

Out of the sites monitored only two, Fortesque and Pot House, showed any increase in nitrate concentration over the sample period. Neither of these sample points is used for the abstraction of potable water. Both locations have had consistently high nitrate readings. Additionally the nitrate concentrations at these sites appear to be trending upward. Of the 95 times that samples were taken from Fortesque spring nitrate concentrations exceeded WHO guideline values 89 times. However of the 96 times that samples were taken from Pot House spring nitrate concentrations only exceeded these guideline values on 4 occasions. Fortesque had a calculated average nitrate value of 12.25mg/L ± 1.603 with a minimum value of 6.04mg/L and a maximum value of 15.3mg/L. The average reading for Pot House over the sample period was 8.428mg/L with a minimum value of 6.09mg/L and a maximum value of 33.1mg/L. Figures 13 through 16 highlight the trends in nitrate concentration for these two sites.

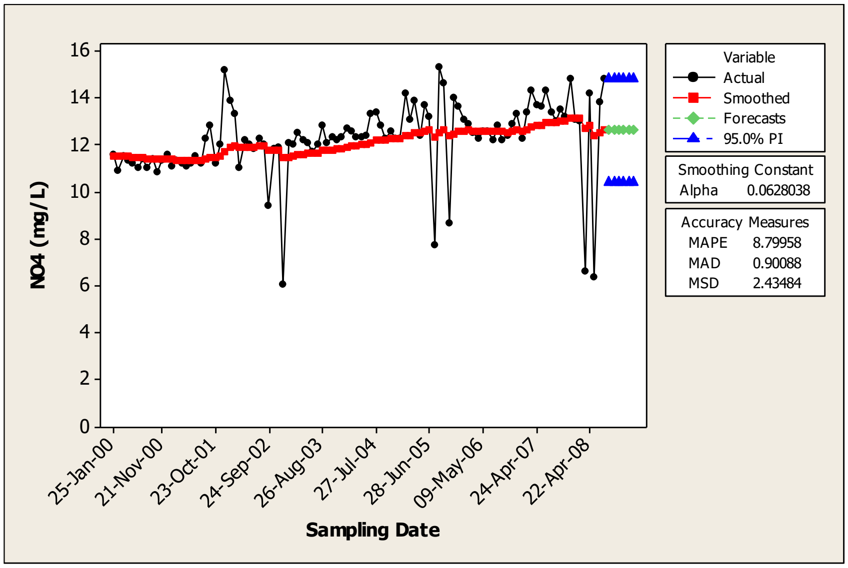

Figure 13: Time Series Analysis for Fortesque spring

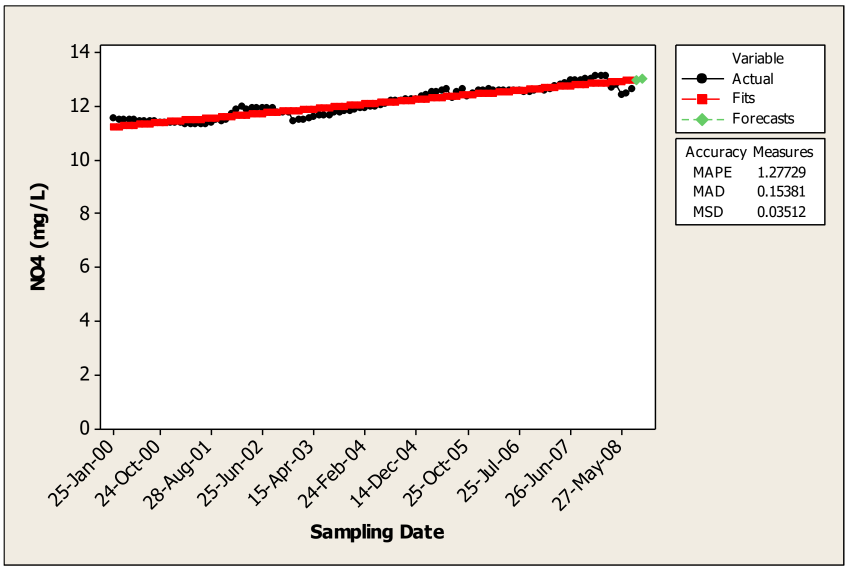

Figure 14: Linear Trend Analysis for Fortesque spring

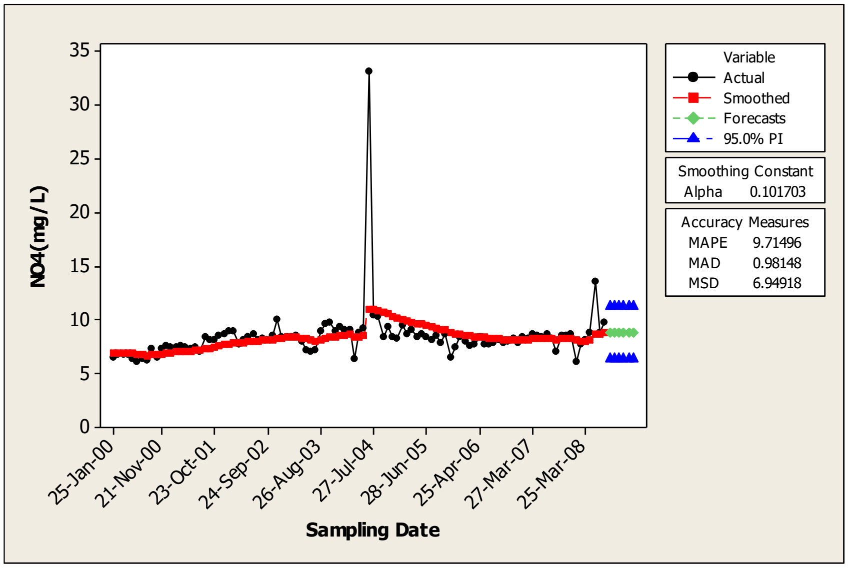

Figure 15: Time Series analysis for Pot House spring

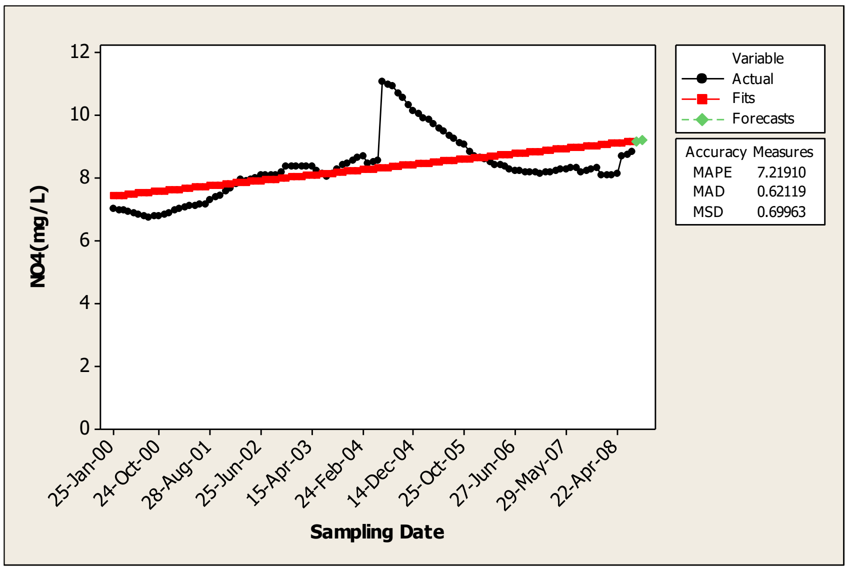

Figure 16: Trend Analysis for Fortesque spring

Calculated forecast have projected the average nitrate concentration for Fortesque at 12.63mg/L with an upper limit of 14.84mg/L and a lower limit of 10.42mg/L within a 95% confidence range. However although the Three Houses spring is less than one mile downstream of the Fortesque site the average nitrate values for the sample period are significantly lower. It should be noted that Fortesque is surrounded by a moderately populated residential area with some agricultural activity which may impact the nitrate readings recorded there. Conversely there is very little residential development in the immediate environs of the Three Houses spring. The calculated average value for Three Houses was 6.934mg/L ± 0.948 with a maximum value of

13.4mg/L and a minimum value of 3.88mg/L. The average forecasted value for Pot House was 8.81mg/ with and upper limit of 11.21mg/L and a lower limit of 6.40 mg/L within a 95% confidence range.

On the contrary, the two springs currently used as potable water sources showed a significant ($p<0.05$) decrease in nitrate concentration over the sample period with readings at the. Average values were 7.43mg/L±1.345 for Benn spring and 8.19mg/L±1.2115 at Codrington College.

Calculated forecast for the Benn spring and Codrington College locations were 6.97mg/L with an upper limit of 8.70mg/L and a lower limit of 5.24mg/L and of 7.78mg/L with an upper limit of 8.74mg/L and a lower limit of 6.82mg/L respectively. Probability calculations have suggested that there is a 2.8% chance of the nitrate values at Benn Spring exceeding the WHO guideline values and a 0.31% chance at Codrington College. Figures 17 through 20 highlight the trends in nitrate concentration for these two sites.

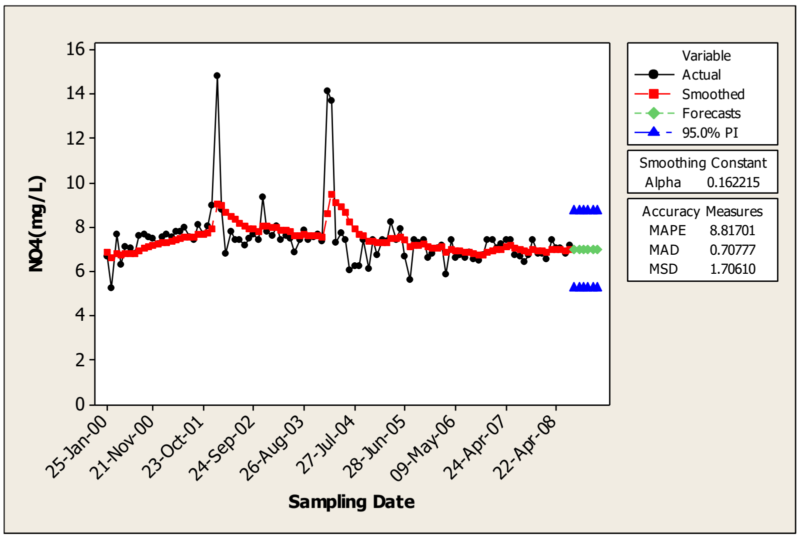

Figure 17: Time Series Analysis for Benn Spring

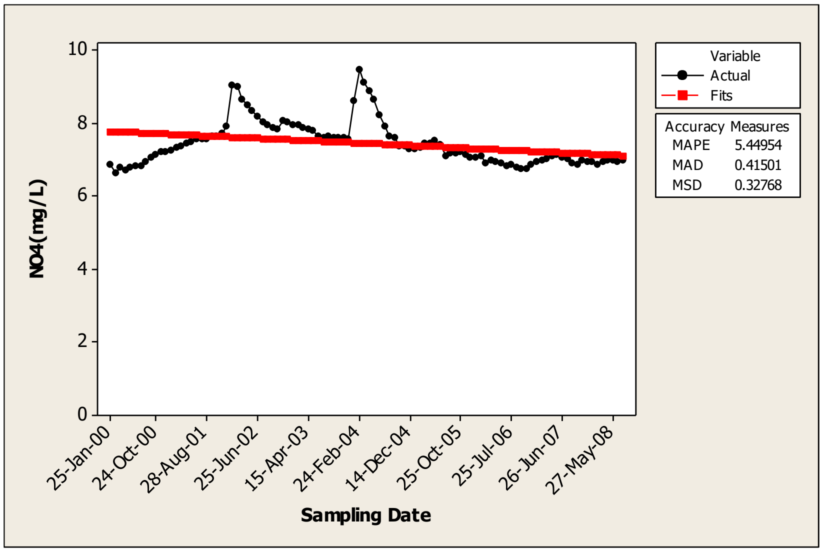

Figure 18: Linear Trend Analysis for Benn Spring

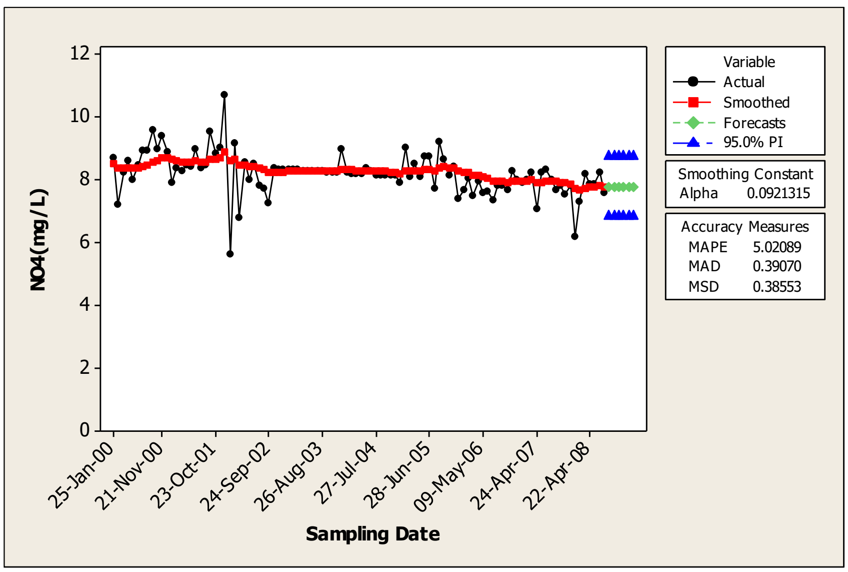

Figure 19: Time Series Analysis for Codrington College spring

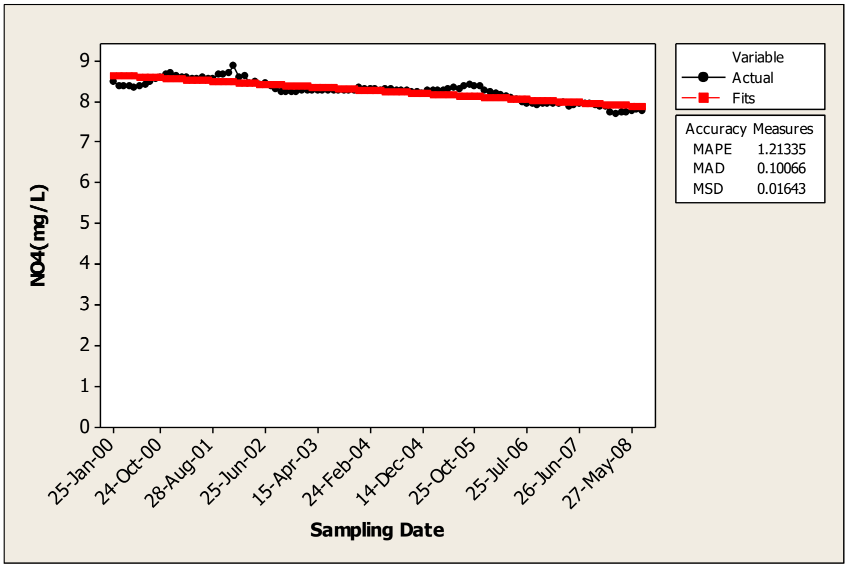

Figure 20: Linear Trend Analysis for Codrington College spring

7 WEEKLY NITRATE MONITORING

7.1 General

Based on previous assessments of nitrate concentrations it was found necessary to carry out weekly monitoring of particular wells which are significant contributors to the national water supply and had frequent high nitrate readings. Three wells were chosen for this exercise, Belle, Trents and Ashton Hall pumping stations. Due to the small size of the data set readings from the Trents station the readings were not analysed in this report.

7.2 Weekly Results

Analysis of the weekly data for the Belle pumping station indicate that although there appears to be an increase in nitrate concentration over the sample period, that this increase is not statistically significant ($p>0.05$). Average value for this site was 8.77mg/L±0.7236. The average forecasted value for this site was 9.53mg/L with an upper limit of 10.56mg/L and a lower limit of 8.50mg/L within a 95% confidence limit. Calculated probability values have suggested that there is a 4.67% chance of the nitrate concentration exceeding the WHO guideline value. This is 8.63% below what was calculated using the monthly data.

Statistical analysis for theAshton Hall pumping station suggests that has been an increase in nitrate concentration and that this increase is significant ($p<0.05$). The average value for this site was 8.11mg/L±1.06. The average forecasted value was 10.16mg/L with an upper limit of 11.58mg/L and a lower limit of 8.75mg/L. Probability calculations have suggested that there is a 6.55% chance of exceeding the guideline value. This is 4.05% greater than was calculated for using the monthly data. Figures 21 and 22 highlight the trends in nitrate concentration for this site.

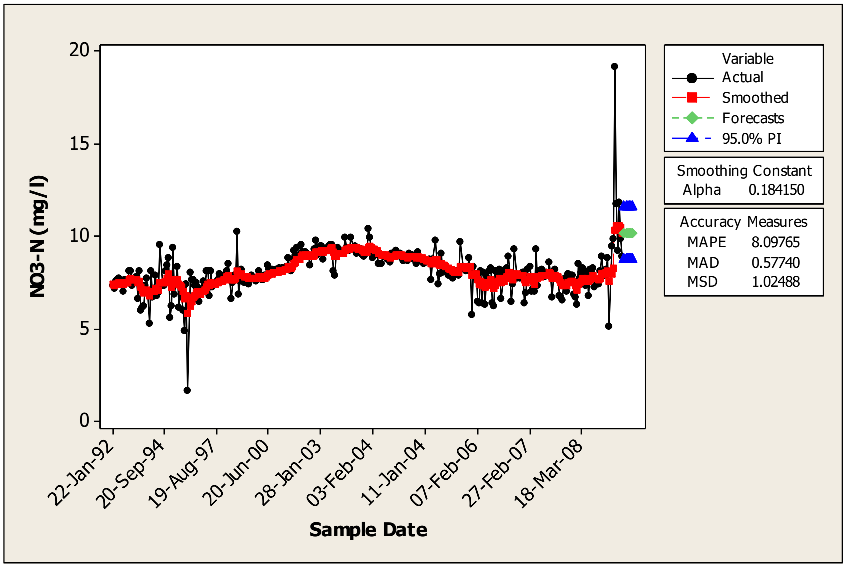

Figure 21: Time Series Analysis for the Belle P.S weekly data

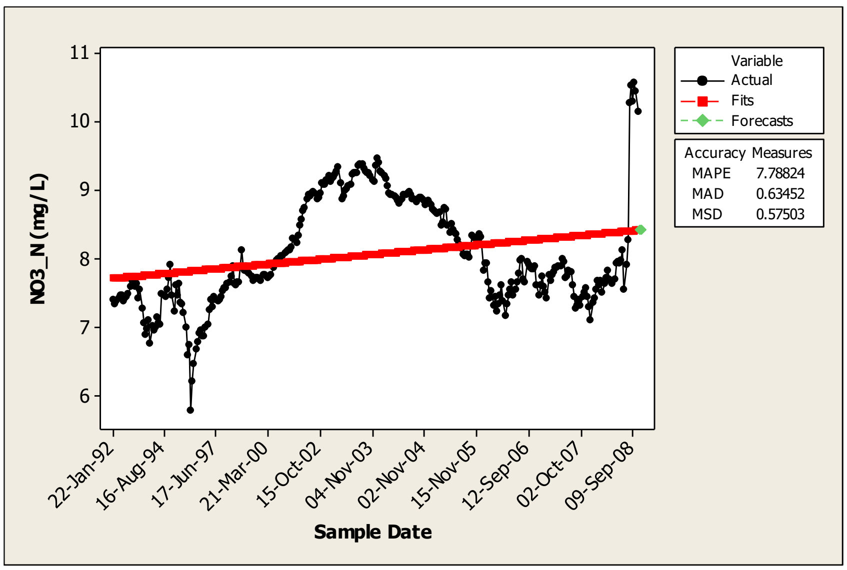

Figure 22: Linear Trend Analysis for Ashton Hall weekly data

8 NITRATE RESULTS FOR AT SOURCE AND END OF PIPE

8.1 General

In order to observe the difference in nitrate concentration between the pumping station and the households which it supplies, samples were taken at the Belle pumping station (Belle P.S) and the Government Analytical Laboratory (GAS) on Culloden Road on the same day, on a weekly basis.

8.2 Results

In most instances nitrate concentrations were significantly higher ($p<0.05$) at the Belle station than they were at the GAS. Further analysis indicates that there is a positive correlation between values at the pumping station and values at the consumer end. This suggests that as the concentration at the well increases that nitrate concentration at the Government Laboratory also increases.

However there were a number of occasions where the concentrations at the consumer end have exceeded that at the source. Of the 287 times that weekly samples were taken at each site, nitrates at the GAS exceeded those at Belle on 16 occasions or 6% of the time over the sample period. Table 5 highlights the occasions where consumer values exceeded those nitrate values seen at the source.

Table 5: Nitrate Concentrations for Belle P.S and GAS

Sample Date	Belle P.S (mg/L)	GAS (mg/L)
17th April 2001	8.02	8.05
24 April 2001	7.98	8.16
12th June 2001	8.59	8.95
25th September 2001	9.10	9.22
23rd October 2001	8.45	8.66
8th March 2005	8.17	8.45
14th June 2005	8.11	8.42
25th May 2004	8.16	8.66
15th June 2004	7.82	8.31
28th February 2006	8.12	8.33
14th March 2006	6.31	7.87
28th March 2006	6.31	7.87
8th August 2006	8.19	9.10
10th July 2007	6.67	8.84
20th March 2008	7.89	8.71
1st April 2008	7.14	7.97

Sample Date	Belle P.S (mg/L)	GAS (mg/L)
2nd September 2008	9.01	10.40

The decrease in nitrates between source and consumer has been attributed in part to the biofilm layer that lines the water mains along the distribution system (pers comm. Alex Ifill 2008). Increases in flow rate or sudden spikes in chlorine levels have been suggest as causes for the removal or death of parts of this layer. The biofilm is thought to be comprised of denitrifying bacteria mainly *Pseudomonas sp* which removes some of the nitrates from the drinking water as it travels through the distribution system.

However the death or removal of this layer does not adequately account for occasions during which the nitrate concentration is markedly higher than that at the source. This increase from source to consumer may suggest ingress of pollutants into the mains as water travels through the system or it may be due to laboratory or sampling error. However the true cause of this increase is beyond the scope of this report and requires further investigation.

9 BADMC WATER QUALITY MONITORING PROGRAMME

Analysis of water quality data for agricultural wells collected by the Barbados Agricultural Management Development Cooperation (BADMC) indicate that in most cases the nitrate concentration at the wells monitored exceeded the WHO guideline value for drinking water. Wells with the highest mean nitrate concentrations included Daniel at 29mg/L followed by Stuart at 24.38mg/L and Griffith at 21mg/L. The highest reading recorded for any well was seen at the Daniel well with a maximum reading of 85.3mg/L.

10 DISCUSSION

Statistical analysis has suggested that the groundwater tested at most of the wells captured in the monitoring programme over the sample period, have had either declining or relatively constant concentrations of nitrates. The small number of exceptions to this trend appears to be predominantly agricultural wells and springs which are not used for the extraction of potable water. Many of the potable water wells tested have exceeded WHO guideline standards on occasion but have in almost all cases fallen below the recommended 10mg/L. However, in some cases the concentrations are only a few units below this recommended guideline value.

Of great concern however, is the steady increase and projected rise in nitrate concentration observed at two of the islands largest contributors to the drinking water supply; the Belle and Hampton wells. Also of note is an increase in nitrates at the Ashton Hall station which is a major supply station for much of the northern most part of the island.

Of the twenty four public supply sources whose nitrate data has been statistically analysed in this report, approximately 46% showed some risk of exceeding the WHO guideline value. These figures range from a probability of 0.03%, seen at the Bowmanston station to 13.6% seen at the Belle. All of these sites occur within a less than one kilometre of areas which are considered to be highly susceptible or extremely susceptible to the ingress of contaminants. The following table has been adapted from a previous assessment of nitrates in groundwater on the island to reflect current probabilities for exceeding guideline values and the number of persons within the local population who are likely would be affected.

Table 6: Exceedence probabilities and number of persons likely to be affected

Supply Source	Population	Total Probability (%)
Ashton Hall **	5263.42	2.5
Belle **	77072.02	13.6
Benn Spring	7758.91	2.7
Bowmanston	12013.41	0.03
Carlton P.S	7895.19	1.9
Codrington	61784.39	7.8
College Spring	1933.09	0.3
Hope	6745.69	0.05
Hampton **	85000	4.1
Hope	6745.69	0.09
New Market	6619.14	0.64
Waterford	11142.70	1.7

****Sites where nitrate concentrations have increased and the upward trend is likely to continue**

Adapted from: Nitrate Vulnerability Assessment, Risk, and Exposure Mapping in Barbados

Studies have suggested that exposure to excessive levels of nitrates through the ingestion of drinking water is detrimental to human health. When ingested the body converts nitrates to nitrites which may lead to the induction of methaemoglobinaemia more commonly known as blue baby syndrome. It is associated with an acute toxic exposure to nitrite which reduces the transport of oxygen by the blood (AWWA, 1992). This ailment most commonly affects children under the age of one due to the relatively low acidity in the stomach which provides a more favourable environment for bacteria needed to convert nitrates to nitrites. Its onset results in lethargy, shortness of breath and a bluish skin colour which may culminate in anoxia and death with very high uptakes of nitrates from drinking water (WHO 2006). Additionally research has also suggested that there may be a positive correlation between elevated nitrate concentrations and various forms of cancer including non-Hodgkin's lymphoma (WHO 2007). As nitrates are converted to nitrites they have been shown to react with compounds within the stomach to form N-nitroso compounds, many of which are carcinogenic (WHO 2007). However, there has been little quantitative data to adequately substantiate this association but research into this link is ongoing.

However the increase in nitrate concentrations in these key supply areas brings into question the efficacy of the current zoning policy and its continued ability to protect groundwater sources in light of increased urbanization, intensified agricultural practices and inadequate sewage treatment options. If such is the rise in nitrate concentration continues or become more common, regulatory agencies must consider more aggressive protection measures, alternate sources of potable water or treatment options for current supplies before distribution.

These problems are not unique to Barbados. Contemporary legislation in many countries is encouraging companies to tackle contamination of potable water at the source instead of relying so heavily on end- of- pipe treatment solutions. In the UK there has been a need to channel capital towards the treatment of raw water in order for regulatory standards to be met (Kay et al 2009). Although there are a range of engineering solutions that may be used to treat drinking water to a standard that is fit for human consumption, the costs are significant and may result in increase subsidy of the product or increase costs to the consumer.

To adequately address these issues there must be sufficient knowledge of the source of the contaminants, a quantitative assessment of effluent volume as well as a characterisation of the discharge from various land based activities. Currently it is thought that the main sources of contaminants of groundwater resources on the island are from agrochemicals; namely nitrogenous based fertilisers and domestic wastewater disposal to suck wells. There has been much debate at to which contributes more to the total nitrate loading. This lack of consensus has in part been responsible for inability to devise solutions to adequately address the main causes of contamination (Halcrow 1998). No comprehensive data set currently exists on the quantities and characteristics of waste produced by each sector. The Environmental Protection is now undertaking studies to this effect in an effort to develop an inventory of land based sources of pollution (EPD 2007).

11 SOURCES OF NITRATES

Several studies carried out by various investigators have identified a number of major sources of nitrate contamination to the groundwater system in Barbados. These include Stanley and Associates (1978), BGS/EED (1991), Delcan (1995) and Klohn-Crippen Consultants Ltd. (1997). The scale, pattern and extent of the distribution of the activities associated with two of these sources of pollution are sufficient enough to contribute to the elevated nitrate concentrations seen at some sample points throughout the island (Klohn-Crippen Consultants Ltd 1997). These sources will be discussed further in this report and are listed as follows:

- Nitrogenous or ammonia based organic and inorganic fertilisers used in cultivated areas
- Domestic wastewater discharged by soakways, septic tanks and pit latrines

- Other: Industrial discharges

11.1 Agriculture

11.1.1 Crops

The impact of the use of agrochemicals, namely nitrogenous fertilisers, on groundwater sources is the greatest issue of concern to potable water quality, as it relates to activities within this sector. Contaminants may reach the aquifer by way of suckwell infiltration, direct infiltration or surface runoff (Klohn-Crippen Consultants Ltd 1997). While the leaching of nitrates is a natural process, the loads that are leached are largely dependent on acceleration in the nitrogen cycle which may result from agricultural operations or land use changes (A. Sapek 2002). For example the ingress of these pollutants into the aquifer may be exacerbated by excessive and inappropriate use of fertiliser or poor irrigation management. Both of these factors may contribute to increase leaching of agrochemicals into the groundwater system.

In Barbados, like with many others areas in the world an increase in fertiliser use and irrigation of farm land corresponded with intensification of agricultural activities and increased mechanisation. Historical evidence used in previous studies has suggested that there was a fourfold increase in nitrate concentration in the groundwater system between 1977 and the late 1980s which was mainly due to activities within the agricultural sector (Brown and Company 1998). This behaviour was characteristic of inland rural areas and did not represent the conditions on the developed coastal zones at the time (Halcrow 1998).

However there are no comprehensive historical records of fertiliser usage or application rates in Barbados. The data that does exist is extremely limited and incomplete. In previous studies trends were postulated from data on annual sugar cane production, as it was the dominant cash crop, fertiliser tonnage and import data for agrochemicals. It must be noted that while fertiliser import data may give some indication of the annual usage patterns, as amounts would fluctuate with demand for the product, it may not necessarily correspond with annual application rates (Halcrow 1998). Figure 23 highlights the average tonnage of fertiliser imported between 1997 and 2008.

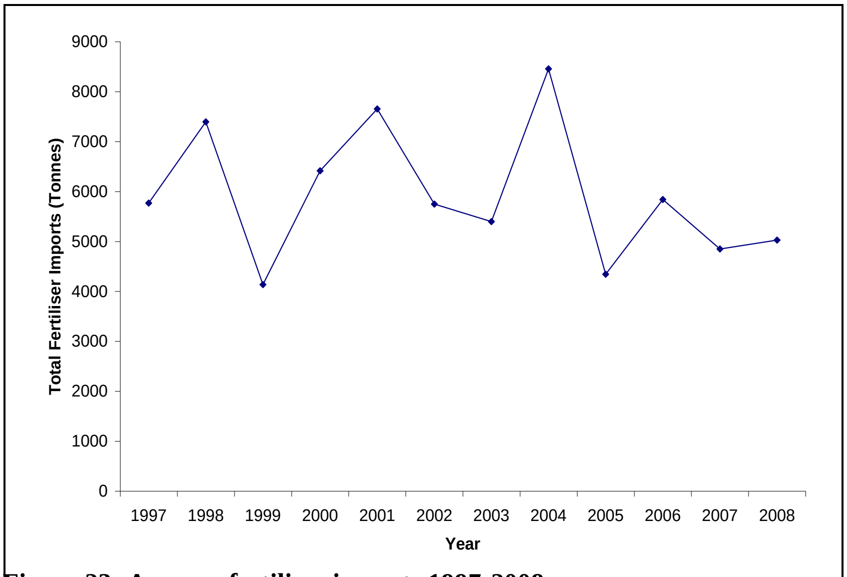

Figure 23: Average fertiliser imports 1997-2008

There appears to be significant fluctuation in the yearly averages over the time period with no clear trend. Previous studies have indicated that the yearly tonnage between 1977 and 1990 was consistently between 7000-10,000 tonnes per annum (Halcrow 1998). Figures for 2005-2008 have fallen notably below that range. The United Nations Environment Programme in its Regional Overview of the Land- Based Sources of Pollution in the Wider Caribbean Region (WCR) stated that the average fertiliser usage in Barbados in 1979 was as high as 162kg/ha and dropped to 91kg/ha in 1989. The 1979 value far exceeded any other territory in the WCR during that time period while the 1989 figure was one of the higher values recorded in that year.

The 1997 Water Resources Management and Water Loss Study identified ammonium sulphate and 24.0.18 (ammonium sulphate (24 parts) and potassium carbonate (18 parts)) as two of the principle fertiliser formulations that were used on the island. It was also found that the annual rate of fertiliser application for vegetable and food crops (2200-2750 kg/ha/yr) was 4-5 times that applied to sugar cane (550kg/ha/yr). This report further estimated that in 1986 the total nitrogen loading applied as fertiliser was 223,000kg. Using the assumption that fifty percent of this was leached from the soil and travelled to the aquifer, the nitrate- nitrogen contribution would be an estimated 65kg/ha. With the 1996 well flows of 940/L in the St. Michael catchment, assuming that none of the nitrogen was attenuated or lost to the sea, the report concluded that the resultant nitrate concentration in pumped water would be approximately 8mg/L. Water quality monitoring data generated by this study calculated the 1996 average concentration for the Belle well as 8.3mg/L. These figures indicate that the use of fertilisers in cultivated areas is of a sufficient scale to be a significant contributor to the elevated nitrate concentrations seen at some groundwater wells (Klohn-Crippen Consultants Ltd 1997).

However in the last thirty years the role that agriculture has played in the local economy has diminished. This is most evident in view of the decline in the cultivation of sugar cane. In 1961 the sugar cane area harvested was 200,00ha while in 2007 it had declined to 6300ha. The amended National Development Plan of 1998 states that the agriculture had occupied 53,000 acres of land of which an estimated 10,000 was idle. Figure 24 highlights that area of sugar cane harvested from 1995 to 2007.

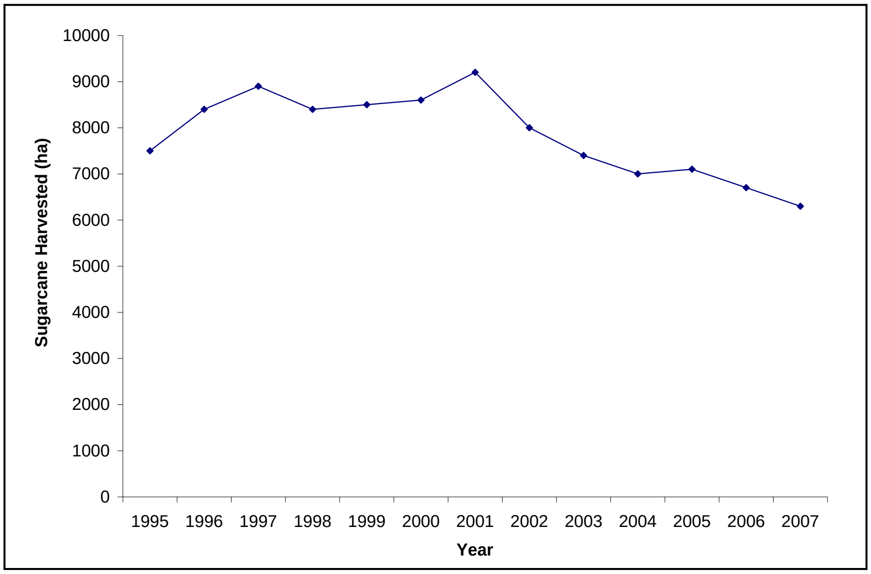

Figure 24: Sugarcane area harvested 1995-2007

A reduction in the area of cultivated land may indicate a decrease in the application rates of fertiliser. To date there is no data to validate this. Rates of application and fertiliser usage are still relatively unknown. Additionally much of the land taken out of cultivation either lies fallow or has undergone a change of use. No conclusive statements can be made as to the current impact of fertilisers on the groundwater system and how this has been affected by changes in land use without further study.

11.1.2 Poultry and Livestock Rearing

The main source of nitrates associated with the rearing of poultry and livestock is derived from animal excreta. The concern therefore is with the disposal of animal waste especially where livestock or poultry is in enclosed environs such as pens or feedlots, where all waste is concentrated in a centralised area. However feedlots are not used in Barbados. In most cases animals are raised in open pasture or in pens (EPD 2008). Waste from these animals tends to be high in nutrients and may have an impact on groundwater quality as contaminants may be transported to the aquifer via run off or direct infiltration.

In 2007 it was estimated that the total nitrate loading from poultry, beef, mutton and pork production was 64,042,647kg. Of this total, poultry farming produced approximately 98% of the nitrate load followed by mutton, pork and beef. This may be reflective of the fact that a large proportion of the chicken and pork sold in the Barbadian market is reared locally while mutton and beef are supplemented by imports (EPD 2008). Table 7 below is taken from an inventory of land based sources of pollution done by the EPD which sought to estimate the land based pollutant loads to the marine environment. It has been adapted to reflect the nitrate loads for poultry and livestock rearing for 2007.

Table 7: Estimated pollutant loading for poultry and livestock rearing 2007

Product	**Amount produced (kg)**	**Estimated Quantity of Nitrates (kg)**
Poultry	14,934,000	62,722,800
Beef	136,100	16,559
Mutton	72,400	24,488
Pork	2,502,000	405,880
Total pollutant loading		63,169,727

Source: Inventory of Selected Land Based Sources of Pollution and Estimation of Land Based Pollutant Loads into the Marine Environment (2008)

The inventory also highlighted that the waste products from this sector are disposed of in a variety of ways, which include disposal at the landfill, burying or burning. Farmers surveyed during this study indicated that while some of the manure could be sold as fertiliser that the market that was available for the product could not absorb all of the waste that was produced. Additionally the sanitary landfill no longer accepts this waste product for disposal. In many instances the burial and burning on site were the most cost efficient and easily available option for disposal. Some of this waste is also used to fertilise cultivated land owned by the farmers.

No guidelines currently exist which speak explicitly to the disposal, storage or handling of waste products of poultry and livestock rearing or that dictate where and how burial or burning of these products should be conducted. The only regulations that may be used at this time are those found under Section 3 (a), (b), (c) and (d) of the Disposal of Offensive Matter Regulations under the Health Services Act 1969. The Act states the following:

"No person shall throw, deposit, let out of place any filth, night soil, dead animal or other offensive matter or thing of any kind on or about-

- *a) The premises of another person*
- *b) Any water- course or beach*
- *c) Any public street, road, lane, passage, or thorough-fare*
- *d) Any other premises or place where such filth, night soil, dead animal or other offensive matter may create a nuisance or be detrimental to the public health*

There is a need for more detailed investigation into the waste disposal practices currently used by farmers who are involved in all types of animal husbandry. Data gathered from such a study would aid in the determination of the potential impacts of this type of agriculture on groundwater quality and public health.

11.2 Domestic Sewage

Domestic sewage for the purposes of this report refers to the liquid effluent that is discharged from private residences, commercial business houses and hotels. A major contributor to the nitrate loading in Barbados, it is comprised principally of putrescible organic material, dissolved and suspended solids, chemical compounds and very likely disease causing microbes. Although sewage is mostly water by weight, the characteristics of its contents as well as the volumes at which it is generated creates difficulties for devising ways for it to be adequately treated and safely disposed of (http://www.britannica.com). This creates major challenges especially for developing countries. This holds true for local sewage management where only two sewage treatment plants have been established and most of the islands waste is disposed of via septic tanks and soakaway pits. Outside of this, a number of hotels as well as industrial, commercial and institutional establishments make use on site package treatment facilities with final discharge into onsite suckwells. Many of these establishments are located within close proximity of the coast. Discharge may therefore have a greater impact on the nearshore environment than on potable water resources.

The two centralised collection and treatment facilities only serve sections of Central Bridgetown and the South Coast of the island. At present 1400 properties are connected to the Bridgetown Sewage Treatment plant and 2222 to the South Coast Treatment Plant. Both facilities currently receive an estimated 9000 gallons of liquid effluent each day. In both instances the treated effluent is disposed of by marine outfall and should have no bearing on groundwater quality. Plans have been developed for an additional plant on the West Coast of the island, but this has yet to be established.

In the Barbados Water Resources Study of 1978, 16mgd of wastewater was thought to have reached the groundwater. Of this an estimated 80% was thought to have recharged sheetwater downstream of the major supply wells along the west and south. In 1991 it was estimated that the NO3-N concentration from wastewater that was discharged to suckwells was approximately 29mg/L in urban Bridgetown and 5mg/L in rural areas. With an assumed average nitrate concentration of 10mg/L wastewater contribution to groundwater was approximated at 320,000 kg/year (Delcan 1995). Additionally the preliminary studies for the West Coast Sewerage Project conducted by the Bellairs Research Institute suggest that as much as 50% of the nitrogen that reaches the marine environment originates from domestic wastewater. These figures highlight the significant impact that domestic sewage is likely to have on the quality of local groundwater resources.

Currently the protection of groundwater resources is done through development controls in an effort to minimise the impact of anthropogenic activity on public water supplies. Five zones currently exist which are representative of restrictions related to all areas of development including sewage disposal and industrial activity. Zone 1 has the highest level of groundwater protection where no new housing, water connections or industrial development can be established and where changes to existing wastewater disposal systems can only occur when the water authority secures improvements. Additionally only septic tanks and filter beds of an approved design can be used.

Although these development controls have had some success in the past with retaining an acceptable quality of potable water supplies, recent investigations have suggested that more intensive agricultural activity and increase housing development has resulted in deterioration in groundwater quality. Despite the development controls, many unregulated dwellings have been erected in areas where the construction of new structures has been prohibited by law. Within most of these residences sewage is disposed of via soakaway pits. Their presence within these areas poses serious and immediate threats to the integrity of groundwater resources and by extension public health. The 2004 Belle Feasibility Study indicated that sewage from soakaway pits and the overland flows that may enter the gully systems in the Belle contributed greatly to the high nitrate and bacteria levels that are seen in the Belle well (Stantec 2004).

Presently the issue of residential areas encroaching on protected groundwater zones is a growing issue of concern. With an estimated 80,000 private residences, a growth rate of 8000-8500 per decade and decreasing household size from approximately 4 persons in 1971 to 2.8 by 2010 these problems are likely to become more widespread (Government of Barbados 1998). Recent studies have suggested that the average water consumption rate is approximately 1800L/ house/day. The nitrogen concentration for domestic wastewater was estimated at 40mg/L. Additionally the Ministry of Housing has stated that there are in excess of 75,000 homes with suck wells. This would result in over 9500 tonnes of nitrogen reaching the groundwater system annually (Burnside in prep).

It is very likely that in the future even planned and regulated dwellings will infringe on Zone One areas and that the effect of domestic sewage on the integrity of potable water resources will be exacerbated. Measures to protect these resources in the face of population growth and increasing housing demand need to be urgently addressed.

11.3 Industry and Manufacturing

The composition of industrial sewage varies greatly depending on the operations and functions of a particular industry. Like domestic wastewater it may contain significant amounts of organic material and have high levels of nutrients but it is distinguished primarily by its chemical composition. Hazardous chemicals not commonly seen in residential wastewater may be present in the by products of industrial activity which may require more specialised forms of treatment and more careful planning of disposal methods to preserve the integrity of the environment into which treated effluent is discharged.

In Barbados the industrial sector does not predominate the economic landscape as is seen with activities within the tourism and agricultural sectors. However the scale of individual operations, even though they may be few, may produce volumes of effluent in amounts that may still significantly influence the quality of groundwater resources.

This sector experienced a decline in the 1980s and although it has rebounded to some extent in the decade that followed, growth is still slow. The majority of the industrial facilities may be found in the parish of St. Michael with many being housed within government owned industrial parks. Outside of these private industrial areas can be found at various locations around the island (Government of Barbados 1998).

Very little data is available on the amounts and characteristics of the effluent discharged from many of the industrial operations. The EPD in its appraisal of selected land based sources of pollution assessed a few of the local operations for which data was available. These included entities involved in the manufacture of dairy and bakery products, sugar production as well as rum distilleries. Tables 8 and 9 have been adapted from the study of these selected industries and highlight the estimated amount of Total Nitrogen (TN) or Total Kjeldahl Nitrogen (TKN) contained in the waste products generated from these activities.

However, these areas of industrial activity are located downstream of major water supply wells or in areas that have not been earmarked for exploitation for potable supply purposes. In view of this these activities are not likely to have any effect on drinking water supplies but may have greater bearing on the quality of nearshore marine water quality.

Table 8: Nitrogen output of select companies within the meat, dairy and bakery industries

Activity	Company	Quantity of Product	Total Nitrogen (Kg/yr) / (tonnes/yr)
Slaughtering, processing and preservation of meats	Southern Meats	1,602,932.94 kg	1,122.05
	Hipac Ltd	164,000 kg	213.20
Manufacture of Dairy Products	Pine Hill Dairy (input)	5,027.50 tonnes	310.65
	Pine Hill Dairy (processed)	6,656.66 tonnes	2,0.63.56
	Peaches & Cream Ltd (input)	2.50 tonnes	0.15
Bakeries	WIBISCO	3,412.33 tonnes	33.50
	Purity Bakery	5,015.93 tonnes	31.53
	Salisbury Bakery	184.75 tonnes	1.15
	Golden Crust Bakery	78.04 tonnes	0.56
Rendering	CR recycling	10,425 tonnes	5,004
	Sunrise Chick	675.54 tonnes	324.26

Table 9: TKN of select companies within the sugar industry

Company	Sample Period	Concentration of TKN mg/L	Load of TKN kg/day
Portvale Sugar Factory	March-September 2006	88.19	2.20
Foursquare Rum Distillery	October 6th 2004 and April 1st 2005	24.50	2.23
West Indies Rum Distillery	July 2005- July2006	273	155

12 IMPLICATIONS OF NITRATE LOADING ON THE MARINE POLLUTION CONTROL ACT

The Marine Pollution Control Act 1998-40 (MPCA) was enacted in 1998 and provides a legislative framework for the protection of the marine environment of Barbados under its mandate for the reduction, prevention and control of land based sources of pollution. The development of this legislation is in response to a decline in the coastal water quality and its subsequent impacts on related ecosystems. Much of this decline has resulted from the impact of terrestrial based pollutants which are transported to the nearshore by way of overland flow and diffused seepage as well as via point sources through direct discharge.

Land based sources of pollution are considered to be some of the leading threats to marine ecosystems throughout the Caribbean (UNEP 1994). Although the impact of land use activities within the various catchments in Barbados on the coastal water quality may not be immediately apparent, the quality of groundwater resources has a substantial effect on the quality of waters within the nearshore. Previous studies have indicated that the primary means of discharge of nitrates to coastal waters is via groundwater which in some instances may be as much as five times greater than surface water loading (Delcan 1995). The 1998 Barbados Coastal Conservation Study indicated that in some areas along the south eastern coast of the island that the maximum terrestrial loading corresponded to the maximum concentrations that were found in coastal waters. The level to which nitrates may influence marine water quality depends to a large extent on the land use practices within the catchment (residential, agricultural, industry etc), the volume of groundwater discharge and near shore currents which would influence the level of dissipation of the contaminant.

Marine water quality is a key indicator of ecosystem health and a limiting factor to the biological processes within organisms, populations and habitats (Pomeroy *et al* 2004). A decline in quality has great implications on the sustainability of the existing ecosystems and the viability of biological communities that are contained within them. Affected by both natural and anthropogenic processes it has the ability to influence the economic sustainability of communities and countries that are heavily reliant on coastal resources. Although point sources of pollution are the most obvious contributors to elevated nutrient levels and declining viability of coastal habitats, land use practices have equal if not greater influence on contaminant loading. The circumlocutory effect of the pollutants from these diffused sources (sewage, fertilizers etc.) is in many cases the mechanism underpinning bottom up controls of reef structure and ecosystem shifts away from coral to macroalgae (Lapointe and Thacker 2002).

The development of this Act signifies the acknowledgement of the fact that prevailing land use practices have great bearing on public health and the viability of costal habitats. Although regulations that directly address non-point sources are yet to be drafted, as the main focus of the legislation is known point sources of pollution, the MPCA is intended to cover all sources of pollution. As such, Section 4 of the Act calls for the development of a register of pollutants, which incorporates all present and possible future sources of pollution. Additionally it requires this pollution be characterized and quantified. The Act states the following:

The Director shall, as soon as practicable after the commencement of the Act, investigate the environment generally and such premises as he thinks necessary in order to

a) Ascertain the extent of pollution and significant sources of pollution from

b) Land based sources

c) Sea bed activities

d) Dumping activities

e) Airborne sources and

f) Characterize or describe that pollution

The Director shall cause a Register of Pollutants to be maintained in such a manner as may be prescribed and the Register shall contain data identifying the quantity, conditions or concentration relevant to the identification of each pollutant.

In 2002 the EPD contracted the services of Stantec Consulting International Limited for the purposes of assisting with the implementation of the MPCA and the Coastal Zone Management Act (CZMA) (Stantec 2003). Within the subsequent Implementation Assistance Project a Marine Water Quality Programme with suggested parameters was put forward which included recommended parameters, sampling locations and protocol as well as suggested data handling and management procedures. The most recent water quality programme established by the EPD had not been structured in a way that it could serve as a comprehensive assessment tool for marine waters. In the recent past its main focus has been a public health one where samples were analysed for microbiological quality with the two main parameters being *faecal coliform* and *enterococci sp* (Stantec 2003). Additionally only selected beaches along the south and west coasts are monitored on a weekly basis.

In 2007 the commencement of the construction of the boardwalk along the south coast of the island acted as the impetus for the analysis of water samples at two beaches, Amaryllis and

Accra, for nutrient content. These samples were tested for the presence of NO_3-N and phosphates. In May 2009 the monitoring programme was further amended with the addition of a number of the parameters that had been suggested in the Implementation Assistance Project where analysis would be done for all previously selected beaches under the weekly monitoring programme. These included testing for the presence of Total Nitrogen rather than NO_3-N as it is considered to be a better indicator of nutrient loading because it takes into consideration the both the inorganic and the organic loading (UWI et al 2004).

Currently wastewater treatment in Barbados is concerned mainly with the reduction of the bacterial load and the organic content of raw sewage. Sewage treatment plants treat only to primary or secondary level, some with disinfection. Outside of this, most wastewater disposal is done through septic tanks or direct discharge to suck wells, which like primary and secondary treatment are ineffective at nitrogen removal. Large volumes of effluent from various sources, even when treated, may have a high nutrient content. Much of this wastewater will eventually find its way into the marine environment whether through direct discharge or through groundwater which has been recharged with the treated effluent. However the inputs from agricultural activity including inputs from golf courses should not be understated and neither should their potential effect on nearshore water quality be ignored. These activities as stated previously in this report also contribute significantly to elevated nutrient levels, and sediment loading.

High concentrations of nitrates and other nutrients have been linked not only to episodes of eutrophication but to impaired host resistance and increased pathogen virulence in certain coral species through out the Caribbean. While these elevated concentrations are not in themselves responsible for an increase in marine disease epizootics, research has suggested that nutrient enrichment could affect the severity of coral disease as well as alter disease dynamics by increasing pathogen fitness and virulence (Brunol et al 2003). Investigations into seawater quality degradation off of Holetown in 2006 suggested that there was a high mean nutrient concentration which could be linked to over application of fertiliser on agricultural land and possible enrichment from urban sources. Marine data suggested that dispersion of contaminants was moving northward directing plumes towards the Bellairs Reef (Tosic 2006). Additional the estimated nutrient concentrations observed during this study was expected to result in eutrophication.

It is hoped that in view of the prevailing conditions that exist with respect to both groundwater and marine water quality that the MPCA would not only act as an effective regulatory tool for the enforcement of ambient water quality and end of pipe discharge standards, but also as a developmental tool to tackle non point sources of pollution and land use management. The mandate under this piece of legislation speaks to a wide reaching investigation into the sources and characteristics of contaminants of concern. It is hoped that this information will be used to inform policy and underpin efforts to effectively manage land use practices in a way that does not impede economic growth but that places less stress on both the groundwater resources and by extension the marine environment. Many elements of this Act suggest a gradual shift in the paradigm of environmental management from public health and habitat protection to wholesale catchment based management. The level of its success in mitigating and reducing pollutant volumes and safeguarding the integrity of the marine environment will require a collaborative effort between various agencies whose responsibilities may not be directly governed by this Act. This level of interagency cooperation that can be established will encourage environmental accountability at all levels and across all sectors which, to varying degrees, all have some influence and impact on groundwater and marine water quality.

13 OPTIONS FOR THE REDUCTION OF NITRATES IN GROUNDWATER IN BARBADOS

There are very few measures that are currently implemented for the protection of local groundwater resources. The most wide reaching of these is that of development control in the form of protection zones described earlier in this report. Outside of this septic tanks, soak aways and two municipal collection and treatment facilities that serve a limited population are used to deal with the waste products of domestic, industrial and commercial activities. Many of these activities have begun to encroach on designated groundwater protection zones. As population size grows and the demand for land for housing and commercial activity increases, there may come a point where the sole use of these zones for the protection of potable water supplies is untenable.

The greatest challenge comes in the dealing with diffused sources of pollution where the origin of the pollutants and nature of disposal may be difficult to identify and the impact more difficult to control (Chave et al 2006).

As in most cases no one method of protection may be the solution to this complex scenario where there is a need for government to sustain economic growth and fulfil its social obligations to the local population while ensuring the provision of quality drinking water and safeguarding public health. The protection of groundwater resources requires an approach that incorporates action at both the well head and across the wider aquifer (Chave et al 2006).

Several agencies hold responsibility for the regulation, monitoring and development of various activities (industrial, commercial, agricultural etc.) within each catchment. For any method or suite of methods to be truly effective a collaborative effort from multiple stakeholders and an intersectoral cooperation is crucial. For smaller countries, especially small island states, finding the best methods to address the issue of potable water protection presents very unique challenges. The complexity of this situation for these countries is evident when viewed in the context of restrictive budgets, few resources, limited capacity and few if any alternatives of drinking water sources and those that do exist are costly.

13.1 Groundwater Protection Zones

Like many methods used for the protection of groundwater resources, groundwater protection zones involves the regulation of activities that may result in the production of pollutants which may potentially undermine the integrity of potable water sources. The overall aim is to control polluting activities around the point of abstraction in order to reduce the potential for the ingress of contaminants into the aquifer. In general the degree of restriction becomes less stringent as the distance from the abstraction point increases. Delineation of these zones may be based on several factors the most common of which are distance from the abstraction point to the point of concern, drawdown, assimilative capacity of the substrata and flow boundaries (Chave et al 2006).

The delineation process may utilise a methodology as simple as one based on fixed distances from points of concern to more complex calculations based on time of travel of the pollutants and the degree of vulnerability of the aquifer (Chave et al 2006). The concept of protection zones is especially useful when there are a number of activities taking place within a catchment with overlapping zones of influence and the pressures of non point sources of pollution on potable water resources may be great. Restricting particular activities from designated areas reduces the risk of contamination of known waste products in the pollution stream without having to pinpoint the exact source of the discharge.

While many countries employ the use of these zones for the protection of their drinking water, the method behind the delineation of protected areas is highly variable and site specific. Often within the same country the zoning policies differ depending on the location of the abstraction point, the level of human activity taking place in the environs, hydrogeological flows, budget restrains and technical capability of local staff *inter alia*.

Where land use pressures are high and where pressure is likely to impact the drinking water quality or where development is likely to encroach on areas which overlie groundwater resources, a system of prioritisation can be used to define what management actions should be taken. Unlike conventional approaches which are concerned primarily with hydrogeological criteria, vulnerability assessments and technical aspects of groundwater protection, prioritization takes both the need for economic development and resource protection into consideration (Chave et al 2006). For example the approach to the demarcation of zones in Western Australia takes into account not only the vulnerability of the resource to pollution but also its strategic importance as well in light of competing land uses. This has resulted in the formulation of a three tiered management approach which may include issues such as designated beneficial uses (drinking, irrigation *inter alia*), water quality, social and economic value as well as current and planned land use (Chave et al 2006).

The current zoning regime in Barbados is done solely on the basis of hydrogeological criteria. Zones have been defined based on calculated transport times of contaminants to the site of abstraction given the die off time required for bacteria. At the time that these zones were implemented, calculations were based on limited data available on aquifer characteristics. Very little changes have been made to the original zones. There have been a small number of changes in zone classification in some areas to facilitate development that would have otherwise been prohibited.

For some time this method was largely successful. Very few cases of severe contamination of potable water have been recorded. However recent aquifer investigations have shown that an increase in anthropogenic activity on the island has lead to deteriorating water quality (Stantec

2004). The 2008 review of the groundwater zoning policy conducted by Burnside International Limited sited several instances where residential developments and agricultural activity had begun to encroach on Zone 1 areas. The demand for land for developmental purposes in Barbados and small islands states like it is such that when economic development and resource value is taken into consideration that competition for land creates monumental challenges in protecting water resources solely through groundwater zones. While larger countries may be able to delegate sections of land for the development and protection of groundwater resources, small island states are restrained by size. The reality is that population growth and the need for continued economic development will inevitably impact on potable water quality.

13.2 Nutrient management for agricultural lands

13.2.1 Crops

Although nitrates are necessary for plant growth and optimal production rates, plants use only what is needed for growth, leaving any excess to be leached from the soil and impact on groundwater resources. The focus of nutrient management should therefore be aimed at employing suitable application methods and amounts for crops which would optimise production while minimising the risk of leaching (Appleyard 2006).

In order to implement effective yet sustainable farming practices, farmers need to be equipped with greater knowledge of the resources which they use. This includes an understanding of soils characteristics such as the nutrient status, soil leachability and erodability; and crop nutrient requirements. The aim is to increase, sustain or improve soil fertility and land productivity while minimising land degradation and groundwater contamination (FAO 2000).

There has been an increased awareness that the implementation of the appropriate nutrient management strategies can result in tangible benefits to the farmer in the form of higher yields and a reduction in overall crop production costs. Such strategies include the use of soil surveys, soil tests, appropriate timing of fertiliser application and crop sequencing to minimise nitrogen leaching (Appleyard 2006).

The success of implementing any nutrient management programme requires a collaborative effort between the government, the farming community and other relevant stakeholder organisations. Assessments of the effectiveness of these programmes have suggested that one of the major limiting factors is a top down approach to the implementation of methodologies for nutrient management. In many cases farmers were exposed to the technologies and methodologies which were deemed by experts to be the best solutions to their particular problems without farmers having a full understanding of the principles and processes of the problems they experienced or the solutions that were offered. This creates difficulty in dealing with new problems and challenges to which these proffered solutions were not applicable creating a cycle of continuous dependence on government assistance and intervention (FAO 2000). Farmers need to have a clear understanding of the principles behind nutrient management strategies so that they can be independently applied and so that the benefits of their implementation can be truly realised.

13.2.2 Poultry, Livestock Rearing and Dairy Operations

The issues that arise with operations such as these are the large quantities of waste generated from a high density of animals. These large numbers of livestock and poultry often situated in relatively confined spaces can result in large volumes of wastewater whether through storm water run off or wash down of the facilities in which the animals are housed. The nutrient concentrations of this waste are often high in nutrients with nitrate being a major contaminant. The proper management of the waste stream generated from these facilities is of the utmost importance if their impact on groundwater resources is to be minimised.

Some of the major considerations should be that of the location of these operations and effective methods of collection and treatment of the resultant waste. Often these considerations are only brought to bear in larger, registered facilities where the management requirements are more obvious. However smaller, informal and often times unregistered establishments have the potential to greatly impact groundwater resources. Effective legislation and enforcement is necessary to ensure that appropriate sites are chosen and adequate waste disposal methods are employed.

Currently there is no legislation that specifically addresses the issue of waste disposal for farming operations and no national protocols are available to guide farmers on how this should be done. Some larger operations have employed the use of cesspools to remove solids after which the liquids and disposed of via suck wells. More recently some facilities have installed septic tanks depending on the volume of waste generated. This has been done at the farmers' discretion and not at the mandate of any government organisation. Additionally a handful of biodigester systems have been installed under a project funded by the Caribbean Development Back (CDB).

13.3 Sewage collection and treatment

The safe and effective treatment and disposal of domestic and industrial waste are important aspects of water and wastewater management in order to protect potable water resources and safeguard public health. Their ability to reduce the microbiological loading in drinking water systems in order to prevent or reduce the incidence of disease is a well known benefit and the most common reason for the installation of these systems. However their use for the removal of chemical contaminants in waste streams, in developing countries in particular is much less prevalent.

The installation of any conventional technologies will have cost implications. The choice of system for any area is therefore heavily dependant on the application of technologies that are appropriate for the local environment but which are still an affordable options' not only in terms of installation, but also in terms of maintenance. The reality is that although source protection may be significantly less costly it may not always be feasible.

Over the years the wastewater treatment technologies that have been employed in Barbados have been focussed primarily on the reduction of the microbiological load of the waste stream in view of the need to protect public health. The vast majority of the systems used are not equipped to treat to a level where the chemicals components of the waste stream are addressed. This has resulted in a trend of increased nitrate concentrations, a significant portion of which may be attributed to domestic sewage. The reality is that contamination from the chemical components of waste may in fact be more difficult and certainly more expensive to control (Howard et al 2006). Nitrates in particular are highly mobile and persistent as they are non volatile and do not bind to soil particles.

Large municipal plants have been considered for the coastal sections of the island resulting in the development of the Bridgetown and South Coast sewage treatment facilities and consideration for the development of a plant to serve the west coast of the island. No such developments have been considered for the inland sections of the island. Such systems would only be economically feasible in areas of high population density (Stantec 2004). Consideration has been given to the possibility of sewering Zone 1 areas, in particular within the Belle Catchment. The aim would be to address the issue of water deterioration in an aquifer which supplies the island's largest abstraction site and provides a significant amount the total water supplied to the local population. It is thought that the sewering of residential areas adjacent to the wells would reduce both the nitrate and bacteria concentrations at the point of abstraction (Stantec 2004). The 2004 Belle Feasibility study provided estimates of the theoretical reductions in nitrate values that would result in sewering selected areas within the catchment that were in relatively close proximity to the abstraction wells. The table in Appendix C has been adapted from the master plan of the Feasibility Study and highlights the total nitrate reduction that has been postulated.

However the benefits of sewering are not expected to be seen until approximately two years after they have been installed and are operational. The report also states that the level of reduction, 2.26 mg/L, brought about solely by sewering of these areas will not solve the problems of elevated nitrate levels in water reaching the public. Although it may bring about some reduction in nitrate concentration in groundwater, treatment options for potable water may be necessary to compliment sewering in order to supply the public with water that has an acceptable level of nitrates. These options which include blending with higher quality raw water from other sources and reverse osmosis to remove nitrates are expected to address the challenges posed by non point sources of pollutants namely from agricultural sources that have proven difficult to regulate and control.

Consideration has also been given to the installation of cluster wastewater treatment facilities for developments whose effluent flows will exceed 3400 gallons/day irregardless of the zone in which the development is taking place. Although this is an approach in the direction towards watershed management and the regulation of activities in land upstream of Zone 1 areas there are legal implications for these actions that need to be given greater consideration. To date there has been no clear legislation drafted as it related to which party will hold the ultimate responsibility for the maintenance and monitoring of these facilities or who would bear the initial or ongoing costs. The issues with this initiative lie with the fact that the developer relinquishes all legal responsibility to the development once the properties have been sold. The only times were the developer will retain these responsibilities are if properties are leased or rented.

Clear guidelines on ownership responsibilities need to be given for guidance so that the state does not end up inheriting the responsibility for monitoring and upkeep of these plants as well as the costs for doing so. Various countries have made use of community councils where fees are paid by the residents of the development for use of the wastewater facilities even if some of these costs are deferred via government subsides. User charges may also be employed by the state which may be variable rate, and linked to water consumption or property values, or fixed rate charges or a combination of the two. Examples of this can be seen in parts of Colombia where sewerage tariffs are levied on up to 60% of the water tariff or in Canada where residents are taxed according to property values or based on a calculation that includes water consumption (Bernstein 2007).

13.4 Policy and legislative framework for the protection of groundwater

In order for any strategies implemented for the protection of groundwater resources to be truly effective, there must be an adequate policy and legislative framework to support them. These policies and statutes act as a guide for acceptable practices whether they are concerned with land use management, methods of waste disposal or monitoring and enforcement of water resources. These statutes set the standards for water and wastewater management; and groundwater protection and clearly outline the roles of organisations which are charged with these responsibilities. Often the situation is such that several government departments hold responsibility for different aspects of water management or the activities that are likely to impact on groundwater resources. When there is no overarching legislation or any lead agency for groundwater protection and management, efforts to this effect can be compromised by the involvement of several government agencies with overlapping responsibilities who may have disparate opinions and approaches to particular development proposals and whose efforts are not effectively coordinated. Reform of current legislation or enactment of new ones may be used to address this. However there must be the political will for it to be realised. Governments are often reluctant to administer more control through statutes or enact retroactive legislation for fear of public resistance to these new controls or restricting economic growth. Often the benefits of such mandates are realised far beyond the time frame in which the public may be affected by their implementation (Howard et al 2006).

There are many challenges associated with implementing policies with regards to diffused sources of pollution. In cases such as these, specific legal direction is not always possible (Howard et al 2006). It would be very difficult to control each aspect of the activities associated with agriculture. In these situations a code of good practices could be used where the best practices with regards to the prevention and minimisation of groundwater pollution are employed and legally mandated.

Measures for water resources management must not be considered within a vacuum. All policy must not only take into consideration the need to protect public health but the resource value and other developmental agendas for the local environment. There must be some balance between meeting groundwater protection and encouraging economic development for any strategies to be truly successful.

14 CONCLUSION

The upward trend of nitrate concentration in the groundwater system is an issue of great concern. Although in most instances concentrations have been recorded at values that are less than the WHO standard of 10mg/L some of the major supply stations have seen recent increases in nitrates. Statistical analysis suggests that these elevated levels are likely to continue at some potable water sites. Among these and of greatest concern are Belle, Ashton Hall and Hampton pumping stations which contribute substantially to the local water supply. If measures to address these challenges are not taken, the situation will not only have serious implications on groundwater resources but on marine resources as well. The discharge of contaminated groundwater to the nearshore marine environment has the potentially to undermine the sustainability of the ecosystems contained within it. Its potential impact on species diversity and habitat health also has economic implications as it adversely affects one of the major attractions within the tourism sector. Research has implicated and increase in nutrient loading in the nearshore as one of the main causes the loss of coral reefs and increases in macroalgal growth.

Barbados' groundwater is generally considered a good source of drinking water. However the karstic hydrogeology of the island means that the aquifers from which we take our supplies are taken are very susceptible to pollution. Consideration must be given to the efficacy of the current zoning policy and whether or not its current format is still relevant some 60 years after it has been implemented. The social and political landscape has changed drastically over that period with very little change to the legislation and policy that governs water and marine resource protection. With increasing population numbers, demand for more housing and pressure for increased development the potential for undermining the integrity of potable water sources is more likely. At present 8% of the total land region of Barbados is designated as Zone 1 and afforded the maximum protection under the Barbados Zoning Policy. There have been calls to revisit the current land development policies with regards to development restrictions for groundwater protection and for less conservative guidelines as it pertains to the zoning policy as the 300 day travel time given more than exceeds the average bacteria die- off period. Any revision of the policy should be given careful consideration and be evaluated on a site by site basis before any definitive decisions are made.

Current methods of groundwater management, land use zoning and waste disposal have provided some level of bacteriological protection. There has been no record of major incidences of microbial contamination of drinking water sources since these measures were implemented. These strategies however do not provide adequate protection against chemical contaminants.

Measures to address the protection and treatment of water supplies must also take into consideration the small land area and the competition that exist for space for residential, commercial and industrial development. If development on the island is to continue it must be in a manner that allows for economic growth but that is also sustainable. For this to truly be effective a legislative framework in which this can be realised is urgently needed. Currently no one agency is completely responsible for all aspects of water resources management. The mandate for supply, regulatory functions and enforcement of legislation for groundwater resources have been assigned to various sections within Government, resulting in a fragmented and disjointed management framework. This has resulted in an inefficient approach to groundwater regulation and protection; and duplication of efforts within the current system.

Interagency cooperation is crucial if the limited resources that are available are to be protected both from an environmental and public health perspective. There is much to lose if measures to address rising nitrate levels are not taken and legislation to support this effort not enacted. The end result needs to be a product that is of a quality suitable for public consumption and by extension the protection of the nearshore marine environment.

15 REFERENCES

A, Ifill, personal communication , October 2008.

Aller,L., T. Bennett, J.H. Lehr, and R.J. Petty. 1985. DRASTIC: A Standardized System for Evaluation Groundwater Pollution Potential Using Hydrogeologic Settings. USEPA 600/2-85/0108. Ada, Okla.: USEPA, Robert S. Kerr Environmental Research Laboratory.

Appleyard, S. 2006. Agriculture: Control and protection. Pages 564-585 in: O. Schmoll, G. Howard, J. Chilton and I. Chorus, (eds.) Protecting Groundwater for health. World Health Organisation. IWA Publishing, London.

Bernstein, J. D. 2007. Economic instruments. Pages 164-190 in: R. Helmer and Ivanildo Hespanhol, (eds) Water Pollution Control: A guide to the use of water quality management principles. World Health Organisation. IWA Publishing, London.

Bouchard D. C., K. M. Williams, Y. R. Surampallir.1992. Nitrate contamination of groundwater: sources and potential health effects. American Water Works Association 84 (9): 85-90.

Brown and Company. 1998. Detailed cadastral survey of all registered plantations and small holder concentrations- Task 1. Report for the Government of Barbados.

Brunol, J. F., L.E. Petes, C.D. Harvell and A. Hettinger. 2003. Nutrient enrichment can increase the severity of coral diseases. Ecology Letters 6: 1056–1061.

Burnside. In prep. Comprehensive review of groundwater protection zoning policy and system in Barbados: Evaluation of environmental conditions and risk assessment-Threats assessment and issues evaluation. Burnside International Ltd, Ontario.

Chilton, J., O. Schmoll and S Appleyard. 2006. Assessment of groundwater pollution potential. Pages 375-409 in: O. Schmoll, G. Howard, J. Chilton and I. Chorus, (eds.) Protecting Groundwater for health. World Health Organisation. IWA Publishing, London.

Chave, P., J. Howard, J. Schijven, S. Appleyard, F. Fladerer and W. Schimon. 2006. Groundwater Protection Zones. Pages 465-492 in: O. Schmoll, G. Howard, J. Chilton and I. Chorus, (eds.) Protecting Groundwater for health. World Health Organisation. IWA Publishing, London.

Delcan. 1995. Terrestrial water quality report. Feasibility Studies on Coastal Conservation. Coastal Conservation Project Unit, Government of Barbados.

Environmental Engineering Division. 1991. Groundwater pollution risk assessment for the Hampton catchment, Barbados. Report to the Government of Barbados.

Environmental Protection Department. 2008. Inventory of selected land based sources of pollution and estimation of land based pollutant loads into the marine environment- Part 2. Government of Barbados 54pp.

Environmental Protection Department. 2007. Inventory of selected land based sources of pollution and estimation of land based pollutant loads into the marine environment – Part 1. Government of Barbados 54pp.

“Environmental works." Encyclopædia Britannica. 2009. Encyclopædia Britannica Online. 26 April 2009 <http://www.britannica.com/EBchecked/topic/189203/environmental-works>.

Food and Agriculture Organisation. 2000. Guidelines and reference material on integrated soli and nutrient management and conservation for farmer field schools. FAO, Rome.

Government of Barbados.1998. National Physical Development Plan.

Halcrow. 1998. Hydrogeology, terrestrial and marine water quality. Barbados Coastal Conservation Programme -Phase 1 Coastal Zone Management Unit, Government of Barbados.

Howard. G., B. Reed, D. McChesney and R. Taylor. 2006. Human excreta and sanitation: Control and prevention. Pages 587-609 in: O. Schmoll, G. Howard, J. Chilton and I. Chorus, (eds.) Protecting Groundwater for health. World Health Organisation. IWA Publishing, London.

Ifill, A.S. 2000. Nitrate vulnerability assessment, risk and exposure mapping in Barbados. Barbados Water Authority, 15pp.

Kay, P., A.C. Edwards, M. Foulger. 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. Agricultural Systems 99 67-75.

Klohn-Crippen Consultants Ltd. 1996. Analysis of the existing water resources situation in Barbados – Report on Task 1. Water resources management and water loss studies. Barbados Water Authority, Government of Barbados.

Lapointe, B.E and K. Thacker. 2002. Community- based water quality and coral reef monitoring in the Negril Marine Park, Jamaica: Land-based nutrient inputs and their ecological consequences.

Ministry of Physical Development. 2002. Barbados national biodiversity strategy and action plan. Government of Barbados.

Pomeroy, R. S, John, E. Parks and L. M. Watson. 2004. How is your MPA doing? A Guidebook of Natural and Social Indicators for evaluating Marine Protected Area Management Effectiveness. The World Conservation Union (IUCN). Gland, Switzerland. 230pp.

Sapek, A. 2002.Agricultural activities as a source of nitrates in groundwater. Pages 3-14 in: L. Razowska-Jaworek and A. Sadurski, (eds.) Nitrates in Groundwater. Selected papers from the European meeting of the International Association of Hydrogeologists, Wisla, Poland 4-7 June 2002. A.A Balkema Publishers, London.

Stanley and Associates. 1978. Water quality, environment and public health. Barbados Water Resources Study, Government of Barbados.

Stantec. 2004. Draft Master Plan Report. Belle Feasibility Study. Report for the Government of Barbados.

Stantec. 2003. Marine pollution control act and coastal zone management act implementation assistance project- Final report. Government of Barbados.

Tosic, M, R. B. Bonnell, P. Dutilleul and H. Oxenford. 2009. Runoff Water Quality, Landuse and Environmental Impacts on the Bellairs Fringing Reef, Barbados. Pages 521-553 in: X. Yang (ed.), Remote Sensing and Geospatial Technologies for Coastal Ecosystem Assessment and Management, Lecture Notes in Geoinformation and Cartography, Springer-Verlag Berlin Heidelberg.

UNEP. 1994. Regional overview of land based sources of pollution in the wider Caribbean region. Caribbean Environmental Program Technical Report 33. UNEP Caribbean Environmental Program. Kingston, Jamaica.

University of the West Indies. 2004. List of prohibited concentrations. Environmental Protection Department, Government of Barbados. 17pp

Ward, H.M., T.M. deKok, P. Levallois, J. Brender, G. Gulis, B. T. Nolan and J. VanDerslice. 2005. Workgroup Report: Drinking- water nitrate and health- Recent findings and research needs. Environmental Health Perspectives 113(11) 1607-1614.

World Health Organisation. 2007. Nitrate and nitrite in drinking water. WHO Press, Geneva.

16 APPENDICES

16.1 Appendix A

Descriptive Statistics for all wells sampled in Barbados

Name	Catchment	Type	Count	Minimum	Maximum	Mean	Standard Error	Median	Mode	Standard Deviation	Sample Variance
Belle	Belle	PS	242	2.462	17.3	8.448	0.0984	8.54	7.34190275	1.530	2.341
Carrington	Belle	PS	121	4.9	8.95	6.741	0.0496	6.7	6.74	0.546	0.298
Codrington	Belle	PS	235	3.84	11.75	8.309	0.0827	8.34	8.1325692	1.267	1.605
Constant	Belle	PS	107	2.54	15.6	7.253	0.1086	7.14	7.11	1.123	1.261
Marchfield	Belle	AG	91	5.71	11.6	7.449	0.0710	7.43	7.76	0.678	0.459
Pine Central	Belle	AG	138	0.08	13.8	4.215	0.2120	4.095	4.9699034	2.490	6.200
Salters	Belle	AG	96	0	10.4	7.979	0.1344	7.97	7.94	1.317	1.735
Sweetvale #1 P.S	Belle	PS	159	0	10.80	5.481	0.0895	5.33	5.2	1.128	1.272
Sweetvale #2 P.S	Belle	PS	118	3.65	6.77	5.353	0.0461	5.27	5.67	0.501	0.251
Waterford	Belle	PS	95	3.17	15.6	7.589	0.1315	7.55	7.54	1.281	1.642
Bowmanston	Hampton	PS	195	1.97	14.5	6.673	0.0742	6.48	6.45	1.036	1.072
Brighton	Hampton	AG	131	2.35	10.59	7.928	0.0851	7.90	7.68	0.974	0.949
Corbin's Farm	Hampton	AG	161	4.59	25.30	8.826	0.1452	8.80	8.1325692	1.843	3.396
Edgecumbe	Hampton	AG	221	2.69	24.31	8.325	0.1180	8.18	8.5843786	1.754	3.075
Hampton	Hampton	PS	245	0	15.09	6.110	0.0792	6.17	4.9699034	1.240	1.538
Kendal	Hampton	PS	211	1.16	13.58	8.044	0.1253	8.02	8.49401672	1.820	3.311
National Hatcheries	Hampton	AG	179	1.99	20.24	9.490	0.1889	9.10	8.1325692	2.527	6.388

Name	**Catchment**	**Type**	**Count**	**Minimum**	**Maximum**	**Mean**	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**
Newmarket	Hampton	PS	217	2.38	13.1	6.868	0.0743	6.81	6.7	1.095	1.199
Packers RDP	Hampton	AG	183	4.88	26.02	11.630	0.1770	11.57	10.9	2.394	5.731
Pool Plantation	Hampton	AG	89	1.18	8	5.637	0.1088	5.77	6.07	1.026	1.053
Bath	Springs	Spring	86	5.34	16.7	13.150	0.1581	13.2	13	1.466	2.150
Benn Spring	Springs	PS	76	5.22	14.8	7.481	0.1776	7.34	6.71	1.549	2.398
College	Springs	PS	75	5.22	14.8	7.491	0.1797	7.37	6.71	1.556	2.422
Fortesque	Springs	Spring	87	6.04	15.3	12.266	0.152	12.3	11.2	1.414	1.9997
Porey Spring	Springs	Spring	88	1.96	8.38	4.89	0.1226	4.71	4.18	1.1501	1.3226
Pot House	Springs	Spring	88	6.09	33.1	8.4	0.3001	8.21	9	2.816	7.928
Three Houses	Springs	Spring	86	3.88	13.4	6.934	0.1023	6.86	6.86	0.948	0.899
Alleyneadale	West Coast	PS	168	0.74	9.96	6.88	0.0777	6.76	6.17	1.007	1.014
Applewhaites	West Coast	PS	240	0	10.05	6.557	0.0732	6.48	7.003	1.134	1.2865
Applewhaites Well Field	West Coast	PS	113	4.21	7.64	6.079	0.0422	6.02	5.88	0.449	0.2016
Ashton Hall	West Coast	PS	171	1.604	10.7	7.982	0.084	7.96	8.12	1.094	1.197
Carlton	West Coast	PS	163	0.587	10.73	7.253	0.099	7.32	7.31	1.27	1.613
Colleton	West Coast	PS	73	4.94	8.37	6.650	0.0742	6.66	6.98	0.634	0.402
Hayman	West Coast	PS	172	1.401	9.669	6.85	0.064	6.70	6.57	0.839	0.703
Hope	West Coast	PS	98	0.46	10.71	7.617	0.167	7.91	7.91	1.655	2.738
Molyneux	West Coast	PS	160	0	8.562	5.84	0.081	5.04	4.7	1.024	1.049
Royal	West Coast	PS	66	0.05	15	5.318	0.283	5.82	1	2.298	5.28

Name	**Catchment**	**Type**	**Count**	**Minimum**	**Maximum**	**Mean**	**Standard Error**	**Median**	**Mode**	**Standard Deviation**	**Sample Variance**
Westmoreland											
Trents	West Coast	PS	152	1.355	9.69	6.52	0.075	6.47	7.884	0.922	0.8503
Whim	West Coast	PS	169	0	9.736	7.159	0.081	7.24	6.77	1.048	1.099

.

16.2 Appendix B

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
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

Supply Well	**Catchment**	**Well Depth (m)**	**Abstraction Rate (m^3/day)**	**Chlorination Method**
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	-

16.3 Appendix C

Theorised reduction in nitrate concentration after sewering

Phase	Areas	Population	Theoretical Nitrate Reduction	Adjusted 70% Nitrate Reduction
Phase 1	Licorish Village (1A & 1B)	1260		
	Belle Tenantry (1C)	444		
	Northwest Ivy (2A)	684		
		2388	0.76 mg/L	0.53 mg/L
Phase 2	Northeast Ivy (2B)	230		
	West Tichbourne (2C)	500		
	Kingston Terrace (2E)	250		
		980	0.31 mg/L	0.22mg/L
Phase 2	Central Ivy (3A)	870		
	Government Hill/ Sion Hill (3B)	1360		
	East Welches (3C)	500		
		2730	0.87 mg/L	0.61 mg/L
Subtotal			1.94 mg/L	1.36 mg/L
Glendairy Prison		1000	0.32 mg/L	0.23 mg/L
Total Nitrate Reduction			2.26 mg/L	0.23 mg/L

**Adapted from the Belle Feasibility Study Draft Master Plan Report 2004

16.4 Appendix D

Correlation factors and forecast data for wells analysed

Sample Site	Stats Test	NO3 status	Forecast	Upper Limit	Lower Limit	Significance	Correlation factor
Alleynedale P.S	SES w/ OA	Decreasing	6.45354	7.81573	5.09135	p=0.00	-0.785
Applewaithes P.S	SES w/ OA	Decreasing	6.49469	7.99348	4.99591	p=0.00	-0.785
Applewhaites Well Field	SES w/ OA	Decreasing	6.17261	5.49361	6.85161	p=0.00	-0.542
Ashton Hall P.S	SES w/ OA	Increasing	7.98105	9.26242	6.69967	p=0.00	0.687
Bath	SES w/ OA	Decreasing	13.09523	14.9422	11.24824	p=0.00	-0.659
Belle P.S	SES w/ OA	Increasing	8.71190	10.8666	6.55718	p=0.00	0.453
Benn Spring	SES w/ OA	Decreasing	6.96974	8.7037	5.23575	p=0.01	-0.317
Bowmanston P.S	SES w/ OA	Decreasing	6.36396	7.6316	5.09634	p=0.00	-0.869
Brighton	SES w/ OA	Decreasing	7.80909	9.04846	6.56971	p=0.00	-0.687
Carlton P.S	SES w/ OA	Decreasing	4.8759	6.5615	3.1904	p=0.01	-0.233
Carrington P.S	SES w/ OA	Decreasing	6.90251	8.02323	5.78179	p=0.01	-0.903
Codrington P.S	SES w/ OA	Change Insignificant	8.21591	10.23998	6.19183	p=0.917	0.006
College	SES w/ OA	Decreasing	7.7816	8.7388	6.8244	p=0.00	-0.869
Colleton P.S	SES w/ OA	Decreasing	6.1138	7.1236	5.1040	p=0.00	
Constant P.S	SES w/ OA	Decreasing	7.41027	8.55129	6.26926	p=0.00	-0.381
Corbin's Farm	SES w/ OA	Increasing	8.93802	10.39945	7.47658	p=0.00	0.811
Desal Product	Too little data available for statistical analysis						
Edgecumbe	SES w/ OA	Change Insignificant	8.1106	10.2902	5.9310	p=0.686	0.025
Enginefield	Too little data available for statistical analysis						

Sample Site	Stats Test	NO3 status	Forecast	Upper Limit	Lower Limit	Significance	Correlation factor
Fortesque	SES w/ OA	Increasing	12.630	14.837	10.422	p=0.00	0.937
Hampton P.S	SES w/ OA	Increasing	6.5301	8.0746	4.9856	p=0.00	0.636
Hayman P.S	SES w/ OA	Decreasing	6.4029	7.5096	5.2962	p=0.00	-0.758
Hope	SES w/ OA	Decreasing	7.3413	9.2985	5.3842	p=0.00	-0.337
Kendal	SES w/ OA	Decreasing	4.9391	7.1867	2.6915	p=0.01	-0.736
King's Road	Too data little available for statistical analysis						
Marchfield	SES w/ OA	Decreasing	7.3814	8.1577	6.6052	p=0.00	-0.777
Molyneux P.S	SES w/ OA	Decreasing	4.3838	5.6762	3.0913	p=0.00	-0.633
National Hatcheries	SES w/ OA	Increasing	11.6495	14.0825	9.2164	p=0.00	0.916
Newmarket P.S	SES w/ OA	Decreasing	6.7641	8.2350	5.2933	p=0.00	-0.777
Packer RDP	SES w/ OA	Decreasing	10.5918	13.7793	7.4043	p=0.00	-0.365
Pine Central	SES w/ OA	Increasing	3.5505	6.7756	0.3254	p=0.00	0.174
Pool Plantation	SES w/ OA	Decreasing	4.3910	5.6506	3.1314	p=0.00	-0.81
Porey Spring	SES w/ OA	Change Unsig	4.6163	6.5701	2.6625	p=0.135	-0.149
Pot House	SES w/ OA	Increasing	8.8052	11.2098	6.4006	p=0.00	0.524
Royal Westmoreland	SES w/ OA	Decreasing	3.7333	6.5206	0.9460	p=0.00	-0.809
Salters	SES w/ OA	Decreasing	7.5564	9.1115	6.0013	p=0.00	-0.845
Sweetvale #1 P.S	SES w/ OA	Decreasing	5.0844	6.4106	3.7582	p=0.00	-0.845
Sweetvale #2 P.S	SES w/ OA	Decreasing	5.0204	5.5975	4.4433	p=0.00	-0.892
Three Houses	SES w/ OA	Change Unsig	6.9616	7.9529	5.9703	p=0.16	0.16
Trents P.S	SES w/ OA	Decreasing	5.9461	7.1048	4.7873	p=0.00	-0.797

Sample Site	Stats Test	NO3 status	Forecast	Upper Limit	Lower Limit	Significance	Correlation factor
Villa Marie	Too little data available for statistical analysis						
Waterford P.S	SES w/ OA	Decreasing	7.628	9.099	6.156	p=0.00	-0.4
Whim P.S	SES w/ OA	Decreasing	7.859	9.317	6.401	p=0.016	-0.173

** Wells with positive correlation coefficients are highlighted in yellow

16.5 Appendix E

Summary table for total estimated pollutant loading for various sector in Barbados

Phase I		Pollutant Loading kg/yr					
Sector/Activity	**Year**	**BOD5**	**TKN**	**COD**	**TP**	**TSS**	**Notes**
Tourism /Package Treatment Plants	2004, 2005	32,211	8,799	53,779	1,779	17,335	
Municipal Wastewater Treatment	2004, 2005	1,440,637	295,553	3,488,970	26,451	1,386,237	
Distilleries	2005-2007	1,560,180	57,428	3,972,506	5,965	1,012	2 of 3 distilleries
Sugar Production	2005, 2006	90,768	804	146,370	818	13,690	1 of 2 sugar factories

Phase II		Pollutant Loading kg/yr					
Sector/Activity	**Year**	**BOD5**	**N**	**P**	**SS**	**Oil**	**Notes**
Poultry Rearing	2007	23,894,400	62,722,800	53,762,400	95,577,600	NA	
Cattle Rearing	2007	62,001	16,559	4,272	455,179	NA	
Sheep Rearing	2007	62,179	24,488	7,027	749,553	NA	
Swine Rearing	2007	1,823,680	405,880	127,880	355,840	NA	
Meat Processing	2007-2008	18,670	1,335	146	14,545	7,887.73	
Poultry Processing	2007-2008	94,758	NA	NA	70,790	31,214	
Rendering	2007-2008	23,866	5,328	444	12,544	7,992	
Bakery	2007-2008	8,435	67	NA	NA	NA	
Dairy Product Processing and Manufacture	2007-2008	40,274	2,365	518	10,136	NA	
Egg Production	2007-2008	7,444	19,541	16,749	29,776	NA	

*Adapted from the inventory of selected Land Based Sources of Pollution and Estimation of Land Based Pollutant Loads into the Marine Environment Part 1 & 2

16.6 Appendix F

Descriptive statistics for water quality data for agricultural wells collected by BADMC

Location	N	Mean	St Dev	Minimum	Median	Maximum
WHEELERS	2	0.305	0.431	0.2	0.505	0.81
THOMAS	15	9.574	3.32	1.98	10.6	12.7
STUART	4	24.38	14.47	11.9	23.55	38.5
STRAKER	24	20.65	11.97	7.32	16.6	47.1
ST. PATRICKS	13	12.538	1.97	10.4	12	16.2
SPENCERS	3	8.69	2.51	5.88	9.5	10.7
SILVER HILL	13	10.607	0.788	8.63	10.7	11.9
SHLLP	11	11.742	2.392	8.23	11.8	15.5
SALTERS	26	8.163	0.857	6.42	8.04	9.75
RVR	1	1	9.32	9.32	9.32	9.32
RUBY WELL	12	11.5	2.076	7.63	12.1	14
RUBY TANK	10	0.573	1.811	7.23	11.5	13.4
PINE(HOWELL)	21	0.688	2.752	0.02	0.615	9.28
PINE(BASIN)	21	6.419	3.288	0.27	7.94	10.2
PHILLIPS	9	5.389	2.262	1.63	6.19	8.37
NICHOLSON	6	9.417	0.711	8.29	9.445	10.3
MT. POYER	8	7.285	0.815	6.4	7.105	9.07
MARSHALL	14	5.564	0.451	4.66	5.65	6.43
MARCHFIELD	13	7.064	0.454	6.17	7.19	7.72
MAPPS	12	12.072	2.68	7.21	12.25	15.3
JACKMAN	17	18.17	12.55	6.19	14.1	53.8
HOME	18	18	7.173	5.66	6.68	14.9
GRIFFITH	21	21	3.1	1.42	3.11	4.49
FORDE	3	3	3.15	5.01	9.88	10.9
DOBSON	15	9.915	2.694	0.5	10.5	11.8
DIXON	14	14	0.754	5.2	6.47	8.44
DIAMOND VALLEY	17	7.164	1.496	1.77	7.47	8.75
DANIEL	29	29	19.84	20.6	33.3	85.3
CRAB HILL	6	20.77	8.51	11.5	20.5	34.5
BRATHWAITE	14	8.154	1.844	2.45	8.45	9.89
BAMBOO	12	18.62	5.6	8.42	21.2	26.3
ATHERLEY Bore Hole	1	0.12		0.12	0.12	0.12
ATHERLEY WELL	5	10.562	0.655	9.905	10.7	11.4