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Monitoring the effects of below average precipitation on water resources in Paget Farm, Bequia, The Grenadines

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ABSTRACT

Monitoring the effects of below average precipitation on water resources in Paget Farm, Bequia, The Grenadines

Silas Durrant

This study attempts to investigate the potential effects of drought on water resources availability in Paget Farm, a small community in Bequia, an island in the Grenadines. The principal aims are to derive a meaningful drought index for the area based on available rainfall data, identify some likely socio-economic consequences of drought, assess water demand and factors associated with the usage of water, evaluate the response of residents to water stress, and recommend possible strategies for reducing the effects of drought in Paget Farm.

The residents of Paget Farm are generally poor, and lack the necessary resources to provide adequate water for their own needs.The main source of potable water for Paget Farm residents is "roof water", which is harvested and stored in tanks. The average tank has the capacity to store enough water for about 3 months. However, tank volumes fluctuate throughout the year, as there are marked variations in annual rainfall distribution. During periods of scarcity, this water is supplemented by supplies brought by '*water boats*' from mainland St. Vincent. However, while this helps to reduce the severity of the shortages, these boats never bring sufficient water to alleviate the problem completely.

The study found that communal water storage is also a problem and there is no public supply network. Since most residents lack the resources to improve their water supply, they hold the view that it is Government's responsibility to do so. It was also noted that the technology used for obtaining and storing water is outdated and inadequate, and that supply was not keeping pace with demand. If, as seems to be the case, droughts are becoming longer and more frequent, the situation will worsen, the vulnerability of Paget Farm residents will increase, and the sustainability of water resources will be severely compromised. For this reason, many residents have developed various ways to cope with water scarcity and conservative use of the resource is clearly their main strategy for dealing with the issue.

Overall, the research suggests that the water situation could further worsen for a variety of reasons such as climate variability and climate change, which may in turn lead to greater frequency and more intense droughts, higher frequency of hurricanes and sea level rise. In addition to the stated climatic effects, other impacts which may increase water scarcity, can be brought about by human activities such as pollution of potential water sources, inefficient water use and failure to maintain faulty water storage equipment.

It can be argued that there is urgent need for an effective drought management plan for Paget Farm, which must be based on the best available scientific, technical and socio-economic information and projections. Appropriate response measures must be developed with short, medium and long-term goals in mind, in order to alleviate present scarcity, while recognizing the need to meet future growing demand. This will require the involvement of all community stakeholders and Government agencies, and should include education and awareness programmes, and capacity building aimed at improvement of water management approaches.

Keywords: drought effects; drought management; water scarcity; water storage

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LIST OF ACRONYMS

E.T.	Ebenezer Theodore
NEAB	National Environmental Advisory Board
NDMC	National Drought Mitigation Center
SPI	Standard Precipitation Index
SVG METS	St. Vincent and the Grenadines Meteorological Service

1 INTRODUCTION

"Unfortunately, we tend to focus on drought when it is upon us. We're then forced to react – to respond to immediate needs, to provide what are often more costly remedies, and to attempt to balance competing interests in a charged atmosphere. That's not good policy. It's not good resource management…To the contrary, we must take a proactive approach to dealing with drought. We must anticipate the inevitable that drought will come and go and take an approach that seeks to minimize the effects of drought when it inevitably occurs" J. R. Lyons (1994).

1.1 St. Vincent & the Grenadines

1.1.1 Location

The small Eastern Caribbean Island state of St. Vincent and the Grenadines comprises more than 30 islands, creeks and cays. The chain stretches southwards for approximately 45 miles from mainland St. Vincent, the largest island, which is situated at latitude 13°15`N and longitude 61°12`W (NEAB and Min. Health and Environment, 2000) (Figure 1.1). The island chain covers a total land area of 345 km^2, with some 91 percent of the population of 111,105 living on mainland St. Vincent.

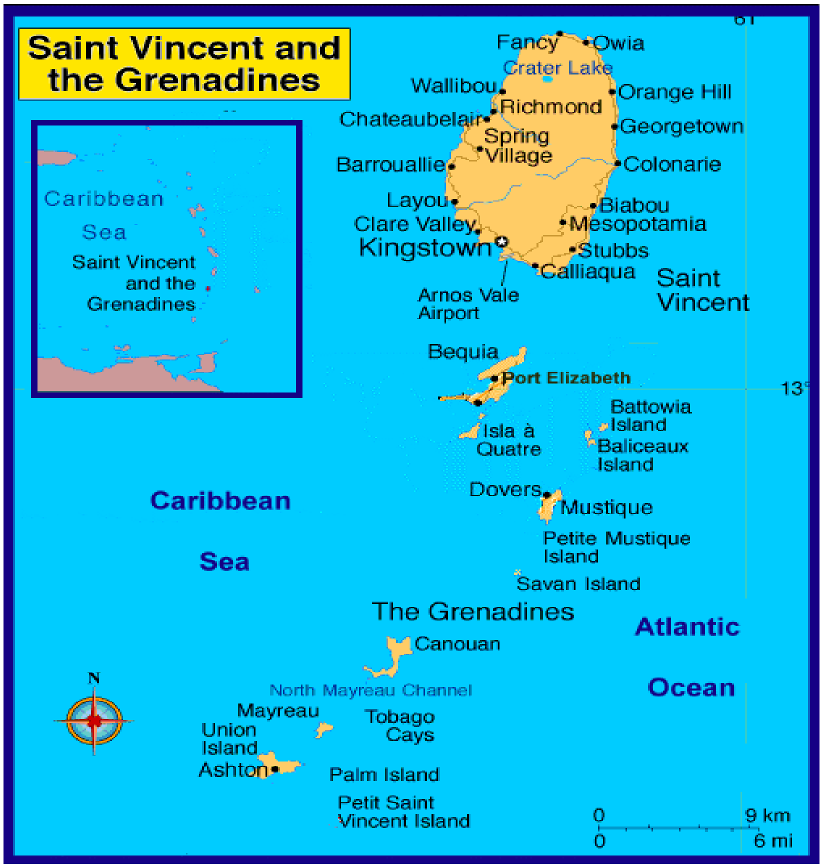

Figure 1.1: Map of St. Vincent & the Grenadines
Source: SVG METS

1.1.2 Climate

St. Vincent and the Grenadines has a tropical climate. At the E.T. Joshua (*Arnos Vale*) Airport on St. Vincent, the recorded temperature ranges from 18^{o}C to 33^{o}C. In the higher elevations throughout the interior of the island, the temperatures are bwer (NEAB and Min. Health and Environment, 2000).

1.2 Bequia study area

1.2.1 Location

Bequia is an island in the Grenadines chain located 9 miles south of St. Vincent. Although a mere seven square miles in area, the island exhibits exceedingly varied topography (Figure 1.2). Paget Farm, the focus of this study, is a busy local fishing village located to the west of La Pompe (Kingston and Redway, 2005). The James F. Mitchell Airport, where most of the country's reliable meteorological data are collected, is also located in Paget Farm at latitude 12^{o}59`N, 61$^{o}$15`W (Joyette, 2007). The most recent population statistics indicate that Paget farm had a total estimated resident population of 724 persons in 2001.

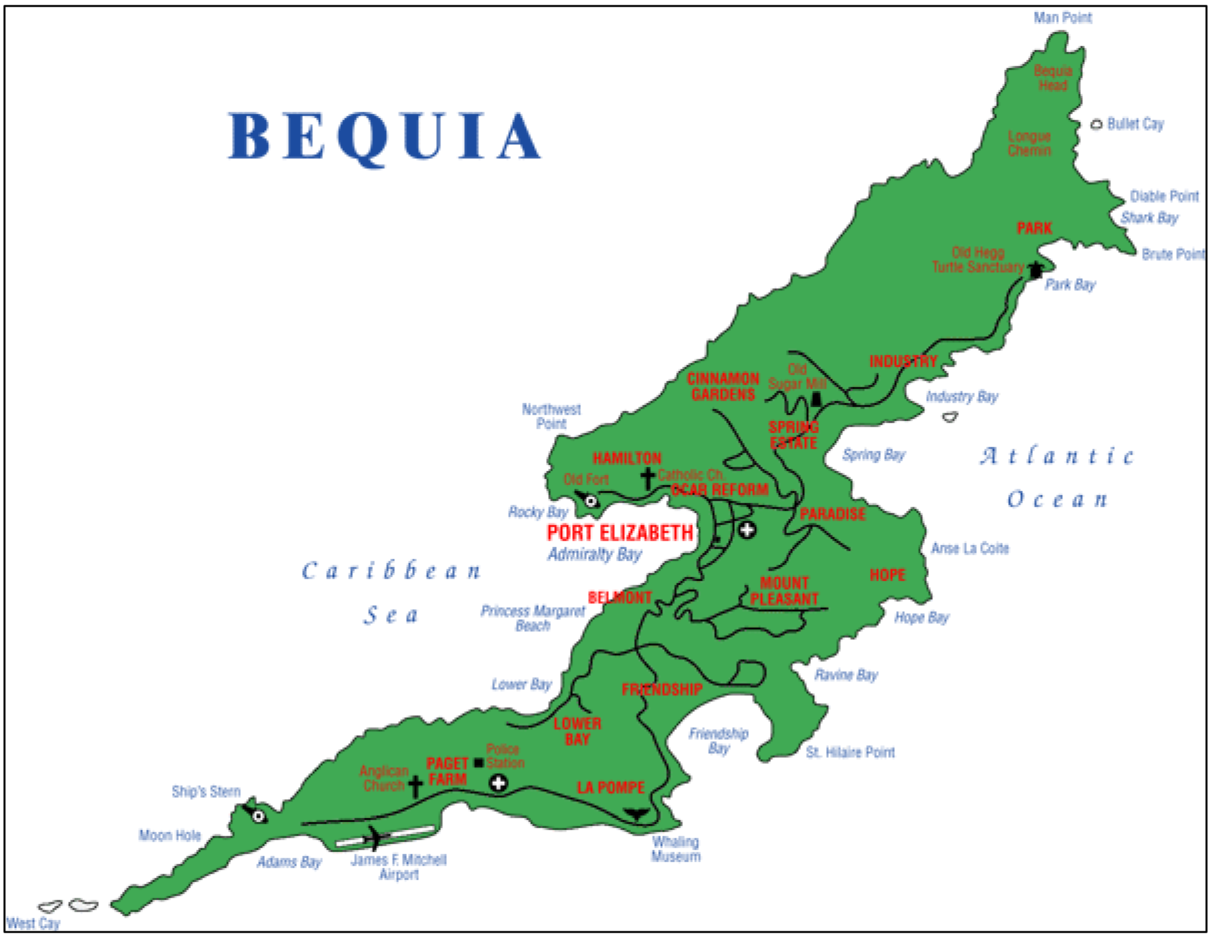

Figure 1.2: The Grenadine island of Bequia

Source: Bequia Tourism Association

1.2.2 Climate

In Bequia, the mean annual temperature varies from 23^{o} C or 70^{0} F to 32^{o} C or 92^{0} F. A definite rainy season is hard to identify. Rain rarely falls for a whole day (Michelle, 2002). The months of January, February and March are normally dry and by April there is sometimes a shortage of water on the island (Stow, 2006).

1.2.3 Water reserves

There is an abundance of surface water in rivers and streams on mainland St. Vincent, while the Grenadines experience severe shortages due to the limited supply of surface or groundwater. The principal fresh water source in the Grenadines is rainwater runoff. These islands import some water, and the rest is obtained from desalination plants. Rainwater runoff is collected using roof catchments systems which are connected to water storage tanks. The availability of water to the domestic sector in Bequia is dependent on the capacity of the storage systems, the water usage characteristic of community members and the annual distribution of rainfall. There is a water catchment in Port Elizabeth, the capital of Bequia, which supplies water to individuals in that area. Although the Central Water and Sewage Authority is responsible for delivering water to the various sectors in St. Vincent, this service has not yet been extended to Bequia. There is no tax for the use of water by the sectors in Bequia (NEAB and Min. Health and Environment, 2000).

1.3 Rainfall distribution in St. Vincent and Bequia

Table 1.1 below provides a listing of available meteorological and hydrological data, the length of the respective data sets, and the main sources of freshwater for mainland St. Vincent and Bequia.

Table 1.1: Availability of meteorological and hydrological data for St. Vincent and Bequia

Island	Study area	Location of study area	Nature of data	Years of monthly rainfall	Main source of water
Bequia	Paget Farm (Community) James F Mitchell Airport Paget Farm	12°59'N, 61°15'W	Social-hydrological (Number of persons who encounter water shortage)	1930-1981 & 1995-1997	Rainwater runoff (roof water)
St. Vincent	E.T. Joshua Airport Arnos Vale (Meteorological Station)	13°09'N, 61°13W	Meteorological (Rainfall distribution)	1976 & 1979-2006	Surface water (watersheds, rivers, streams)

Figure 1.3 shows the average monthly rainfall from January to December for the E.T. Joshua Airport, St. Vincent, and the James F. Mitchell Airport in Bequia (refer also to Appendix 4 & 5). The critical point to note is that the pattern of rainfall distribution is similar at both places, although as indicated in Table 1.2, monthly average rainfall for Bequia is lower than the monthly average for mainland St. Vincent[1]. This would suggest that rainfall trends in St. Vincent may be assumed to be reasonably representative of conditions likely to be experienced on Bequia. For this reason, the more reliable rainfall record for St. Vincent will be used in developing drought index values for Bequia.

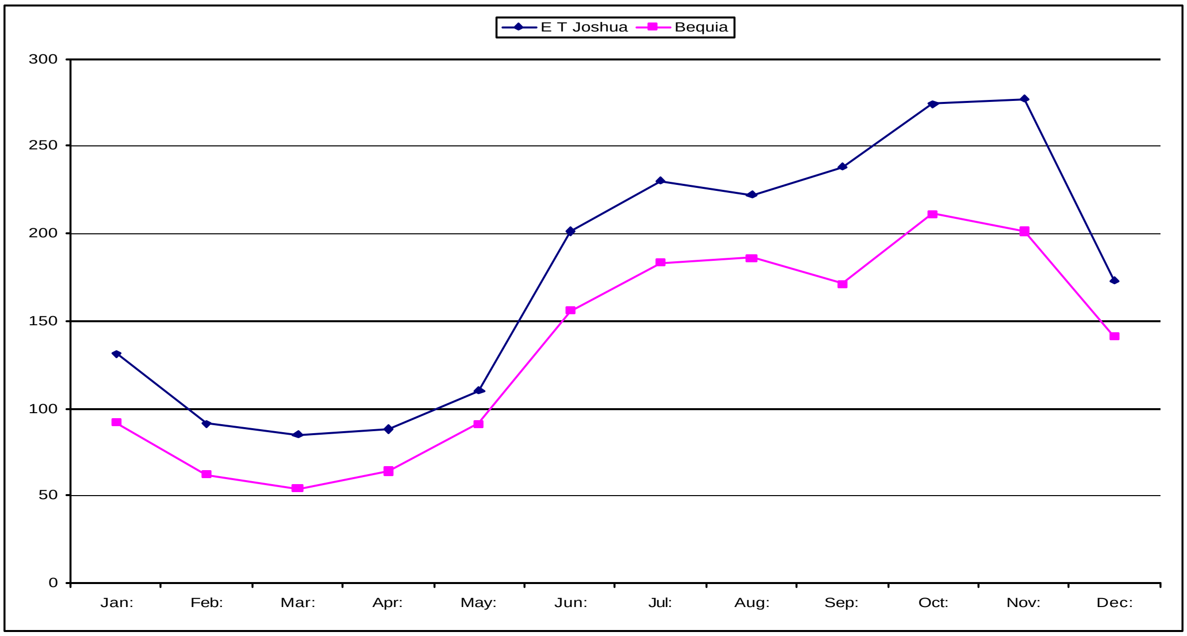

Figure 1.3: Average Monthly rainfall for St. Vincent and Bequia Airports

Table 1.2: Difference in average monthly rainfall for St. Vincent and Bequia

Month	Difference in average rainfall (mm)
January	39
February	29
March	31
April	24
May	19
June	45
July	47
August	37
September	67
October	63

[1] The reasons for the lower average monthly rainfall in Bequia are unclear. However, it is possible that they may be due to the different lengths of the data sets, and the fact that the two stations are some 9 months distant from each other.

November	76
December	32

1.4 Drought effects in the Caribbean

All climates may experience drought but its characteristics differ considerably in various regions (NDMC, 2006). Drought commences slowly as a natural risk, gradually develops over months or even years, and can affect extensive areas of a territory. It is not easy to determine when it begins, when it terminates or its intensity. Early mitigation and preparedness can minimize some of the effects of drought. Just as other disasters, drought can have severe social, economic and environmental consequences (Knutson and Wilhite, 2005). The islands of the Caribbean are located within the Tropics and many boast a rich agricultural history and abundant plant life. Over the years this image has helped to foster the false claim that the region is not very susceptible to droughts and extreme land degradation. However, population pressures and climate change effects have served to magnify the potential effects of drought and environmental degradation on the region's natural resources (Murray, 2003).

Water resources are important to the success of the domestic, tourism, agricultural, health and other socio-economic sectors in all countries. There are various indices used to quantify and express the extent to which rainfall has deviated from historical averages for a given time period. Even though none of the major indices is intrinsically better than the other, some indices are more appropriate than others for certain uses (Hayes, 2006).

1.5 Operational definitions of drought

1.5.1 Conceptual and operational definitions of drought

For practical purposes, it is necessary to distinguish between conceptual and operational definitions of drought. Conceptual definitions would provide no quantitative indication of the duration or magnitude of drought, and therefore is not very helpful in making management decisions. Contrastingly, operational definitions seek to provide a basis for establishing the start, finish, area of coverage and intensity of a drought. They are usually limited to a certain region and are subject to scientific analysis, which comes after the detailed examination of definite quantities of hydro-meteorological data. Such indices are useful in establishing guidelines for drought response, establishing monitoring networks, identification of mitigation methods and finalizing arrangements for readiness. Operational definitions are therefore usually derived from and based on quantitative indices of drought (Smakhtin and Hughes, 2004).

1.5.2 Types of drought

Scientists identify many different types of drought. Essentially, meteorological drought is said to occur when there is a long period of below-average rainfall. Hydrological drought is expressed in terms of the effect of precipitation deficit on surface or subsurface water supply, and may be manifested as reduced stream, lake, ground water and reservoir levels. Agricultural drought arises when there is not enough soil moisture to sustain crop growth. Socio-economic drought happens when the demand for an economic good is greater than the supply because of a meteorologically associated deficit in water supply (NDMC, 2006). Figure 1.4 is a schematic showing the relationship between precipitation deficit, types of drought and their effects.

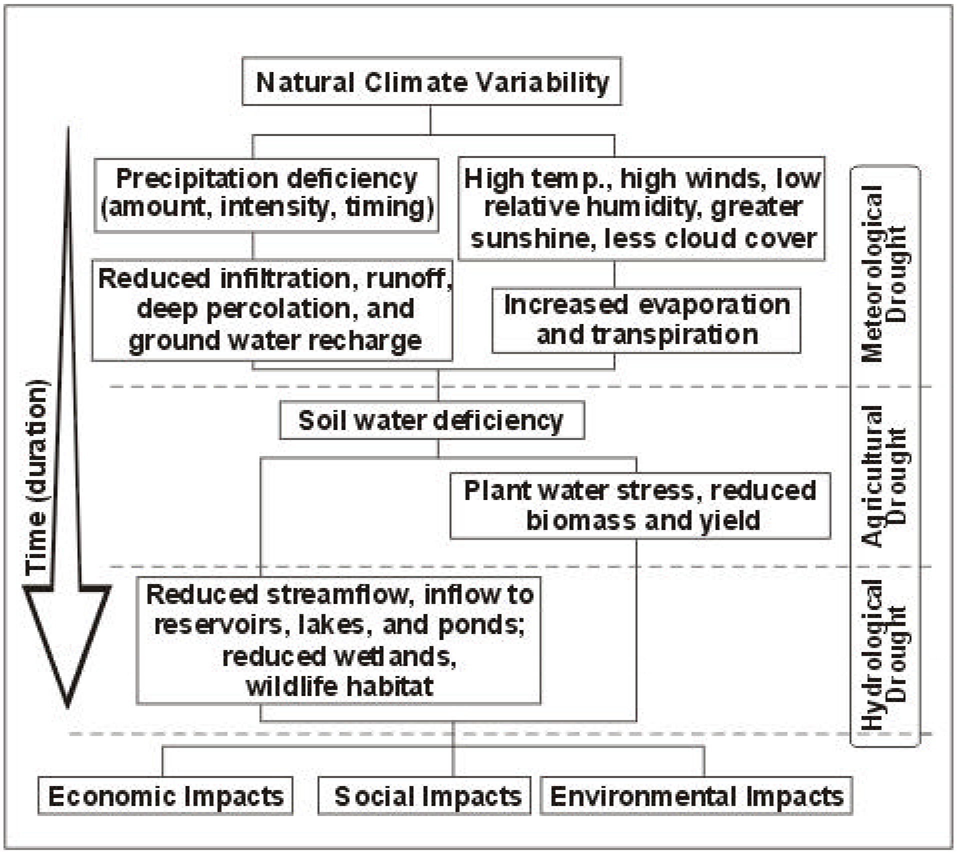

Figure 1.4: Types of drought and their impacts
Source: NDMC 2006

1.5.3 Sequence of impacts

In a sense, the differences between the different types of drought are partly reflected in the sequence of impacts associated with each. When drought starts, the agricultural sector is often the first to encounter the effects because it depends significantly on soil water reserves. A rapid reduction in soil water can occur during long dry periods. If rainfall deficits persist, then persons who rely on associated sources of water will begin to experience water scarcity. Those who depend on surface water (e.g. reservoirs and lakes) and sub-surface water (that is, ground water), are usually the last group to experience the effects of the drought. A drought that continues for a short duration of say three to six months may only have insignificant impacts on these sectors, depending on the management system in place and water use requirements (NDMC, 2006).

When typical levels of precipitation are reached and the effects of meteorological drought have been reduced, the natural chain of events leading to the restoration of surface and sub-surface water supplies may be expected. Stored soil water would be replenished initially, followed by the recovery of stream flow, reservoirs, lakes and ground water. Drought impacts may be quickly lessened in the agricultural sector as soil water recovers, but may continue to be experienced for months or even years in other sectors which rely on stored surface or sub-surface supplies. Persons who utilise ground water are often the last to experience the effects of drought during its initial stages, and are possibly the final ones to experience a return to typical water levels. The time period of the recovery is a function of the severity of the drought, the time for which it continues, and the amount of precipitation acquired as the sequence of events ends (NDMC, 2006).

1.6 Rainfall indicators of drought

1.6.1 The Percent of Normal Index

This is the least complex index to use to measure rainfall at a location. The method is very useful for analyzing precipitation records in one time period or region. This index is obtained by dividing actual precipitation by *normal precipitation* (30 year mean), and then multiplying by 100 percent. This can be calculated for various time scales, from one or several months representing a seasonal time period, to a year. Normal precipitation is stated as 100 percent (Hayes, 2006).The main limitation is that the formula does not take the effect of seasonal variation into consideration. Since the distribution of monthly or seasonal precipitation is not a normal distribution, the index will indicate a deficit if only a small amount of precipitation occurs in the particular month or season. In fact this may be normal for the location, and the apparent 'deficit' may not appear when the full year's record is considered (Hayes, 2006).

1.6.2 Standard Precipitation Index (SPI)

The Standard Precipitation Index is calculated by taking the difference in actual precipitation from the average for a particular time scale, and dividing it by the standard deviation (Sofia, 2004). The relationship is expressed by the formula:

$$SPI = (x_i - \bar{x}_i) / s$$

Where x_i represents precipitation observations at the ith time scale;
$\bar{x}_i$ represents long-term mean precipitation observations at the ith time scale; and
s represents the standard deviation of precipitation (Agnew, 1999).

Theoretically, the SPI represents a z-score, or the number of standard deviations an event is greater than or less than the mean, assuming a normal distribution (see also figure 1.5 and table 1.3). However, the rainfall distribution from the E T Joshua Meteorological Station presented in Figure 1.6, that was used for developing SPI indices for Bequia, does not conform to a normal distribution, but rather is positively skewed. Therefore it would be necessary to transform the data into a normal distribution. This was computed using a transformation method developed by Abramowitz and Stegun (1995) (Edward, 1997). See also Appendix 3.

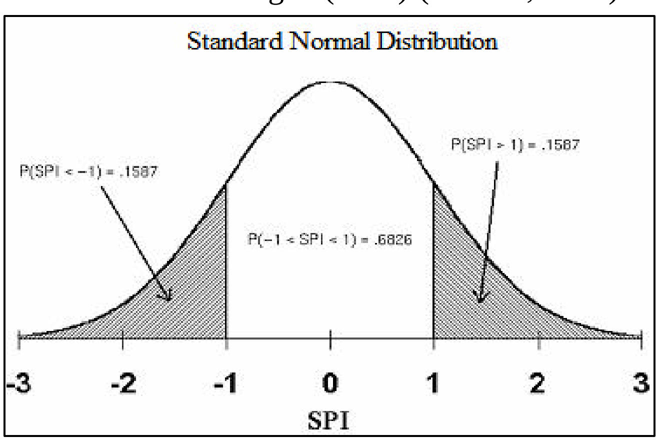

Figure 1.5: Standard normal distribution with the SPI (mean = zero and variance = one)
Source: NDMC
Table 1.3: SPI values and corresponding cumulative probability

SPI Cumulative Probability (Z)	Cumulative Probability (H(*x*))
-3	0.0014
-2.5	0.0062
-2	0.0228
-1.5	0.0668
-1	0.1587
-0.5	0.3085
0	0.5
+0.5	0.6915
+1	0.8413
+1.5	0.9332
+2	0.9772
+2.5	0.9938
+3	0.9986

Source: NDMC

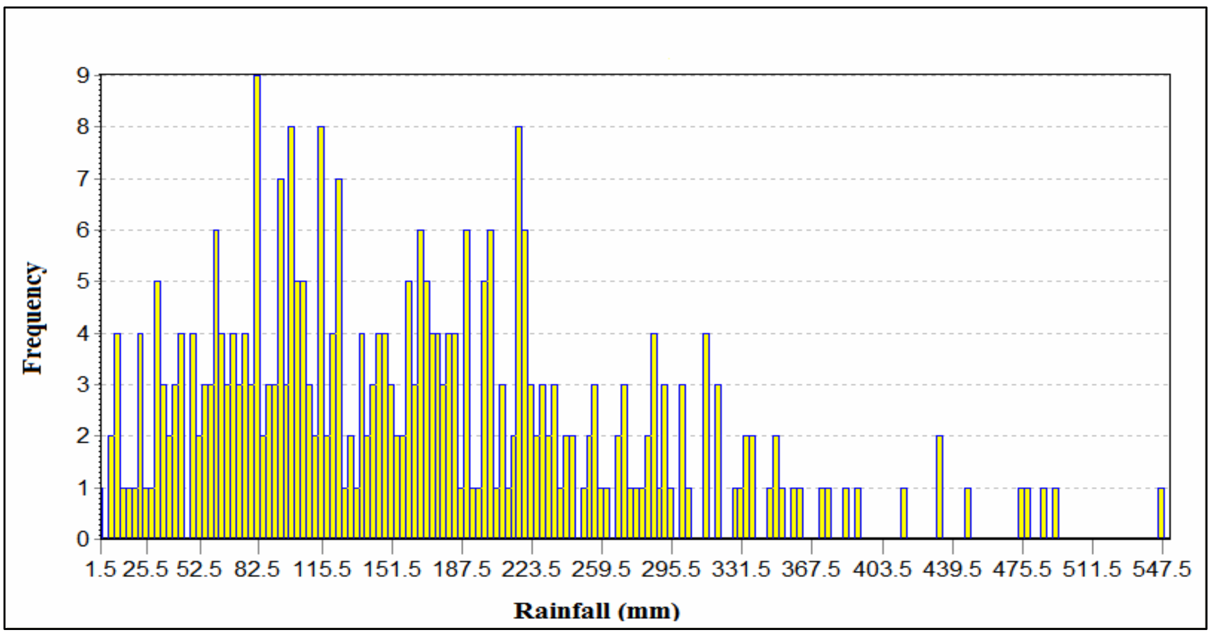

Figure 1.6: E T Joshua Monthly Rainfall Frequency Distribution (mm)

Positive SPI values mean that the precipitation exceeds the median, while a negative SPI is an indication that precipitation is less than the median. Since the SPI is a normalized index, wetter and drier climates can be represented in the same way, and so it is possible to monitor wet periods (surplus) using the SPI as well. A drought event is said to occur when the SPI becomes negative and attains a level of -1.0 or less. The drought is said to have ended when the SPI becomes positive. It is therefore possible to define the commencement and ending of every period. The severity for each month that the drought persists can also be defined. The overall magnitude of an event is represented as the sum of the SPI values for all months during which the event occurred (Edward, 1997).

The SPI was developed by McKee *et al.* (1993) for purposes of defining and monitoring drought. The index allows one 'to measure the rarity of a drought or an unusually wet occurrence at a particular time scale for any region in the world that has records of precipitation observations' (Edward, 1997).

1.7 Objectives of the study

The main objective of this research is to investigate the potential effects of drought on water resources availability in Paget Farm, a small community in Bequia, an island in the Grenadines. Bequia was chosen because the island is more prone to water shortages than mainland St. Vincent. Paget Farm was chosen partly because the community consider drought to be a potentially serious threat to their livelihood, and consequently they exhibited a high degree of interest in the project.

Initially, an attempt was made to focus on the tourism sector in Bequia, however the response was poor. It may be significant that the only completed questionnaire was submitted by the Frangipani Hotel, which obtains a year-round supply of freshwater from its own desalination plant. While reference will be made to the impacts of drought on a number of socio-economic sectors, the primary focus will be on the domestic sector, specifically the availability of freshwater for potable purposes. In particular, the study will attempt to:

i. establish an appropriate drought index for the area, based on temporal rainfall distribution;
ii. identify the likely socio-economic consequences of drought on the sector;
iii. assess the demand for water by residents of Paget Farm and factors associated with the usage of water;
iv. evaluate the response of residents to water stress; and
v. recommend possible strategies for reducing the effects of drought in Paget Farm.

2 METHODOLOGY

2.1 Data sources and survey instrument

In most small islands, including those in the Caribbean, the amount of rainfall recorded is regarded as a crude but useful indicator of the presence or absence of meteorological drought (Murray, 2003). In this study, rainfall distribution for Bequia will be analysed, and an attempt will be made to transform the results into a drought index, which it is hoped will also provide some indication of the severity of the phenomenon. Since the Standard Precipitation Index (SPI) and the Percentage of Normal are widely accepted drought indicators, and given that they can be determined from rainfall values alone, these indices will be used in this report. The data source for this analysis is the rainfall time series for the E.T. Joshua Airport for the period 1979-2006, the most reliable and complete data set available (refer to Table 1.1).

It should be pointed out that much initial consideration was given to the application of the Palmer Drought Index in this study. However, while this is a popular and widely applied drought index, its calculation requires data on soil moisture content, and such information is not available for St. Vincent and the Grenadines. It was therefore considered that the Percentage of Normal and the SPI would be the most appropriate indices to use in the present study, given the limited data available.

A questionnaire survey and the examination of relevant published documents are the principal instruments that were employed to collect information on critical parameters including *freshwater availability* during the dry season, number of persons at risk from drought, and water storage capacity (i.e. availability of water storage systems). Since both the *quantity* and *quality* of water can be affected by drought conditions, these will be considered critical elements of overall water availability in Paget Farm. A copy of the questionnaire is provided in Appendix 1. The questionnaire was distributed to community members, with a stamped self-addressed envelope to facilitate easy return by mail. The questionnaire could be completed in minimal time, as the response required factual but simple information such as the number of persons living in a household. The survey sought to estimate the amount of money residents spend to provide water, while assessing knowledge, attitudes and perception of the impact of drought on water resource availability. The survey was also used to try to determine in which months of the year water shortages were most likely to be encountered, and the extent to which individuals could cope with a typical dry season, with minimal disruption of their lifestyle. This information would be useful in identifying the kind of strategies needed to increase the level of participation in 'socio-hydrological monitoring' of drought and to develop cost effective adaptive strategies.

2.2 Difficulties encountered in survey

There were several misconceptions about the survey which the researcher attempted to deal with from the outset. In the first place, the project was mistaken as a government-controlled survey, and residents expressed some concern that the information might be used in a punitive way (e.g. taxation) by Government. In addition, many individuals who had access to wells, for instance, were concerned about losing their 'water resource privileges'. It was therefore made clear to all participants that (a) the survey was purely for academic research, it had no connection to the Government and would not be used for purposes of taxation (b) the information would be held in strict confidence and (c) the information would not be used in any way to cause residents to lose any existing water resource 'privileges'. The main misconception is that persons assumed that one has to encounter a problem in order to participate in the survey.

Unfortunately, the response was extremely poor, as only one resident returned a questionnaire, which carried a statement indicating "disgust" with government authorities. Thus, the survey ultimately had to be based on direct interviews and meetings with individuals (residents and Government officials) who were willing to participate. It should be noted however that the researcher used the same questions listed in the questionnaire as a basis for discussion and eliciting direct responses fromwith individuals. The questionnaire therefore remained a primary data collection instrument for the research.

2.3 Limitations of study

While all care had been taken in the data collection process, it is acknowledged that some possible sources of error remain. The main limitations arise from the following factors:

i. Lack of a longer, more complete set of rainfall observations. The most reliable data set covers a period of only 18 years (1979-1986). In addition, although not many, there are some gaps in the data set.

ii. The rainfall data come from one station, and therefore it is assumed that the available record is representative of conditions at the study site;

iii. There are known limitations associated with the numerical methods used to calculate the drought indices; and

iv. The quality of the information obtained from the survey is dependent on factors outside the control of the researcher, e.g. number of residents willing to participate in interviews with the researcher, and the accuracy of the responses.

v. It became relatively expensive for the researcher to find accommodation on Bequia during the period of the survey, and therefore factors of time and costs constrained the exercise.

3 RESULTS AND DISCUSSION

3.1 Rainfall distribution models

Figure 1.6 shows that the rainfall distribution of monthly precipitation amount from January 1979 to September 2006, is positively skewed. The gamma distribution would be used to model this observed distribution. This would be used because it is used to model positive distributions and it is one of the distributions used to model rainfall. An example of another distribution used to model rainfall is the Pearson III distribution which is considered slightly better than the Gamma Distribution (Svaboda, 2007).

3.2 SPI outputs on various time scales

3.2.1 1-Month SPI

Figure 3.1 below depicts a 1-month SPI from September 2004 to September 2006. The one-month SPI represents short-term conditions, and usually reflects short-term soil moisture and crop stress during the growing season. The 1-month SPI is therefore only meaningful for short term monitoring of water stress.

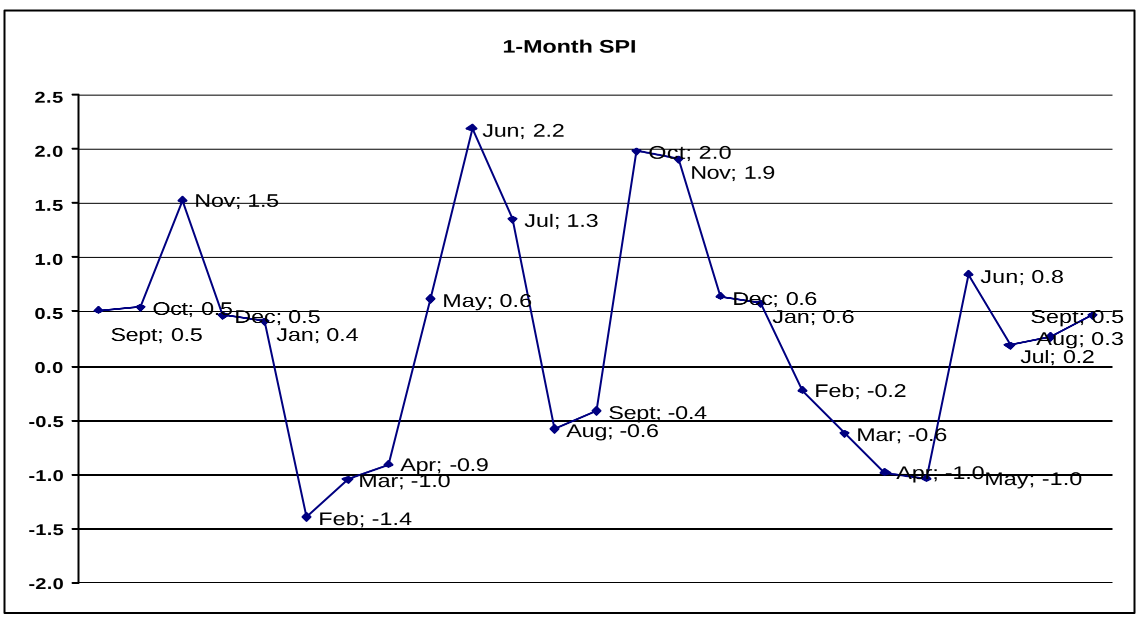

Figure 3.1: 1-Month SPI, September 2004-2006

3.2.2 4-Month SPI

Examination of rainfall distribution for St. Vincent and the Grenadines reveals that there is a seasonal variation of approximately 4 months between the wet and dry season. It was therefore decided that a four-month SPI based on data from the E.T. Joshua Meteorological Office would be used to assess the potential for meteorological drought in Paget Farm. Since the various sources of water respond differently to drought, and the effects of drought are manifested over different time scales, an analysis of temporal variations in rainfall would provide some indication of water availability in the Paget Farm.

The graph in figure 3.2 shows that April and May have the lowest index values, with April being the driest month on average in Bequia. Historically, April is also the month when the impact of below average precipitation is usually felt most in Bequia. The lowest 4-month Standard Precipitation Index was recorded in May 2006, which coincided with a period of severe water shortage on mainland St. Vincent. The effects of this drought were reported to be more widespread and serious than in previous years as noted by Gerald Primus in The Vincentian Newspaper May 19, 2006.

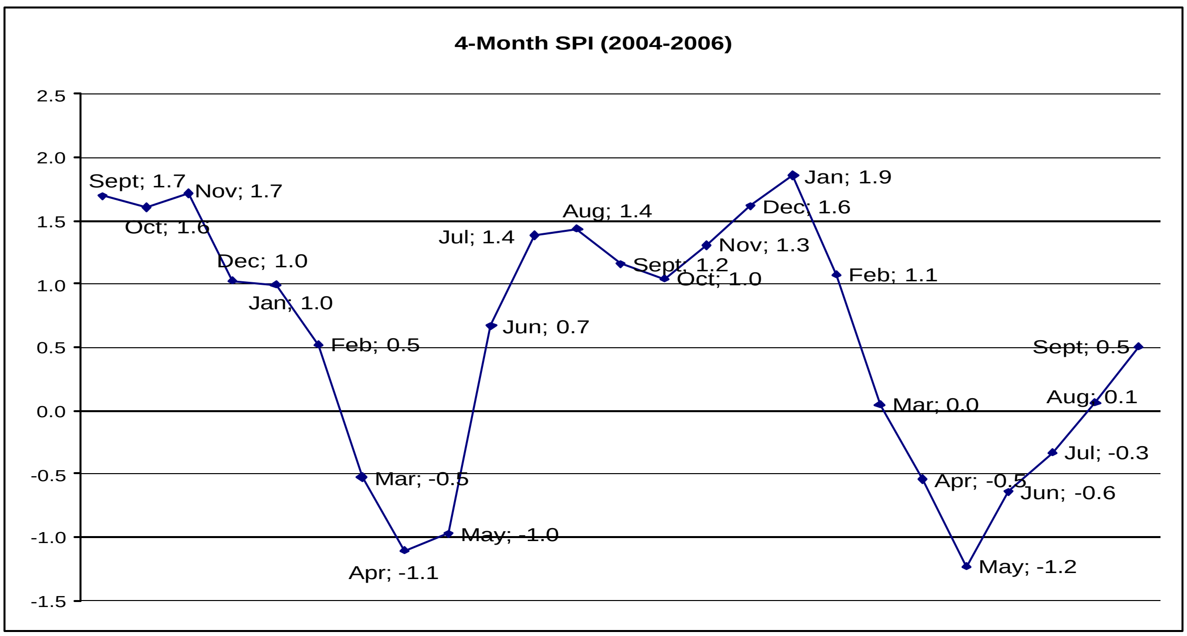

Figure 3.2: 4-Month SPI derived from E.T. Joshua Airport data

In 2005 the drought index value was lowest in April, while in 2006 the month of May recorded the lowest value. This shows that even though seasonal drought effects are intense in the month of April, the intensity could increase until the following month. In 2005 the 4-month seasonal drought index became positive just after the middle of May, whereas in 2006 the index became positive at the end of July. The duration of meteorological drought in 2005 was approximately 3 ¼ months, while the 2006 dry period lasted for about 5 ¾ months. This result would imply that the effects of the 2006 event would have been much more severe than in the 2005 drought. The results also show that the 2006 drought had a longer duration and greater maximum intensity than the 2005 drought, even though it started later than the one in 2005.

There is an annual trend for the 4-Month SPI indices variation in that it falls until the 4th month of the year on average. The community members would already have experiential knowledge of this trend and how to respond. The information which could not be gained by experiential knowledge on this time scale is the actual month and week when drought of a certain intensity would arise. Once the drought starts in February or March, it could easily be predetermined that the index variation would continue to fall. The annual dry and wet season trends allow for the prediction of the variation of the drought indices on this time scale. The 4-month SPI information could therefore be used in determining seasonal potential impacts of drought.

3.2.3 16-Week Percentage of Normal

Figure 3.3 is a 16-week Percentage of Normal graph that is capable of providing information on seasonal trends in drought that are equivalent to a 4-month time scale.

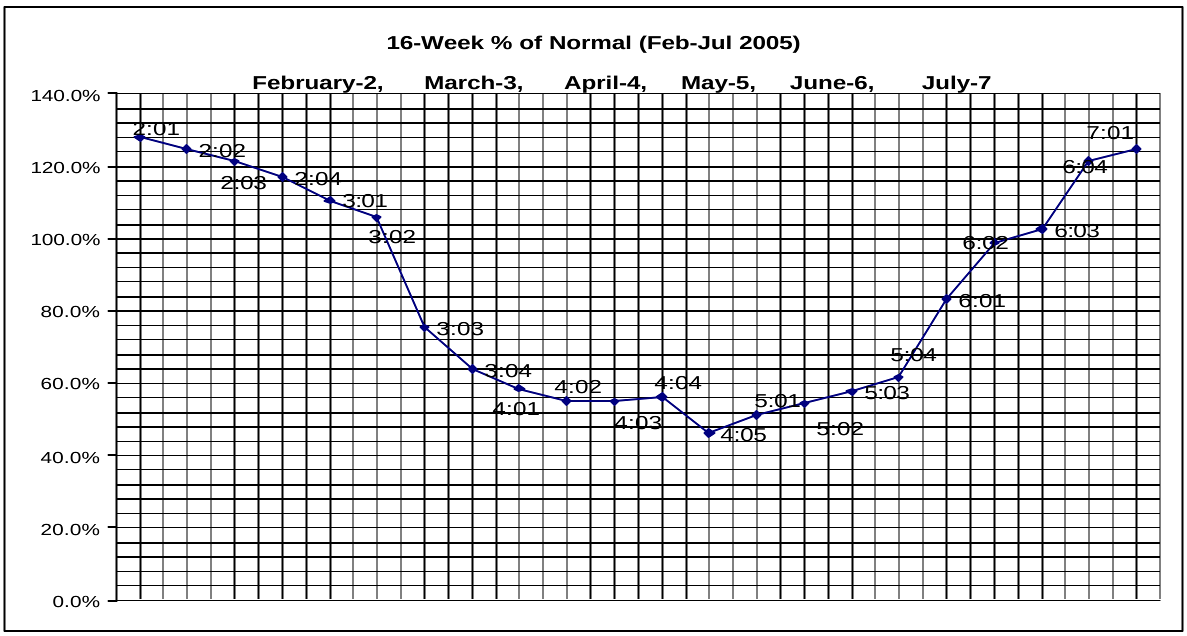

Figure 3.3: 16-Week Percentage of Normal Graph

The graph shows that the onset of a drought event would have commenced around the end of the 2nd week in March 2005, and would have ended just after the end of the 2nd week of June 2006.

In contrast, the 4-month SPI graph shows that based on the pattern exhibited, the drought event would start in the middle of February, or around the 2nd or 3rd week of that month (Figure 3.4). The drought would end just after the middle of the month of May. This suggests that the start and ending of the drought for the 16-week Percentage of Normal lags the 4-month SPI by about 1 month. Thus, assuming that the lag is real, and not a result of differences in the method of computation, it is possible that the Percentage of Normal may be used as a prediction tool, as it suggests that the drought would occur 1 month later.

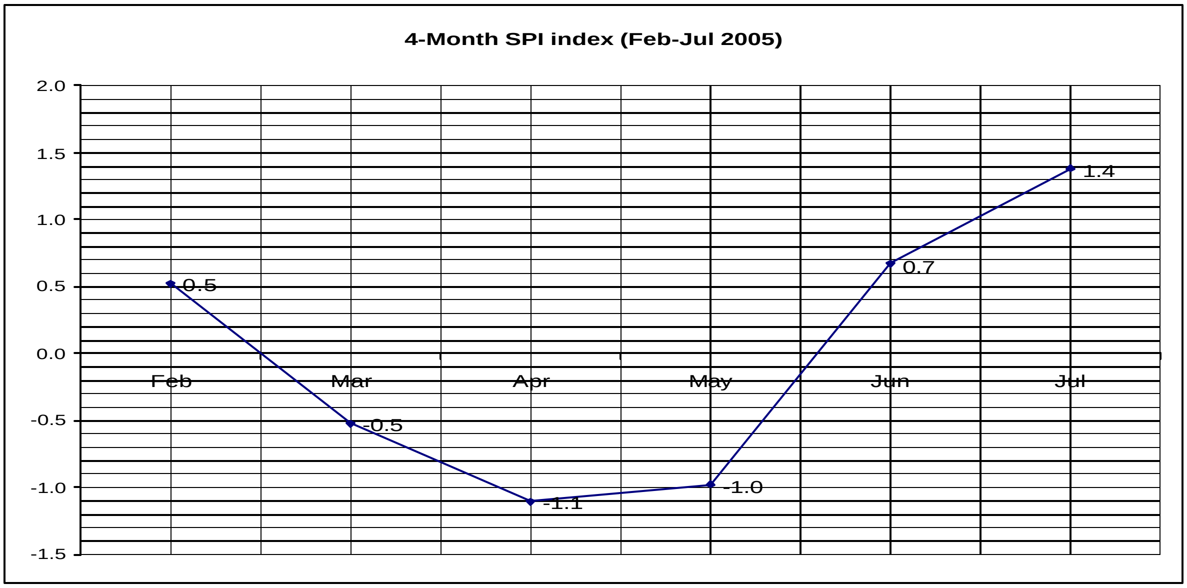

Figure 3.4: 4-Month SPI Index

The Percentage of Normal could also be used to assess the progression of drought severity, and possibly predict effects, on a weekly basis. If it were possible to link typical effects to drought severity, using this tool it might be possible to predict the kinds of water stress-related changes that might be expected in Paget Farm as one moves from one end of the severity range to another. For example, if it was known that crop failure occurs when the Percentage of Normal falls between 120% -100%, one would be able to predict such an outcome once the drought severity is forecast to approach this range.

It is also possible to compute the 1-week Percentage of Normal (Figure 3.5) to show weekly rainfall fluctuations. While weekly variations in rainfall cannot be used as indices of drought on their own, they can be useful for identifying possible acute fluctuations in the water levels of storage tanks in Bequia during a seasonal drought.

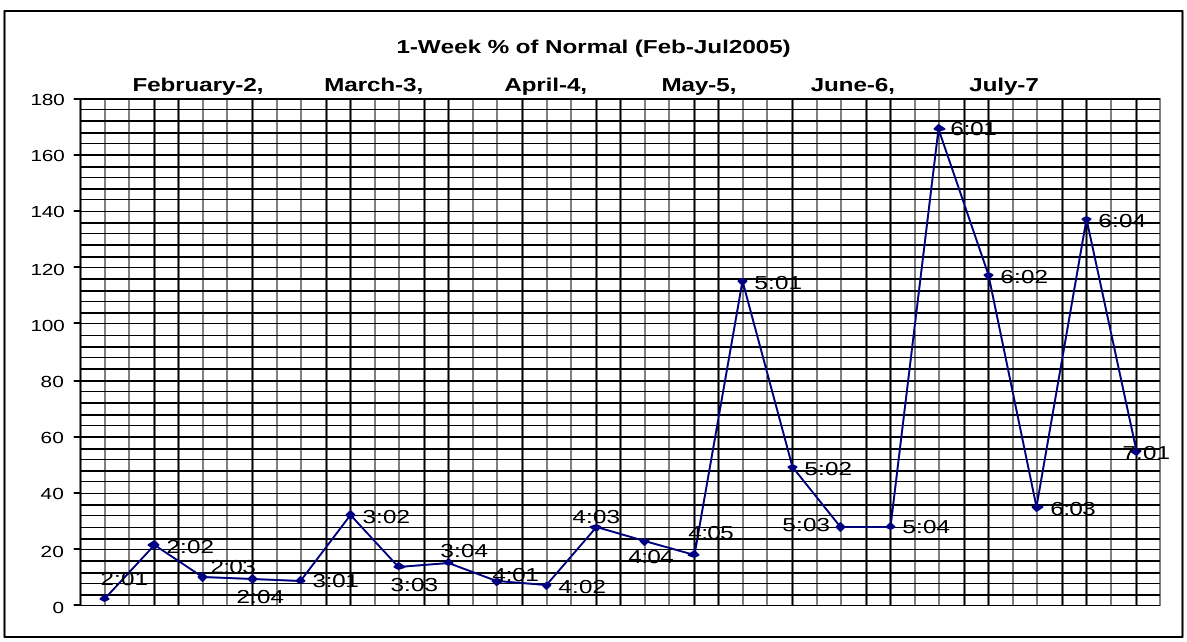

Figure 3.5: 1-Week Percentage of Normal

3.2.4 12-Month SPI

The 12-month SPI is more appropriately applied when attempting to identify levels of potential stress for water sources which respond to longer time scales. The index would be mostly applied in assessing the magnitude and fluctuation in stream flow, reservoir and groundwater levels at time scales of annual or longer duration. Its application would therefore be recommended when seeking to forecast flow volumes on mainland St. Vincent's watershed areas for example, as well as water availability during times of seasonal drought for the community at Paget Farm.

Figures 3.6 and 3.7 are two such graphs calculated from the St. Vincent data, for the years 2004-2006 and 1999-2001, respectively. The two SPI graphs show different long-term drought severity, with the time period from September 2004 to September 2006 indicating positive SPI values, while the period December 2000 to September 2001 reflects negative values. It would be recalled that in 2001 St. Vincent and the Grenadines experienced a long period of intense drought. As a result, there was noticeable reduction in river and stream flow especially on mainland St. Vincent, which caused severe water shortages. At the same time, this meant that there was also no surplus water available to the residents of Paget Farm to get them through the 'normal', shorter-term seasonal drought.

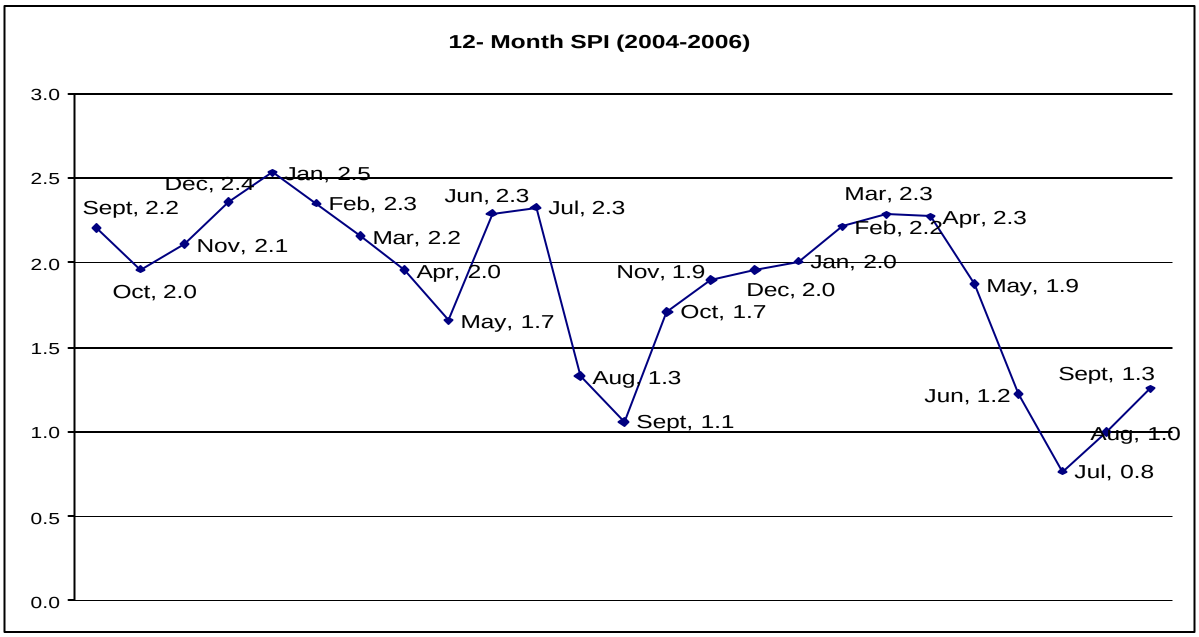

Figure 3.6: 12-Month SPI, 2004-2006

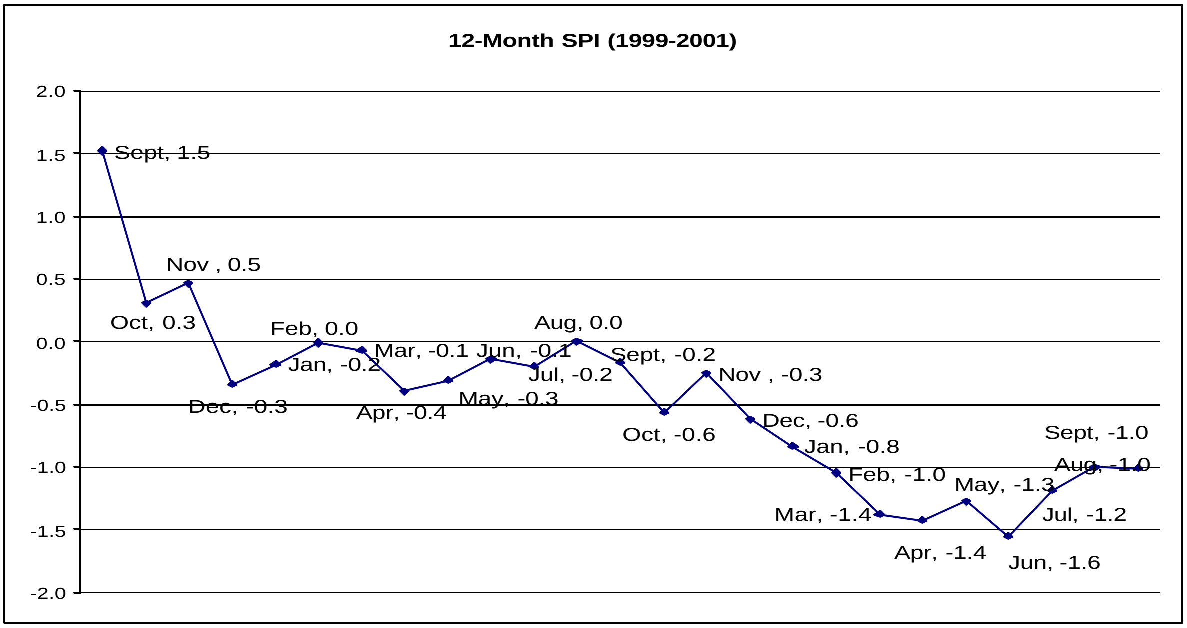

Figure 3.7: 12-Month SPI, 1999-2001

3.3 Drought phase identification and potential human response

One of the main reasons for calculating drought indices is to provide useful information and guidance for planning human response to the phenomenon. In order to identify appropriate human response to drought, water resource managers and planners need to be aware that there are often different *phases* during a single event. Furthermore, the severity of water stress is likely to vary from one phase to another, and therefore individuals may have to adopt different strategies to cope. In such circumstances the 4-month SPI can have good practical application, as it can be used to help identify the different phases of a drought and the appropriate response required.

Figure 3.8 is a graph showing the 4-month SPI for February to July 2005, while Table 3.1 lists the different phases during the period of drought, along with the responses that might be reasonably expected in order to cope during the period of water stress. This information permits water resource managers and individuals to follow the progression of the drought from its onset to the time that it ends, and provides a clear indication of the relative intensity or severity of each phase of the event. Obviously, the human response would vary according to the severity of the situation, and therefore it would be reasonable to expect a series of different responses as the drought progresses through various phases. Both the SPI and the information presented in the table can therefore be used as effective tools for managing situations of water stress, as would occur in Paget Farm. Obviously, considerations such as actual water demand relative to supply, government policy (e.g. which sectors get priority during water shortages), and the institutional arrangements in place for managing the resource, would determine how the phase responses might be actually implemented.

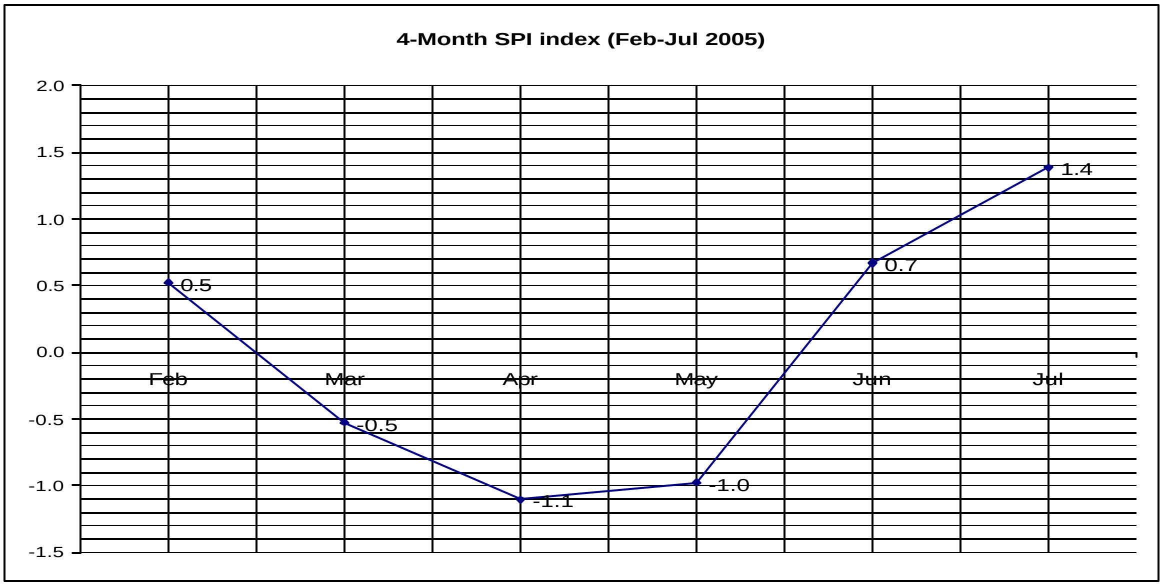

Figure 3.8: 4-Month SPI, February - July, 2005

Table 3.1: Drought phases and possible response for the 4-month SPI, February – July 2005

4-Month SPI Index	(Feb-Jul 2005) 4-Month, Index Value	Drought Phase	Phase Response
0.5 – 0.0	February, 0.5	Proximal drought phase	Optimise storage capacity
0.0 – -0.5		Primary(weak) drought phase	Carry out conservative measures
-0.5 – -1.0	March, -0.5	Secondary (mild) drought phase	Terminate non essential Water usage activities
-1.0 – min value		Intense drought phase	Use public emergency Water facilities
Min value – -1.0	April, -1.1	Terminal drought phase	Send water boat Share water resource Alert volunteers
-1.0 – -0.5	May, -1.0	Extended drought phase	Voluntary assistance if necessary
-0.5 – 0.0		Final drought phase	
0.0 – 0.9	June, 0.7	Recovery drought phase	

Clearly, the phase characteristics of an event are important in defining the severity of the drought. The index value alone is not the sole parameter that determines severity. Obviously, drought severity increases as the SPI value increases (and vice versa). But drought severity is determined by both *intensity* and *duration* of the event. This is why, for example, the 2006 drought was more severe than the dry season of 2005. The 2006 event was more intense and lasted for a longer period than the event experienced the previous year.

In addition, while the increase in intensity may be presented as a linear function, this does not mean that the magnitude of the effects will increase in a linear fashion. Rather the effects become multiplied with every increase in magnitude, so that human capacity to respond becomes an increasingly greater challenge as intensity increases. For example, a drought intensity value of -0.5 recorded 1 month after a drought intensity of 1.2 would not have as severe an effect as an intensity of -0.5 which follows 1 month after a drought intensity of -1.2, as the cumulative effects are determined by the events which precede them. In effect, as a drought progresses, its impact multiplies as various connected events unfold. The chain of events might involve economic, social and environmental impacts, and therefore affect almost every sector and group in the community.

With respect to recovery from the event, it should also be emphasized that a simple decrease in the severity of the meteorological drought index should not be interpreted to mean that there is an immediate reduction in water stress. Unless supplementary water resources become available as the drought event progresses, natural recovery will be delayed until a certain minimum threshold is reached.

3.4 Main findings from structured interviews and meetings

3.4.1 Principal water sources

All persons interviewed agreed that the principal source of potable water for Paget Farm residents is "roof water", which is collected and stored in tanks. While the size of storage tanks varies from household to household, the average tank has the capacity to store enough water for about 3 months. However, the storage tanks do not retain this volume for the entire year, as there are acute fluctuations in water levels in the tanks throughout the year on account of rainfall distribution. Traditionally, Paget Farm residents have also relied on 'water boats' to supplement local resources. These boats bring supplies from mainland St. Vincent to Bequia during the dry season. At times of acute shortage, that is every year during the dry season, there is an urgent direct request made to the government by community members to get a boat to bring water directly to Paget Farm. However, while supply from this source helps to offset the shortage, experience has shown that these boats never bring sufficient water to Paget Farm during serious water shortages. As a case in point, while this study was being carried out (October, 2006), there were many residents in need of water for essential, domestic purposes.

Discussions also revealed that about forty years ago there were two functioning stone tanks located at a church site in Paget Farm. These tanks provided community members with water during the annual drought (dry season). One tank has since been damaged by land slippage, and no longer functions as a source of potable water. Older residents also recalled that in the past some water used to be obtained from a shallow aquifer, but this is no longer the case. No one seems certain why this source has been abandoned, or what its present status is.

Although not the focus of this study, it should be noted that the business and commercial sectors on Bequia including the tourist industry, satisfy nearly all of their water needs by storing large volumes imported from mainland St. Vincent. One hotel on Bequia, Frangipani, provides all of its own water from a desalination plant.

3.4.2 Impact of poverty and financial constraints

In Paget Farm, many community members are extremely poor, and most individuals earn less than EC$40 to $50 per day. For the most part residents pursue livelihoods that are fairly independent of the mainland. Many individuals engage in small scale farming which involves the planting of corn, peas and cassava. In addition, many persons are self-employed and become involved in activities such as fishing and sailing. Some others also have close ties with the tourism sector.

Most respondents indicated that poverty and lack of financial resources were the main problems for the residents in Paget Farm, and that the poor is the group most affected by water shortages. As a result, many households do not have the capacity to improve or expand their water storage facilities. Most individuals felt that it was the Government's responsibility to provide adequate water supplies for the country, since only a small percentage of the population has the means to do so.

Respondents noted that development and expansion of water resources were lagging behind population demand, and as a result water scarcity was becoming more acute. It was stated that the current technology used to store and obtain water is very much limited to direct rainfall collected from the roofs of buildings (*rainfall harvesting*). Further, residents indicated that the situation worsens when tropical storms and hurricanes pass close to the island, as houses often lose their roofs due to the strong winds associated with these systems. Roofs are critical for household water collection. Thus, once the roof (or part of it) is lost, the potential for *rooftop harvesting* declines. The lack of access to other potentially useful technologies is clearly linked to the factor of poverty and financial constraints, as most individuals cannot afford to invest in alternative methods of supplying water.

One of the most serious concerns expressed by residents was the lack of a public water supply network. Without such a system in place, the vulnerability of the residents to water scarcity would be enhanced, as there would be no backup facilities in place when rooftop harvesting fails to meet demand. Given that Paget Farm is a poor community, the cost of providing a public water supply system would be beyond the financial capability of residents. Obviously, this is a problem that cannot be easily resolved at the individual level, but will require action on the part of the Government. In fact, one resident recommended that Government should urgently establish a water supply network, so that households could obtain adequate volumes from a central catchment during the dry season[2].

3.4.3 Perception of vulnerability to water stress, adaptation & conservation practices

Some residents indicated that they did not consider themselves vulnerable to water stress, and a few did not consider that there was a water scarcity problem in Paget Farm. This was a rather surprising response, especially since most individuals identified a number of challenges (poverty, limited technology, lack of public network, etc) that singly and collectively would increase their vulnerability to water stress. There appear to be only two plausible explanations for this response. First, it may be that the residents of Paget Farm have become so accustomed to dealing with water stress for such a long time, that they have adjusted their expectations accordingly. Thus, episodes of water scarcity may be perceived as 'normal' events with which residents simply have to cope. Secondly, it is possible that not all residents fully understood the meaning and implications of the term 'vulnerability', as neither a definition nor explanation was given in the questionnaire. The provision of definitions for key technical terms is therefore something that should be considered for future similar surveys.

With respect to adaptation measures and ability to cope with water scarcity, it was revealed that some community members had huge water tanks which are capable of supplying adequate amounts of water throughout the year. It was also noted that in many cases owners of large tanks shared their supply with other community members during the dry season (often around the

[2] Personal communication with Mr. Morrison Baisden. 19th June, 2006.

month of April), and this helps to lessen the problem of many residents. However, on occasions this practice causes those with high capacity to run out of supply quickly, as many persons who have 'large' storage tanks sometimes barely survive during the dry season[3].

Some individuals were also strong in their view that too much water was wasted by residents when it is in abundance, while making little provision for storage in difficult times. Consequently, it was these persons (i.e. those who 'wasted' water) that tended to be more affected by drought, as they often run out of water during the dry season. On the other hand, it was acknowledged that there are also many other persons who adhere to strict water conservation practices.

Overall, many of the islanders on Bequia, and Paget Farm in particular, appear to have developed a water usage ethic that is based on principles of conservation. Conservative use of the resource is clearly their main strategy for coping with water scarcity, although the few individuals who could afford to do so have occasionally attempted to boost their private supply with other means (e.g. larger storage tanks, additional tanks, etc.). However, conservative usage as a coping strategy over the years has not completely solved the problem in Paget Farm, as many residents continue to be confronted by water shortages almost on a continuous basis.

3.5 The Potential for Future and Enhanced Water Scarcity in Paget Farm

In the perception of most of the persons interviewed, the two main ways by which drought effects on water resources in Paget Farm could be magnified are by (a) an increase in local demand for water and (b) a reduction in supply. Although these answers may appear to be obvious, they suggest that residents in Paget Farm have a sound understanding of the nature of the problem confronting them, and therefore stakeholder "buy-in" to future adaptation policies and strategies might more easily be achieved.

With respect to increased demand, it has already been pointed out that Paget Farm is a poor community, and there should be some expectation that economic and social activities will increase over time. In fact, even if economic activity remains at the present level, there is still likely to be an increase in demand for water, as the resident population grows[4]. Apart from the pressure caused by greater numbers, demand for water could potentially increase for a variety of reasons, including the following:

i. the introduction of 'new' economic activities to the area, e.g. light industry and agro-processing
ii. tourism-related expansion into the area
iii. increase in housing and other construction activities
iv. expansion in agriculture which require more irrigation water
v. lifestyle improvements and greater access to modern household conveniences and appliances, e.g. flush toilets, washing machines

Reduction in water supply could also occur for a number of reasons such as:

i. climate variability and climate change, which may lead to (a) reduced rainfall (b) greater frequency and more intense droughts (c) higher evaporation and evapotranspiration losses related to increased temperatures and higher wind speeds

[3] Personal communication with Mr. Trevan Stow, 28th October, 2006.

[4] The Census statistics indicate that the population of Paget Farm increased by almost 6 % between 1991 and 2001.

ii. higher frequency of hurricanes causing removal of roofs of buildings needed for collecting rainwater for storage
iii. sea level rise, which could cause contamination of aquifers due to salt water intrusion
iv. pollution of potential water sources (e.g. aquifer, streams) from human activity
v. inefficient use and wastage, e.g. lack of conservation practices, and low-use technologies, failure to replace leaking mains, faucets and storage tanks.

4 CONCLUSION AND RECOMMENDATIONS

4.1 Recommendations for the Development of a Drought Response Plan

The results of the preceding analysis suggest that while the calculation of a drought severity index is an important element in the development of a drought monitoring plan, the actual impact of the drought cannot be determined by the index alone. In fact it has been shown that a factor such as *duration* of the drought is one of the most important factors that determine the level of impact of the event. Similarly, the overall impact of a drought is partly determined by the events preceding the event. So that for example, if a location experienced several months of below average rainfall or successive drought years, the next event would likely have a greater impact than if these conditions were absent. The results also imply that the relationship between the *intensity of drought* and *magnitude* of its effects is not linear, as the impacts appear to multiply as intensity increases. These impacts can have environmental (e.g. reduced river flow and runoff; reduced development of flora and fauna), economic (e.g. crop failure, soil erosion) as well as social consequences (e.g. loss of income and revenues, poor nutrition). Ideally, an effective drought response plan for Paget Farm should seek to anticipate the chain of events that are likely to follow, once a certain water shortage threshold is reached. This would afford a better opportunity to implement pro-active and timely mitigation, before the event reaches peak intensity.

In light of the preceding, it is recommended that the following considerations should be incorporated into the design of a meaningful drought response framework for Paget Farm:

i. Once the computed index suggests that drought may be imminent, maximum water harvesting and storage should be undertaken. In other words, the drought severity index could be used as an early warning of likely water scarcity. Clearly, storage facilities would need to be upgraded and expanded if this action is to have maximum beneficial results. In addition, it should be emphasized that the timing of this activity is critical, as it should be completed in advance of the onset of the drought.

ii. Improved collection, storage and analysis of meteorological data must be viewed as a vital part of the drought monitoring and response. The plan must be based on sound, reliable information derived from a data series of sufficient length to capture the main aspects of climate variability experienced at the location. The effectiveness of a plan that ignores these considerations would be highly questionable.

iii. Information on present water availability would also be necessary for planning an effective response to shortages and drought. There is no clear indication that this information is known or available. However, lack of such data would be a major obstacle to development of a drought management plan. Furthermore, it would be almost impossible to assess the potential impact of climate change on water supply, if the status of current availability is unknown.

iv. Water conservation measures need to be implemented on an ongoing basis, and not simply when water scarcity is being experienced, as is often the case in Paget Farm. This should be planned as a medium to long-term initiative, with careful targeting of the different stakeholder or target groups. This is important especially for the very poor sections of the community whose adaptive capacity is low, and are therefore the most vulnerable persons when there is a water crisis.

v. An effective drought response strategy must seek the genuine involvement of all community members, otherwise implementation of any plans or programmes will be jeopardized. Stakeholder commitment to implementation of the drought management plan must be seen as a necessity. Strong commitment from all community groups is also likely to lead to positive behavioural change.

vi. In addition, a study of local demand would need to be carried out in order to quantify the seasonal and annual water needs of the residents of Paget Farm. For purposes of medium and long-term planning, such a study should also consider the rate of growth of demand, so that reliable projections of future water requirements may be obtained.

vii. Also, a comprehensive response plan should consider all viable options for providing water for the community of Paget Farm, taking into account their financial, economic, social and environmental costs and benefits. This would help to ensure that the best combination of options are included in the overall drought management strategy.

viii. Although there is no public water supply network in Paget Farm, there is a need for the strengthening of the Government departments responsible for the management of water resources at the national level. The effects of water scarcity and drought can easily be made worse if the management system is weak. Therefore, technical and other types of training should be a priority, as this could help to improve the planning and provision of water services in outlying districts like Paget Farm, where there is a severe water shortage.

4.2 Summary conclusion

In summary, the development of an effective response plan to water scarcity must involve a logical sequence of actions. At a minimum the process should include an evaluation of the status of water availability in Paget Farm, an assessment of current and future water needs, a characterization of the vulnerability of the resource based on future climate-related risks, identification of appropriate adaptation and risk reduction options, and ongoing implementation of agreed strategies. Attention must be paid to the effective communication of the plan to all residents of Paget Farm, particularly in those instances where water shortages and drought are predicted to occur. Timely communication should be regarded as an important aspect of any early warning system, so that prompt, appropriate and prompt action can be taken by all concerned. All groups must be fully engaged in the implementation process, with stakeholder education being a crucial element of the plan. Finally, the meteorological and climate data on which the plan depends must be accurate and reliable, and to the extent the Government must invest in the necessary resources to ensure that this requirement is met.

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6 APPENDICES

6.1 Appendix 1: Questionnaire for water shortage susceptibility in the domestic sector

Personal information **ID#:|__|__|__|__|__|**

NAME (BLOCK CAPITALS)

FIRST NAME |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|
SURNAME |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|

PLACE OF RESIDENCE: |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|

Kindly complete the following questionnaire. The answers from this survey provide a medium for assessing your vulnerability to water shortage and to assist with improving the understanding of the risks involved. Data gathered from the survey will be of tremendous use for meeting the water resource needs of the public.

In order to maintain your water resource privileges, your rights to your livelihood would be respected. Your participation is invaluable.
Thank you in advance, for your participation

Demographic

1. How many persons live in your household?

   Number of adults: Less than 5 ? Between 5&10 ? Greater than 10 ?

   Number of children: Less than 5 ? Between 5&10 ? Greater than 10 ?

2. How long have you lived in this community?

   Less than 5 yrs ? Between 5& 15 yrs ? Greater than 15 yrs ?

Climate Induced Water Shortage

3. How significant was the water shortage during the dry season

   in 2006? Extremely ? Moderately ? Very Little ?

   in 2005? Extremely ? Moderately ? Very Little ?

   in 2004? Extremely ? Moderately ? Very Little ?

   in 2003? Extremely ? Moderately ? Very Little ?

   in 2002? Extremely ? Moderately ? Very Little ?

4. Which of the following is your main source of fresh water?

   Harvested rainwater ? Ground water ?

5. Which was/were the month(s) when water shortage was noticeable?
in 2006?______________ and in 2005?________________

6. Typically, how was your lifestyle affected with respect to fresh water utility during the dry season

in 2006? A lot ? Moderately ? Not much ?
in 2005? A lot ? Moderately ? Not much ?
in 2004? A lot ? Moderately ? Not much ?
in 2003? A lot ? Moderately ? Not much ?
in 2002? A lot ? Moderately ? Not much ?

7. Recall recent dry year. What were the effects?
____
____

8. During the dry season did you share fresh water resources with other households/sectors apart from yours?

Always ? Sometimes ? No ?

9. Do you use freshwater for agricultural activities ***(gardening is included)***?

Always ? Sometimes ? No ?

10. Estimate, how much in terms of buckets of fresh water is used per day?

Less than 5 ? Greater than 5 ?

Economic Cost

11. How much did you spend on purchasing water last year?

Less than $100 ? Between $100 & $500 ? Greater than $500 ?

12. Which month(s) did you spend most on purchasing water last year? ___________________

13. Give the names of places and their location where water was purchased.
____
____

Public Outlook

14. How do you rate your level of concern about climate and manmade induced water shortage?

Very concerned ? Moderately concerned ? Not concerned at all ?

15. How much do you consider yourself vulnerable to water shortage?

Extremely ? Somewhat ? Hardly at all ?

16. Do you think that this island is prepared to handle water shortage?

Yes ? No ?

Public Response

17. What has been done to lessen the effects of water shortage in this island

by you?

____
____
____

by your community?

____
____
____

by your country?

____
____
____

18. What has been done to worsen the effects of water shortage in this island

by you?

[***All information provided would be strictly confidential***]

____
____
____

by your community?

____
____
____

by your country?

____
____
____

National Response Outlook

19. My government should take a stronger role to address the impacts of climate induced water shortage in the communities.

Strongly Agree? Agree? Neutral? Disagree? Strongly Disagree?

20. I am prepared to pay a little more or put up with some inconvenience to help sustain fresh water availability.

    Strongly Agree? Agree? Neutral? Disagree? Strongly Disagree?

21. There is nothing a small island like mine can do about climate induced water shortage.

    Strongly Agree? Agree? Neutral? Disagree? Strongly Disagree?

Environmental Response

22. What has prevented action from being taken about increasing your ability to store water?

    ____
    ____
    ____

23. In order to enable this project to effectively meet your water resource needs, suggest action(s) that should be taken.

    ____
    ____
    ____
    ____

6.2 Appendix 2: Questionnaire for water shortage susceptibility in the tourism sector

Personal information **ID#:|__|__|__|__|__|**

NAME (BLOCK CAPITALS)

FIRST NAME **SURNAME**

|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__| |__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|

NAME (N) & LOCATION (L) OF:

Apartment ? Restaurant ? Guest House ? Snackette ? Hotel ? Bar ? Other ?

(N)|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|**& (L)**|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__|__

Kindly complete the following questionnaire. The answers from this survey provide a medium for assessing your vulnerability to water shortage and to assist with the understanding your knowledge of the risks involved. Data gathered from the survey will be of tremendous use for meeting the water resource needs of the public.

In order to maintain your water resource privileges, your rights to your livelihood would be respected. Your participation is invaluable.
Thank you in advance, for your participation

Demographic

1. How many persons are employed at your location?

Less than 5 ? Between 5&15 ? Between 15 & 25 ? Greater than 25 ?

2. How long have you been in operation at this location?

Less than 5 yrs ? Between 5 & 15 yrs ? Greater than 15 yrs ?

Climate Induced Water Shortage

3. How significant was the water shortage during the dry season

in 2006? Extremely ? Moderately ? Very Little ?

in 2005? Extremely ? Moderately ? Very Little ?

in 2004? Extremely ? Moderately ? Very Little ?

in 2003? Extremely ? Moderately ? Very Little ?

in 2002? Extremely ? Moderately ? Very Little ?

4. Which of the following is your main source of fresh water?

Harvested rainwater ? Ground water ?

5. Typically, how were your activities affected with respect to fresh water utility during the dry season

in 2006? A lot ? Moderately ? Not much ?

in 2005? A lot ? Moderately ? Not much ?

in 2004? A lot ? Moderately ? Not much ?

in 2003? A lot ? Moderately ? Not much ?

in 2002? A lot ? Moderately ? Not much ?

6. Which was/were the month(s) when water shortage was noticeable?
in 2006?________________ and in 2005?__________________

7. Recall recent dry year. What were the effects?

____

____

____

8. During the dry season do you share fresh water resources with other private or public department/sectors apart from yours?

Always ? Sometimes ? No ?

9. Do you use freshwater for agricultural activities ***(gardening is included)***?

Always ? Sometimes ? No ?

10. Estimate, how much in terms of bucket of fresh water is used per day?

Less than 5 ? Greater than 5 ?

Economic Cost

11. How much did you spend on purchasing water last year?

Less than $100 ? Between $100 & $500 ? Greater than $500 ?

12. Which month(s) did you spend most on purchasing water last year?

____

13. Give names of the places and their location where water is purchased.

____

____

____

Public Outlook

14. How do you rate your level of concern about climate and manmade induced water shortage?

Very concerned ? Moderately concerned ? Not concerned at all ?

15. How much do you consider yourself vulnerable to water shortage?

Extremely ? Somewhat ? Hardly at all ?

16. Do you think that this island is prepared to handle water shortage?

Yes ? No ?

Public Response

17. What has been done to lessen the effects of water shortage in this island

by you?

____

____

____

by your community?

____

____

____

by your country?

____

____

____

18. What has been done to worsen the effects of water shortage in this island

by you?

[***All information provided would be strictly confidential***]

____

____

____

by your community?

____

____

____

by your country?

____

____

National Response Outlook

Please indicate how much you agree or disagree with the following:

19. My government should take a stronger role to address the impacts of climate induced water shortage in the communities.

 Strongly Agree? Agree? Neutral? Disagree? Strongly Disagree?

20. I am prepared to pay a little more or put up with some inconvenience to help sustain fresh water availability.

 Strongly Agree? Agree? Neutral? Disagree? Strongly Disagree?

21. There is nothing a small island like mine can do about climate induced water shortage.

 Strongly Agree? Agree? Neutral? Disagree? Strongly Disagree?

Environmental Response

22. What has prevented action from being taken about increasing your ability to store water?

____
____
____

23. In order to enable this project to effectively meet your water resource needs, suggest action(s) that should be taken.

____
____
____
____

6.3 Appendix 3: Computational method developed by Abramowitz and Stegun (1965)

This computational method makes possible the transformation of the cumulative probability H(x) to the standard normal random variable Z.

Using the constants $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$
$d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$

where $$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad \text{for } 0 < H(x) \le 0.5$$

and $$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad \text{for } 0.5 < H(x) \le 1.0$$

then $$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for } 0 < H(x) \le 0.5$$

and $$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{for } 0.5 < H(x) < 1.0$$

6.4 Appendix 4: Average monthly rainfall data from the Bequia Station

Year:	Jan:	Feb:	Mar:	Apr:	May:	Jun:	Jul:	Aug:	Sep:	Oct:	Nov:	Dec:
1930	75.7	43.7	57.2	110.0	89.9	151.0	236.0	108.0	116.0	137.0	148.0	103.0
1931	149.0	17.8	86.1	72.1	107.0	202.0	331.0	234.0	141.0	425.0	279.0	94.5
1932	77.7	39.9	86.4	102.0	77.0	164.0	204.0	161.0	102.0	272.0	224.0	208.0
1933	140.0	65.5	82.6	129.0	81.5	235.0	219.0	282.0	325.0	164.0	305.0	55.9
1934	107.0	85.6	46.7	127.0	112.0	75.9	129.0	200.0	245.0	205.0	160.0	185.0
1935	50.5	68.6	43.4	60.5	259.0	154.0	281.0	335.0	226.0	93.2	161.0	163.0
1936	113.0	27.7	9.4	35.1	129.0	199.0	390.0	181.0	150.0	197.0	289.0	61.2
1937	236.0	30.7	26.9	62.7	1.3	137.0	120.0	110.0	84.3	230.0	236.0	139.0
1938	79.5	92.5	120.0	39.9	302.0	221.0	204.0	387.0	315.0	297.0	312.0	325.0
1939	90.9					227.0	114.0	115.0	96.8	425.0	197.0	156.0
1948			59.2	2.5	81.8	153.0	373.0	179.0	171.0	232.0	355.0	77.5
1949	22.4	76.5	22.6	29.0	104.0	96.8	55.4	150.0	253.0	291.0	273.0	174.0
1950	64.5	87.1	119.0	17.5	159.0	210.0	130.0	103.0	169.0	279.0	336.0	69.9
1951	80.5	178.0	51.1	82.3	39.4	81.0	290.0	153.0				331.0
1952		41.1	103.0	34.5	82.3	149.0	249.0	86.1	191.0	128.0	245.0	173.0
1953	64.0	17.5	44.4	26.9	226.0	171.0	280.0	156.0	279.0	215.0	231.0	211.0
1954	102.0	66.3	58.2	98.8	86.4	120.0	157.0	96.3	194.0	209.0	346.0	122.0
1955	123.0	18.8	14.2	11.4	51.6	229.0	195.0	245.0	86.6	221.0	268.0	84.8
1956	216.2	157.2	104.1	77.7	112.0	130.0	137.7	219.7	124.7	190.5	166.4	91.2
1957	66.5	29.5	26.9	113.3	26.2	31.8	77.7	122.2	89.9	84.8	61.2	160.0
1958	6.1		31.5		57.2	155.2	212.9	119.4	71.6	96.8	83.6	53.1
1959	81.3	79.5	43.9	60.2	128.5	73.4	72.9	107.7	129.0	261.6	105.7	126.5
1960	67.1		73.9	26.9	30.0	230.4	145.0	153.2	86.9	219.7		
1961	96.3	71.1	50.5	67.6	58.9	198.6	134.9	148.3	80.3	244.1	210.1	106.9
1962	97.3	53.6	0.0	5.8	26.4	143.0	184.2	303.8	214.9	179.6	68.1	46.7
1963	164.0	48.0	50.8	64.5	69.9	197.0	292.0	128.0	178.0	99.1	199.0	110.0
1964	44.7	48.0	38.1	112.0	61.5	206.0	175.0	136.0	120.0	237.0	42.2	64.5
1965	98.0	0.0	77.7	14.5	0.0	117.0	187.0	146.0	190.0	90.9	116.0	153.0
1966	16.5	102.0	76.2	41.4	107.0	246.0	176.0	299.0	367.0	263.0	136.0	185.0
1967	49.3	54.6	76.7	109.0	96.8	117.1	98.8	123.4	391.9	227.1	182.4	120.4
1968	54.6	22.1	109.2	61.0	105.2	206.0	61.0	164.3	210.8	137.7	186.9	142.7
1969	259.8	33.0	52.8	90.9	146.3	252.7	99.8	247.7	174.0	175.3	124.0	163.1
1970	75.2	33.3	54.1	34.5	77.5	299.7	366.0	215.4	179.8	183.9	166.1	217.2
1971	79.5	118.6	35.6	21.8	56.9	48.8	135.1	258.6	213.6	229.4	319.0	319.5
1972	214.4	161.5	85.6	33.5	44.5	51.8	187.5	167.1	63.5	96.0	185.9	65.8
1973	90.9	72.6	10.9	69.3	47.5	132.1	54.6	89.4	82.8	202.9	153.9	32.8
1974	64.8	53.8	88.1	19.3	277.1	57.2	137.4	86.1	149.9	178.1	211.1	100.8
1975	55.9	52.6	23.4	71.6	18.8	35.8	34.8	261.9	137.7	336.6	146.8	188.2
1976	95.5	90.2	20.8	21.8	79.5	51.3	121.7	183.6	140.2	169.4	116.3	253.7
1977	20.6	4.1	0.0	62.5	58.2	107.2	133.9	141.2	262.6	348.5	197.9	86.1
1978	48.0	0.0	54.4	49.8	50.8	268.0	271.8	284.0	182.9	229.6	167.4	99.8
1979	26.7	26.9	56.1	66.8	91.4	280.4	367.8	283.7	63.5	315.5	522.2	160.3
1980	175.5	67.6	26.7	39.1	77.5	122.4	178.1	267.5	254.3	230.6	216.4	274.6
1981	92.7	156.7	23.4	363.2	100.3	164.9	142.2	211.1	114.3	98.6	85.6	132.8
1995				18.2	25.5	168.6	0.0	204.3	120.7	148.3	121.4	22.4
1996	20.8	31.2										
1997						106.7	292.5					

6.5 Appendix 5: Average monthly rainfall data from the E.T. Joshua Station

Year:	Jan:	Feb:	Mar:	Apr:	May:	Jun:	Jul:	Aug:	Sep:	Oct:	Nov:	Dec:
1976							150.9	167.6	210.6	238.8	220.7	257.3
1979	20.4	28.9	99.8	53.0	61.0	301.0	321.0	342.0	89.0	180.0	295.0	133.4
1980	174.0	113.1	86.2	40.8	56.8	152.5	210.9	175.3	327.1	185.7	159.4	225.1
1981	128.4	150.0	40.9	301.1	142.0	200.1	232.6	200.2	103.4	74.6	198.1	263.0
1982	88.6	123.3	32.3	89.8	58.0	52.7	167.4	328.0	160.7	323.3	191.6	176.5
1983	157.2	23.8	67.9	43.7	144.2	124.2	309.8	163.0	296.0	180.6	146.3	222.3
1984	180.2	133.0	120.0	40.6	93.6	111.5	265.9	199.7	189.6	228.3	246.8	117.9
1985	113.2	94.0	90.1	101.7	110.0	157.0	243.2	236.0	156.1	399.8	248.5	238.3
1986	128.1	70.2	68.9	86.8	79.0	239.0	171.9	235.9	424.8	227.1	288.1	108.6
1987	96.1	18.5	16.7	9.5	132.3	340.6	151.5	225.6	357.8	188.8	345.4	228.4
1988	129.1	109.4	90.5	42.0	91.5	206.8	283.1	357.2	286.7	484.1	290.8	131.0
1989	119.7	14.7	238.1	91.9	30.9	107.7	276.4	176.7	278.0	176.3	218.3	207.3
1990	173.9	84.2	70.6	124.2	262.2	291.9	197.1	192.6	239.6	367.2	177.6	107.1
1991	73.0	105.7	123.9	137.5	64.8	115.2	252.7	225.2	243.3	109.6	651.1	104.1
1992	109.5	123.1	35.4	73.2	103.6	302.6	168.4	208.6	384.6	132.8	557.3	152.3
1993	211.9	67.1	109.2	46.8	211.6	185.1	224.5	176.5	346.9	153.8	249.5	62.6
1994	134.4	80.3	48.3	41.1	86.0	198.3	187.1	230.7	194.2	224.6	191.1	136.7
1995	76.1	124.2	90.2	62.8	36.1	201.5	117.1	279.2	267.7	296.3	177.8	106.7
1996	193.8	147.3	100.5	116.3	183.7	217.3	227.9	272.3	240.3	442.7	392.9	115.6
1997	115.5	72.8	68.4	41.3	47.9	211.5	265.6	138.0	228.3	144.3	169.4	91.1
1998	204.5	29.5	82.1	112.0	189.5	302.2	169.4	122.6	297.4	727.9	210.5	494.5
1999	81.6	90.2	130.3	160.7	19.6	101.2	242.8	166.3	222.9	295.5	264.7	232.9
2000	131.7	143.8	111.8	57.2	47.2	153.0	227.0	228.0	171.7	170.8	360.1	119.0
2001	68.6	80.2	18.2	44.2	89.7	75.8	329.0	281.0	168.5	381.1	58.4	210.7
2002	153.7	96.1	101.7	181.3	81.2	84.2	169.7	163.9	309.4	353.5	323.2	50.3
2003	62.0	104.0	30.7	51.2	21.4	176.0	280.5	187.5	183.6	311.1	312.0	108.4
2004	130.0	125.1	147.1	158.3	342.1	254.3	322.3	487.5	212.8	216.2	370.2	207.4
2005	200.3	51.5	69.7	78.6	227.0	502.6	337.9	101.5	115.0	457.1	442.2	229.8
2006	221.0	132.1	98.3	73.9	70.6	258.3	174.5	183.4	207.4			