CERMES Technical Report Nº 75

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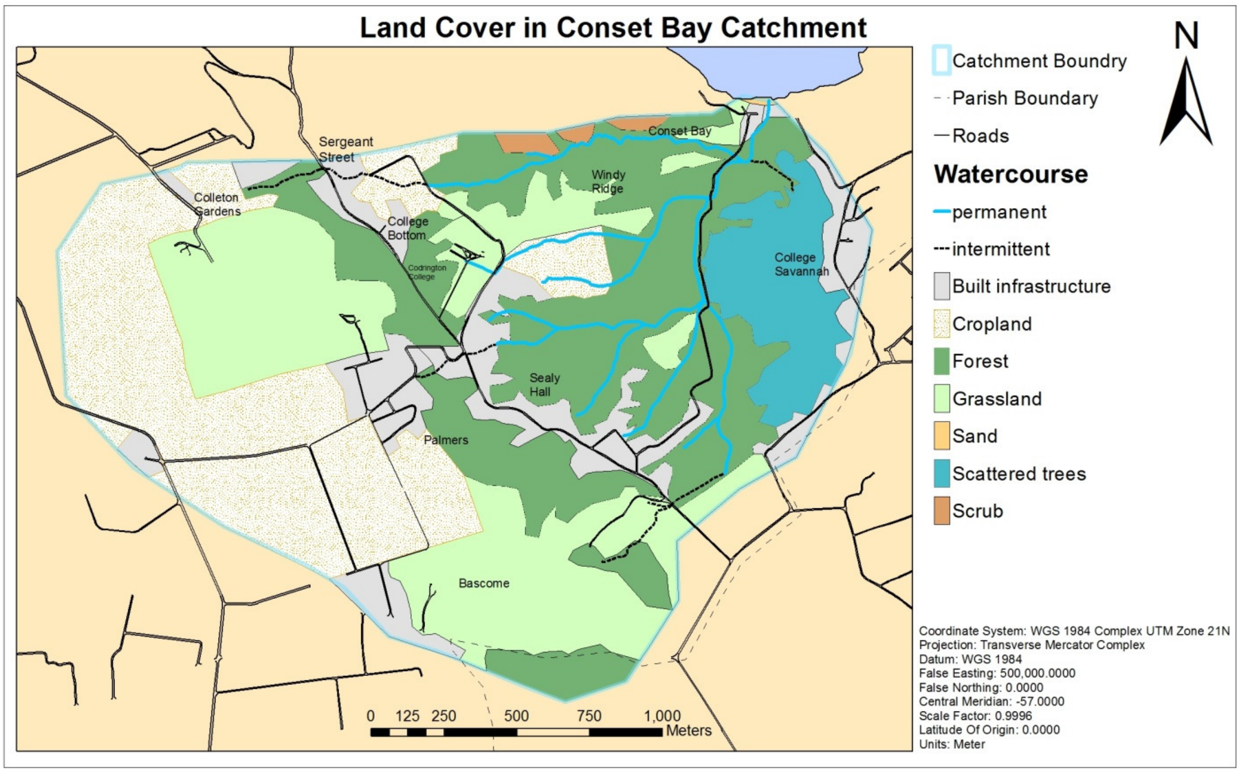

Centre for Resource Management and Environmental Studies (CERMES)
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2015

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ACKNOWLEDGEMENTS

We would like to thank Renata Goodridge for her indispensable technical expertise and assistance. Our gratitude is also due to Katherine Blackman, Neetha Selliah, Brandon Peterkin and Marium Alleyne for their help in the data gathering process.

Citation:

Gosine, T. and R. Mahon. 2014. Mapping land-use, human activities and vegetation in the Conset Bay watershed, Barbados, to determine potential sources of coastal pollution. Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados, CERMES Technical Report No 75: 49pp.

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SUMMARY

Watersheds and coastal zones in the insular Caribbean are home to some of the world's most diverse and productive land and marine ecosystems. These ecosystems act as food sources and support economic activities such as fisheries, tourism, recreation and transportation. Such ecosystems provide a number of important services including protection and stabilization of coastal areas, flood regulation, water purification and climate regulation. The capacity of these areas to provide these services is increasingly being compromised as they are subject to a number of external pressures such as pollutants and habitat destruction. Sewage, hydrocarbons, sediments, nutrients, pesticides, litter and marine debris have been identified as the land-based pollutants that pose the greatest threat to coastal and marine environments in the Caribbean. These pollutants arise from land-based anthropogenic activities lead to degradation of coastal and marine ecosystems.

The study was conducted to investigate how land-use practices might affect the quality of water entering the marine environment in Conset Bay, Barbados. This watershed highlights strong interdependencies of the terrestrial and marine environments. It also illustrates the potential for land-use to impact marine productivity. The study aims to link terrestrial activities within the watershed with possible impacts on the nearshore marine environment. In order to pursue this, land cover and land-use within the watershed were characterised using GIS tools and site surveys. The riparian vegetation distribution and spatial extent was assessed and characterised using rapid assessment techniques. Water quality data were collected and analysed for microbial levels, nutrient levels and physical water quality parameters. An activities survey was also conducted to gain a comprehensive understanding of how the location is utilised.

The water quality data collected from the Conset Bay watershed suggest that levels of microbial and nutrient pollutants entering the marine environment are higher than the prescribed discharge standards. The data show the major land covers to be primarily forest (30%), grassland (24.6%) and cropland (25.1%) with a small portion of built infrastructure (12.8%). The major land-uses were natural vegetation (62%), agriculture (26%) and residential (12.3%). Eleven types of riparian vegetative cover were found within the catchment. Riparian vegetation exists throughout the majority of stream network where only 5% flowed through built-up areas and bare ground. Closed forest was the most common representing 61% while open forest made up 20%. Grassland and cultivated land made up 4% and 3% respectively. Scrub and marshy grassland made up 1% each. The main activities cited by respondents as taking place in Conset Bay itself included swimming (20%), fishing (20%), farming (15%), fishing in rivers for crayfish bait (10%) and kayaking (5%) while a small number of respondents utilise the streams directly for irrigation of crops and crayfishing.

1 INTRODUCTION

The expansion of the world's population primarily in coastal regions, coupled with environmental stressors created by economic growth and climate change create complications in addressing marine conservation (Miloslavich et al. 2010). Industrial activities, agriculture, sewage and solid waste have all led to the rapid increase in input of contaminants and nutrients into watersheds and coastal areas resulting in the degradation of coastal ecosystems (Yang and Zhi 2005).The vital ecosystem goods and services that watersheds and coastal areas provide make it evident that these areas need to be protected and managed in a sustainable manner. Already these environments are subject to terrestrial and marine biodiversity loss, uncontrolled development, coastal erosion and pollution such as aquifer and surface water quality degradation (UNEP et al. 2002).

Watersheds and coastal zones in the insular Caribbean are home to some of the world's most diverse and productive land and marine ecosystems. The region is home to approximately 13,000 plant species 50.4% of which are endemic to the islands (UNEP 2010). It also houses the highest concentration of marine species in the Atlantic Ocean making it a global hotspot of marine biodiversity (Miloslavich et al. 2010). This diversity often occurs in watersheds and coastal areas which are home to unique complex ecosystems such as coral reefs, sea-grass beds, mangroves and river deltas (UNEP 2010). As essential ecosystems they provide a myriad of ecosystem functions that benefit human wellbeing. These ecosystems act as food sources and support economic activities such as fisheries, tourism, recreation and transportation (UNEP et al. 2002). Such environments are important for a number of factors including protection and stabilization of coastal areas, flood regulation, water purification and climate regulation (Millennium Ecosystem Assessment 2005; UNEP 2010). The capacity of these areas to provide these functions is increasingly being compromised as they are subject to a number of external pressures. For example two thirds of the Caribbean's coral reefs are under threat as a result of coastal development, sedimentation, water acidification, overfishing and toxic chemicals. Already 30% of coral reefs have been destroyed or are under threat, while 20% more is expected to be lost over the next 10-30 years (Burke and Maidens 2004; Sherman and Hempel 2009).

Pollution enters the marine environment in many ways. These include atmospheric deposition, marine-based sources from ships and marine structures, and land-based sources which are the topic of this study (UNEP-CEP 2001). Land-based sources of pollution can reach the sea either directly at the coast or through rivers. Pollutants fall into two categories; point sources and non-point sources. The former characterises pollutants entering the coastal environment at one definitive location such as the release of industrial effluent or discharge from sewage treatment plants while the latter enters via mediums such as storm water runoff, overflow discharges subsurface infiltration or surface run off (UNEP-CEP 2001). Pollutants such as sewage, oil, hydrocarbons, sediments, nutrients, pesticides, litter and marine debris and toxic waters have been identified as the land-based pollutants that pose the greatest threat to coastal and marine environments in the Caribbean (UNEP-CEP 2001). Land based anthropogenic activities have been found to cause degradation of coastal and marine ecosystems in Barbados (Leitch and Harbor 1999). Changes over time to the landscape such as removal of vegetation cover, intensive farming practices and anthropogenic by-products such as sewage and solid wastes have impacted the coastal and marine environment (Arriola 2008). This paper focuses on land based sources of pollution entering the marine environment through coastal watersheds; in particular non-point source pollutants. By identifying the locations, types and quantities of pollutants, efforts can be made to mitigate and control pollution effects.

The Conset Bay watershed was chosen for this study to complement the pilot project "Upscaling Sustainable Resource Management in Coastal Watershed Communities of Barbados' National Park and System of Open Spaces" (Conset Bay Pilot Project). The project was conducted by the United Nations Environment Programme (UNEP), the Ministry of Environment and Drainage of Barbados, together with the Centre for Resource Management and Environmental Studies (CERMES) from the University of the West Indies (UWI), Cave Hill. This pilot project is part of a broader project "Strengthening National Capacities for Sustainable Resource Management in Latin America and the Caribbean". One of the main goals of the project is to improve management and monitoring of nearshore marine and terrestrial natural resources within coastal watershed areas. The Draft/Preliminary State of the Environment Report (SER) addressed this goal and provides a baseline study on the Conset Bay watershed environment (Selliah et al. 2012).

The current study was conducted to investigate how land-use practices might affect the quality of water entering the marine environment in Conset Bay. The study aims to link terrestrial activities within the watershed with possible impacts on the nearshore marine environment. In order to pursue this, land-use and human activities within the watershed, the distribution of riparian vegetation and water quality are assessed.

Conset Bay and its surrounding communities have close ties with the terrestrial and marine habitats in the area through agriculture, fishing and recreation. Many of the residents rely on the marine environment for their livelihoods and as well as utilise the land for small-scale farming (Selliah et al. 2012). The importance of these environments to the local community is evident as well as their understanding of the connection between land-based activities and their impacts. Residents of the area have expressed concern about land-use affecting marine habitats and marine productivity (Cumberbatch and Simmons 2010).

Fisheries is a significant part of Conset Bay history. It is one of the eight primary landing sites on the island, and is currently the 4th most important landing site (Selliah et al. 2012). The Bay is also a key sea egg fishing area as well as a recreational fishing site (Selliah et al. 2012). Conset Bay supports a variety of marine life including reef fish such as the rarely seen rainbow parrotfish and groupers whilst it also acts as a feeding area for endangered green turtles (Selliah et al. 2012). Degradation of the reef system is evident in the form of coral bleaching and there is a noted reduction in abundance of reef fish (Selliah et al. 2012). Siltation from the Conset Bay River has also been observed to be affecting the reef and resulting in shallowing of the nearshore region (Cumberbatch and Simmons 2010).

The Conset Bay watershed is drained by a number of streams that empty into Conset Bay River which ultimately empties into Conset Bay. These rivers and streams flow through a mix of land-uses within the watershed, transporting surface runoff. It has also been noted that a large number of households within the area utilise toilet facilities that empty into soakaways; this can allow nutrients and other chemicals to leach into groundwater which may reach streams (Selliah et al. 2012). The hydro-geologic environment and topographic nature of the area suggest low permeability of underlying rock together with steep drainage flow paths. These paths flow directly into the sea and create an avenue for pollutants to enter coastal waters (EPG et al. 2004a). The district is also prone to slippage and high levels of erosion (EPG et al. 2004a). The coupling effect of the existing conditions can lead to adverse changes in water quality, increase in water volumes, eutrophication, increased turbidity and sedimentation, all of which contribute to degradation of the marine environment (Caribbean Environmental Health Institute 2008).

The area highlights strong interdependencies of the terrestrial and marine environments. It also emphasizes the potential for land-use to impact marine productivity. Mapping areas such as the Conset Bay watershed can inform resource managers and communities of current conditions in the watershed and allow for more informed decision-making and management actions.

This study focuses on mapping of a coastal watershed to:

- Characterise land cover and land-use within the watershed using GIS tools;
- Assess and characterise riparian vegetation distribution and spatial extent within the watershed;
- Identify potential sources of pollutants entering the coastal area via the watershed due to land-use and other human activities within the area.

2 BACKGROUND

2.1 Land-use/land cover impacts on watersheds

Land cover relates to a physical description of space; it is defined as the observed (bio) physical cover of the earth's surface (Di Gregorio and Jansen 2000; European Communities 2001). It is that which is spread over the surface covering the ground. Using this definition, various biophysical categories can be illustrated. Some of these include areas of vegetation such as trees or fields, areas of bare soil, hard surfaces such as rocks or buildings and wet areas and bodies of water such as sheets of water, watercourses and wetlands (European Communities 2001).

Land-use is described by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (Di Gregorio and Jansen 2000). This definition creates a link between land cover and the utilisation of surroundings by individuals (Di Gregorio and Jansen 2000). A sequential approach to land-use which has been developed specifically for agricultural purposes, relates land-use to the interaction of the human element with the natural environment with the intention to obtain products and/or benefits through using land resources (Mucher et al. 1993). However, from a functional perspective it refers to the description of areas in terms of their socio-economic purpose, whether this may be residential, industrial or commercial, agricultural or conservational (European Communities 2001).

Whereas land cover may be observed by different methods, attempts to observe land-use on its own would be a challenge. Difficulties are likely to occur as the decision-making process for the use of land cover may require information which may not be readily available from a single “source of observation”, such as by the human eye or aerial photographs (European Communities 2001). It was noted in the 2001 European Communities Report on Concepts of Land Cover and Land-use Information Systems that whilst using a functional approach to land-use, inference of land cover may be helpful, a sequential approach would often require a more in-depth collection of various attributes (European Communities 2001).

A watershed may be defined as an area in which water, sediments and dissolved material drain to a common outlet such as a river, lake, bay or ocean (Environmental Protection Agency 1998). A drainage basin refers to the area drained by a river and its tributaries; it is delineated by its watershed (Smithson et al. 2008). The region enclosed by the watershed is referred to as the drainage area or catchment area and is the fundamental land surface that produces river flow (Smithson et al. 2008). Drainage basins can be considered environmental systems having both inputs (precipitation and ground water flowing into the catchment) and outputs (discharge, evaporation, transpiration and any ground water that flows out of the catchment through the rock) (Smithson et al. 2008). Water enters the drainage basin through precipitation some of which enters water courses directly, some falls onto leaves and other surfaces which prevent it from reaching the surface of the land (interception) while the remainder falls directly unto the land surface. Initially in dry conditions water will be absorbed by the soil, referred to as infiltration, water may then enter underlying rock where it is stored as groundwater. Once groundwater stores are filled with water, further infiltration leads to the overlying soil becoming filled with water (soil water) this is utilised by plants and soil organisms. When saturated further, precipitation results in sheets of surface water washing over the water logged soil directly into water courses known as overland flow as well as downward through the soil and into underlying rock; lateral flow also occurs within the soil (throughflow) and the rock (baseflow). All these flows eventually reach water courses unless they are taken up by biota or water is removed by evaporation. Flows reaching the watercourse together with the channel precipitation contribute to the total river flow and are transferred downstream to the point of discharge from the drainage basin (Smithson et al. 2008).

The impacts of land-use on water resources within a watershed are dependent on several factors. Physical factors include topography, soil structure and climate. Socio-economic factors may include economic ability and awareness of farmers, management practices and infrastructural development (Kiersch 2001). The need for change in land cover from forested lands to croplands, housing, pastures, plantations and other built environments stems from the growing demands of populations for food, water, shelter, goods and services as well as developmental policy shifts (Foley et al. 2005; Stonestrom et al. 2009).

In the insular Caribbean, land space is limited and the majority of development and expansion is concentrated on the islands' coasts. Increased human development in coastal watersheds can be detrimental for nearshore environments as growth in coastal areas is a major contributor to changes in hydrology and the level of non-point source pollution (Tang et al. 2005). Non-point source pollution can be attributed to a number of land-based activities though it is difficult to define the specific location at which the pollutant enters the waterways (Enivronmental Protection Agency 1994). For example agricultural land has been known to introduce pollutants such as nutrients, chemicals and sediment into riverine systems through surface runoff while urban areas have been known to contribute heavy metals and rubber fragments to run off (Tong and Chen 2002). Built up areas can also contribute to an increase in storm water discharge due to changes in permeability of the ground surface (Basnyat et al. 2000).

2.1.1 Land-use and watershed scale

Land-use in watersheds has been noted to have an observable impact, especially in smaller watersheds. The impacts of land-use decrease as watershed size increases due to offset effects such as storage capacity of the river bed and the self-cleaning capacity of the river (Kiersch 2001).The spatial dimensions of land-use effects are summarised in Table 1.

Table 1 Spatial dimensions of land-use impact with regard to basin size

Impact Type	Basin Size km^2						
	0.1	1	10	100	1,000	10,000	100,000
Average flow	×	×	×	×	-	-	-
Peak flow	×	×	×	×	-	-	-
Base flow	×	×	×	×	-	-	-
Groundwater recharge	×	×	×	×	-	-	-
Sediment load	×	×	×	×	-	-	-
Nutrients	×	×	×	×	×	-	-
Organic matter	×	×	×	×	-	-	-
Pathogens	×	×	×	-	-	-	-
Salinity	×	×	×	×	×	×	×
Pesticides	×	×	×	×	×	×	×
Heavy metals	×	×	×	×	×	×	×
Thermal regime	×	×	-	-	-	-	-

Legend: × = Observable impact; - = no observable impact .Source: (Kiersch 2001)

2.1.2 Land-use/Land cover and water quantity

Land-use and vegetation cover changes in watersheds can have severe effects on the volume of water available for ecosystem function and human use (Mustard and Fisher 2004). These effects can be long-term as seen in the permanent increase in annual water yield when forested lands are transformed to agricultural lands; these increases range from 140 to 500 mm per year (Parés-Ramos et al. 2012; Bruijnzeel 2004). Variation in vegetation coverage and type can alter ground characteristics, water balance, hydrologic cycle, and the surface water temperature via evapotranspiration, interception of rainfall, infiltration capacity of soils, percolation and absorption (LeBlanc et al. 1997). Evapotranspiration together with vegetation cover both link land-use changes to hydrological processes (Fohrer et al. 2001). Evapotranspiration is the combined loss of water to the atmosphere through evaporation of water from soil or plant surfaces and transpiration of plants through stomata (Hatfield and Prueger 2011). Vegetated landscapes display higher rates of evapotranspiration compared to un-forested areas as a result of a higher level of canopy interception and transpiration (Lawton et al. 2001; Kiersch 2001; Bosch and Hewlett 1982). During dry conditions roots allow vegetation to access water within the soil, with deeper rooted forest cover promoting a greater level of transpiration as compared to shallower rooted short crop cover. Evapotranspiration loss in Barbados ranges from 1,016 mm to 1,422 mm annually (EPG et al. 2004a). Evapotranspiration is a key component in determining mean surface run off; the type of vegetation present also plays a significant part in this. Bosch and Hewlett's review of 94 catchment experiments concluded different vegetation types have varying influence on water yield where coniferous forests and deciduous hardwood trees had a greater impact in reducing yield than brush and grasses (Bosch and Hewlett 1982). Frequent conversion from one land-use to another is common in the tropics as lands are quickly altered from a vegetative state to agricultural and pastoral. Such lands are often eventually left abandoned. Whilst afforestation is commonly viewed as a solution to revitalizing these deforested areas, restoration from the effects of human influence on overall water balance can take months to centuries (Susswein et al. 2001)(Table 2).

Table 2 Impacts of land-use and their recovery time

	Cause and effect of disturbance	Terms of water balance affected	Recovery time
Trees	Logging and fire reduce tree cover	Interception and transpiration	Water use can recover in 1-3 years, Leaf Area Index and interception in 4-10 years, tree biomass will take decades and species composition a century or more
Forest Soil	Compaction, decline of infiltration rate due to loss of macropore formation	rate of surface infiltration, percolation and subsurface lateral flow, surface evaporation	Surface permeability can be restored in <1 year, soil macroporosity may take decades
Forest Landscape	Paths, tracks and roads lead to quickflow, levelling and swamp drainage reduces surface buffer storage capacity	Time available for surface infiltration, percolation and subsurface lateral flow	Channels can be closed and surface roughness restored rapidly through specific actions

Source: (Susswein et al. 2001)

By decreasing vegetation within a watershed the resulting increase in runoff can lead to an increase in base flow (Parés-Ramos et al. 2012). Calder (2000) argues that the effects on base flow is principally site specific and relies on other simultaneous mechanisms taking place such as evapotranspiration and the infiltration capacity of the soil (Kiersch 2001).

Peak flow which occurs during periods of intense rainfall may be impacted if soil infiltration capacity is affected by land-use changes (Kiersch 2001). In areas where soils are compacted or there are alternative drainage paths such as roads and trails, storm peaks increase and streams rise and fall more quickly having prominent downstream effects on watersheds less than 100 km^2 in area (Parés-Ramos et al. 2012). The effect of land-use changes on groundwater recharge may vary dependant on evapotranspiration rates of prevailing vegetation cover and infiltration capacity of the soil (Kiersch 2001).

In Barbados, the woody vegetation found on the island is "subtropical or tropical, ranging from xeric forests and shrub lands to semi deciduous, seasonal evergreen or evergreen forests including cloud forests" (Helmer et al. 2008:3). In the Conset Bay area, the vegetation is predominately deciduous, evergreen coastal and mixed forest or shrub land with or without succulents (Helmer et al. 2008). The second most common type of land cover is pasture or inactive agricultural land and bare soil. There are also pockets of semi-deciduous and drought deciduous forest of high-medium or low-medium density, as well as drought deciduous open woodland (Helmer et al. 2008).

2.1.3 Land-use and water quality

Water quality is one of the key environmental indicators of the health of a watershed. It ties together the interaction between the hydrological, geomorphic and biological processes and changes in these processes that influence the prevailing water quality (Basnyat et al. 1999). Water quality in itself is a function of either or both natural influences and human activities (Carr and Neary 2008). As a result land-use and land cover characteristics can have profound effects on the prevailing water quality in a watershed. Land-use and water quality have been inextricably linked through watershed hydrology, sediment influx and chemical loads (Basnyat et al. 1999; Basnyat et al. 2000). Changes in land-use from natural vegetation to agriculture or other human uses can result in an increase of pollutants in surface run-off and in turn an increase in nonpoint source pollution (Maillard and Pinheiro Santos 2008). These changes alter water quality in rivers and streams, lakes, wetlands, coastal areas and groundwater by introducing pollutants such as:

- Excess fertilisers, herbicides and insecticides from agricultural lands and residential areas
- Oil, grease and toxic chemicals from urban runoff and energy production
- Sediment from improperly managed construction sites, crop and forest lands and eroding stream banks
- Salt from irrigation practices and acid drainage from abandoned mines
- Bacteria and nutrients from livestock, pet wastes and faulty septic systems

(Enivronmental Protection Agency 1994).

Sediment enters waterways through natural processes as well as through a variety of human activities such as agriculture, forestry, mining and urbanisation (Carr and Neary 2008). Increase in sediment load is associated with the removal of vegetation, channelisation of rivers, and removal of natural land cover/ replacement with built land cover such as roads (Carr and Neary 2008).

The nutrient levels of nitrogen and phosphorus in watersheds can be affected by changes in land-use and vegetation cover. Deforestation can contribute to higher nitrate levels due to a reduction in uptake by plants or decomposition of organic material (Kiersch 2001). Changes in land-use from forested areas to arable lands can also contribute to higher nutrient levels in water ways (Kiersch 2001).

Knowledge about land-use and land cover can be instrumental in addressing issues of water resource management, flood prediction, soil degradation and nutrient loss. Landscape level environmental indicators such as watershed land cover/use and riparian buffer zones can provide quantitative estimates of coastal and estuarine habitat conditions and trends (Klemas 2001). Basnyat et al (1999) examines the relationship between mixed land-use and non-point source pollution on the water quality of streams. The models link three different spatial scales of land-use and land cover in a watershed; the entire basin, the contributing zone defined for each stream based on a number of characteristics and the riparian zone given by the proportion of stream length occupied by each vegetation cover type. The contributing zone is identified as the area surrounding a stream that as a result of land-use practices and other human activities contributes nutrients and other non-point source pollutants to surface and subsurface waters and in turn streams (Basnyat et al. 1999). The study suggests forests are a transformation zone; as the proportion of forest area increases within the contributing zone, nitrate levels downstream will decrease. The study also suggests a significant relationship between water quality and riparian zone land-use where non-invasive land-use has a positive effect on water quality while more intensive uses such as agriculture and built-up areas impact negatively.

2.1.4 Riparian vegetation in watersheds

Riparian vegetation is defined as “plants and communities adjacent to and affected by surface or groundwater of perennial or ephemeral water bodies” (James and Barnes 2011). The exact extent as to what is considered “riparian” is undefined. Lowrance et al. (1985) define riparian buffers as:

> "a complex assemblage of plants and other organisms in an environment adjacent to water. Without definite boundaries, it may include stream banks, floodplain, wetlands as well as sub-irrigated sites forming a transitional zone between upland and aquatic habitat. Mainly linear in shape and extent, they are characterized by laterally flowing water that rises and falls at least once within a growing season".

Riparian vegetation forms a buffer which defends against bank erosion, upholds water quality and shelters stream ecosystems (Osmond et al. 2002). These buffers exist in various land-use types ranging from urban to forest and can consist of grasses, shrubs, trees or mixed vegetation (Osmond et al. 2002). Dosskey et al. (2010) gives a detailed review of the processes by which riparian vegetation regulates stream water quality as well as the ways different vegetation types affect riparian vegetation functions. It is important to note the role riparian vegetation plays in protecting streams from non-point source pollution by improving water quality through direct and indirect processes. This understanding is vital to effectively use prevailing vegetation condition as a gauge of water quality protection and to determine ways to improve water quality through restoration (Dosskey et al. 2010).

2.2 Water quality

Water quality is of utmost importance for aquatic environments to support life and sustain biodiversity. The physical, chemical and biological composition of water and its availability affect the ability of aquatic environments to sustain healthy ecosystems: as water quality and quantity are eroded, organisms suffer and ecosystem services may be lost (Carr and Neary 2008). Various requirements exist for water quality depending on its use, for example requirements for drinking water quality may be more stringent than for recreation, agriculture and industrial uses. As water quality diminishes the volume of water available for sustaining life diminishes (Carr and Neary 2008). Such changes in environmental quality may be concomitant with water quality parameters such as sediment load, nutrient concentrations, temperature, dissolved oxygen levels, and pH (Carr and Neary 2008). Other pollutants such as naturally occurring or synthetic compounds such as oil and grease, pesticides, mercury and other trace metals, and non-metallic toxins (Polycyclic aromatic hydrocarbons, PAHs and Polychlorinated biphenyls, PCBs) are dangerous to biota and humans (Carr and Neary 2008). It can then be seen that water quality in coastal ecosystems is of great importance when assessing ecosystem health.

Sediment within the water ways can have physical and chemical impacts on water quality and aquatic ecosystem health. Excess sediment in water ways have negative effects on turbidity of streams reducing the amount of sunlight penetration (Carr and Neary 2008; Kiersch 2001; Osmond et al. 2002). Increased sediment load in rivers and streams can have negative downstream effects on agricultural lands and irrigations systems (Kiersch 2001). Moreover siltation is a major issue associated with increased sediment influx as it may result in reduction of reservoir capacity, smothering of coral reefs and loss of spawning grounds for aquatic life (Carr and Neary 2008; Kiersch 2001; Osmond et al. 2002). Sediment may also bring entrained with it absorbed chemicals such as metals, phosphorus and hydrophobic organic compounds (Kiersch 2001). Increased sediment influx also negatively affects property values, recreational uses such as boating, swimming and fishing, as well as navigation (Osmond et al. 2002).

Nutrients such as phosphates and nitrogen enter waterways resulting in harmful effects for both humans and aquatic ecosystems. Phosphates enter streams most often through surface runoff attached to sediments, while organic forms of nitrogen can enter water ways through surface flow attached to sediments, as part of organic matter or through subsurface flow by forming nitrate-nitrogen; a mobile form of nitrogen that readily moves with soil water (Osmond et al. 2002). Excess of these nutrients can have detrimental effects on primary production in the marine and freshwater ecosystems resulting in eutrophication, algal blooms, reduced transparency and fish kills (Martin et al. 2001; Osmond et al. 2002). The algal blooms can lead to loss of aquatic plants that require high levels of oxygen and in turn a loss in biodiversity (Carr and Neary 2008). Groundwater may also be affected as surface water may percolate into groundwater aquifers. The process of eutrophication can pose severe consequences for human health as it can result in the production of cyanobacterial toxins in the water (Carr and Neary 2008). Eutrophication can also result in the infilling of irrigation channels, loss of recreational areas due to slime, weed infestations and noxious odours and economic losses due to the disappearance of species targeted in commercial and sport fisheries (Carr and Neary 2008).

Bacterial contamination occurs as a result of run-off from animal waste, septic tank systems, soakaways and discharges from waste-water treatment plants. Microbial pollution poses severe health risks or even death to humans and livestock due to microbial pathogens (Carr and Neary 2008). High levels of microbial pollution can also impact tourism and the fishing industry as it may result in the closure of beaches and contamination of filter feeders (Carr and Neary 2008; Osmond et al. 2002).

Barbados has established The Marine Pollution Act Proposed Discharge Standards seen in Appendix 1 (Environmental Protection Department 2004). The Environmental Protection Department (EPD) conducts weekly sampling at 19 beaches on the North, South and West Coasts of Barbados (Environmental Protection Department 2011). The samples are analysed for enterococci and faecal coliform organisms at the Sir Winston Scott Polyclinic Laboratory, with quality standards determined by the proposed Marine Pollution Control Discharge Standards. Information such as beach and water debris, cloud cover, rainfall data, sea conditions, air and water temperatures and bather density are also collected (Environmental Protection Department 2011). However this monitoring programme has not yet been expanded to include Conset Bay or any other part of the east coast of the island (Selliah et al. 2012). No historic water quality data were found for Conset Bay (Selliah et al. 2012).

2.3 Benthic reefs ecosystem

Selliah et al. (2012) give a detailed account of the benthic marine environment as described by a Conset Bay fisherman. The area provides a nursery for juvenile fishes, sea cats (octopus) and sea eggs (*Tripneustes ventricosus*). The reef also provides an environment for parrotfishes, angelfishes, grunts, crevale, snappers, surgeonfishes, groupers, triggerfishes, filefishes, horse-eyes, jacks, tabios and rainbow parrotfish (Selliah et al. 2012). The coastal benthic habitat in Conset Bay is diverse comprising of sea-grass beds, hard coral, patch reefs and bars, brown algal pavements, coral rubble and the gorgonian pavements as shown in Table 3 (Selliah et al. 2012).

2.4 Existing institutional and policy framework

The Coastal Zone Management Unit (CZMU) and the EPD are the bodies responsible for the marine and coastal environment in Barbados. EPD is also responsible for the environmental monitoring and pollution control of the land, air and water in the island (Environmental Protection Department 2013). The Marine Pollution Control Act (1998) serves to, “prevent, reduce and control pollution of the marine environment of Barbados from whatever source”. The legislation was enacted to facilitate action against progressively deteriorating coastal water quality in some locations as a result of increased infrastructural development in coastal areas over the past 30 years.

Table 3 Coverage of benthic habitat in Conset Bay

Composition of the benthic habitat in Conset Bay Rank	Type	Area Covered/ m2
1a	Bare sand	2,800,000
1b	Bare sand	27,950,000
2	The Gorgonian Pavement	13,240,000
3	Brown algal pavement	2,130,000
4a	Large Sea grass Patch	80,000
4b	Smaller Sea Grass Patch	70,000
5	Coral rubble	950,000
6	Hard coral	20,000

Source: (Selliah et al. 2012)

The CZMU was developed from the Coastal Conservation Project in 1983. It was officially established in 1996 performing a variety of coastal management functions such as coral reef monitoring, updating the inventory of coastal resources, consultations with the Town and Country Development Planning Office (TCDPO) regarding all coastal development, beach erosion and accretion monitoring and control, updating the inventory of coastal structures, regulation of marine research, public education of ICZM, coastal conservation project designs and management, and the review of any coastal projects.

The Coastal Zone Management Act (1998-39) provides for a more effective management of the coastal resources of Barbados, for the conservation and enhancement of those resources. The Act specifically deals with the preservation and enhancement of marine areas, beach and coral reef protection. CZMU also presides over the designation of marine protected areas and marine parks. The Act also provides the legal basis for the preparation of the Coastal Zone Management Plan. An Integrated Coastal Management Plan for the Atlantic (East) and Caribbean coast (west and south coast) of the island has been prepared. The plan provides for the conservation and management of coastal and marine biodiversity. It provides for the conservation and management of Natural Heritage Conservation Areas (OS 2) and Coastal Landscape Protection Zones (OS 3) established under the Physical Development Plan.

In addition, the Environmental Management and Land-use Planning for Sustainable Development Project completed in 1998 sought the development of a draft 1998 Environmental and Natural Resources Management Plan. The Plan proposed a number of institutional changes for a more streamlined and integrated approach to natural resources management. It also embodied the Draft Environmental Management Act which provides for the wise and sustainable use of the natural environment and resources of Barbados. The draft has been in existence since the early 2000's (Selliah et al. 2012).

The terrestrial environment is steered by various legislations and regulatory provisions. The National Physical Development Plan makes provisions for the establishment of a National Park and System of Open Spaces (NPSOS) to ensure the protection and conservation of natural and cultural assets, while supporting the socio-economic development of communities within the park boundaries (Selliah et al. 2012). The NPSOS consists of six open space categories (Selliah et al. 2012):

- OS 1-The Barbados National Park-International Union (IUCN) Category 5 Protected Landscape/Seascape (entire area of National Park)

- OS 2-National Heritage Conservation Areas
- OS 3-Coastal Landscape Protection Zone
- OS 4-Public Parks and Open Spaces
- OS 5-National Attractions
- OS 6-Barbados National Forest Candidate Sites

The objectives of the NPSOS are to encourage landscape preservation, ensure the conservation of natural areas, fulfil the recreational needs of residents of Barbados and improve facilities for residents and tourists alike (Government of Barbados 2003). The Natural Heritage Department (NHD) of the Ministry of Environment and Drainage in charge of the NPSOS, focusing particularly on OS 1 and OS 4 (Selliah et al 2012). The Conset Bay watershed is situated within the Barbados National Park and as a result development and activities within the area fall under the purview of NPSOS restrictions.

3 STUDY AREA

The Conset Bay watershed study area was delineated using watershed mapping data from the Gully Ecosystem Management Study (EPG et al. 2004b)(Figure 1). The watershed data were verified using a topographic contour map of the area. Conset Bay is located at 13.179783° N and 59.465883° S and as defined by the Gully Ecosystem Management Study of 2002, is situated on the Atlantic Coast of Barbados on the eastern side of the island in the Parish of St John. The watershed includes the communities of Conset Bay, St. Marks, College Savannah, Sealy Hall and Sargeant Street (Figure 2). It covers approximately 3.9 km^2 and is located on the southern boundary of the Barbados National Park as seen in

Figure 3 (Government of Barbados 2003). According to the Physical Development Plan (2003), the use and management of the land and marine resources within the Barbados National Park should be of a sustainable manner and also supportive of the social and economic development of the local communities (CERMES 2012).

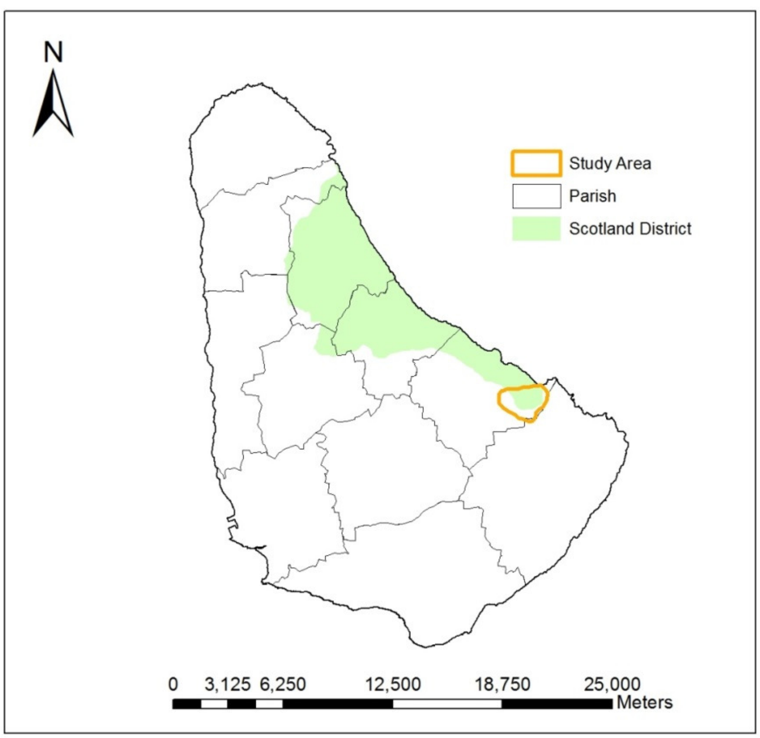

Figure 1 Location map of Conset Bay catchment

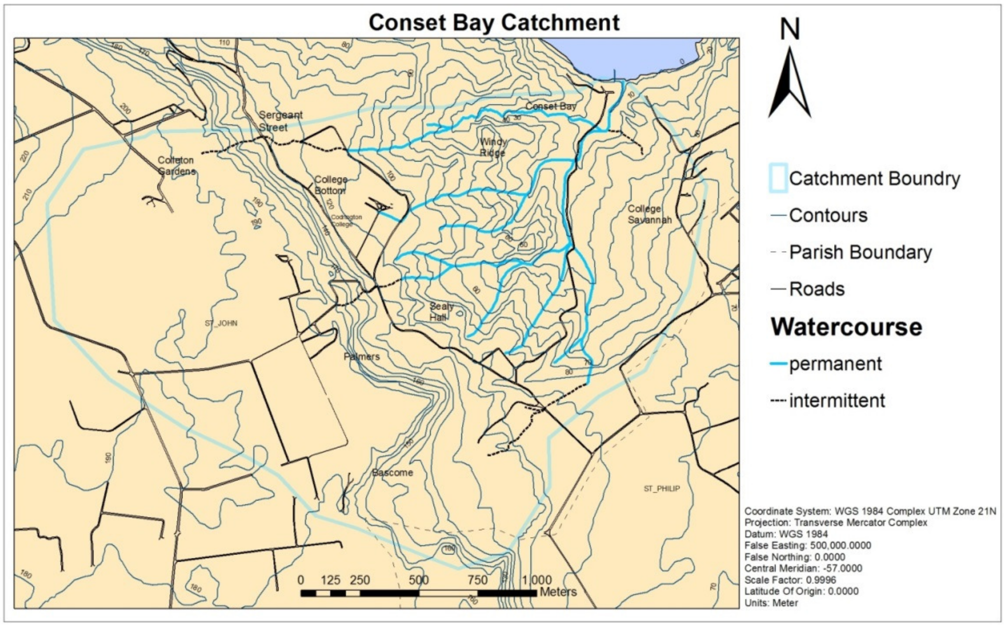

Figure 2 Conset Bay catchment, watercourses and communities

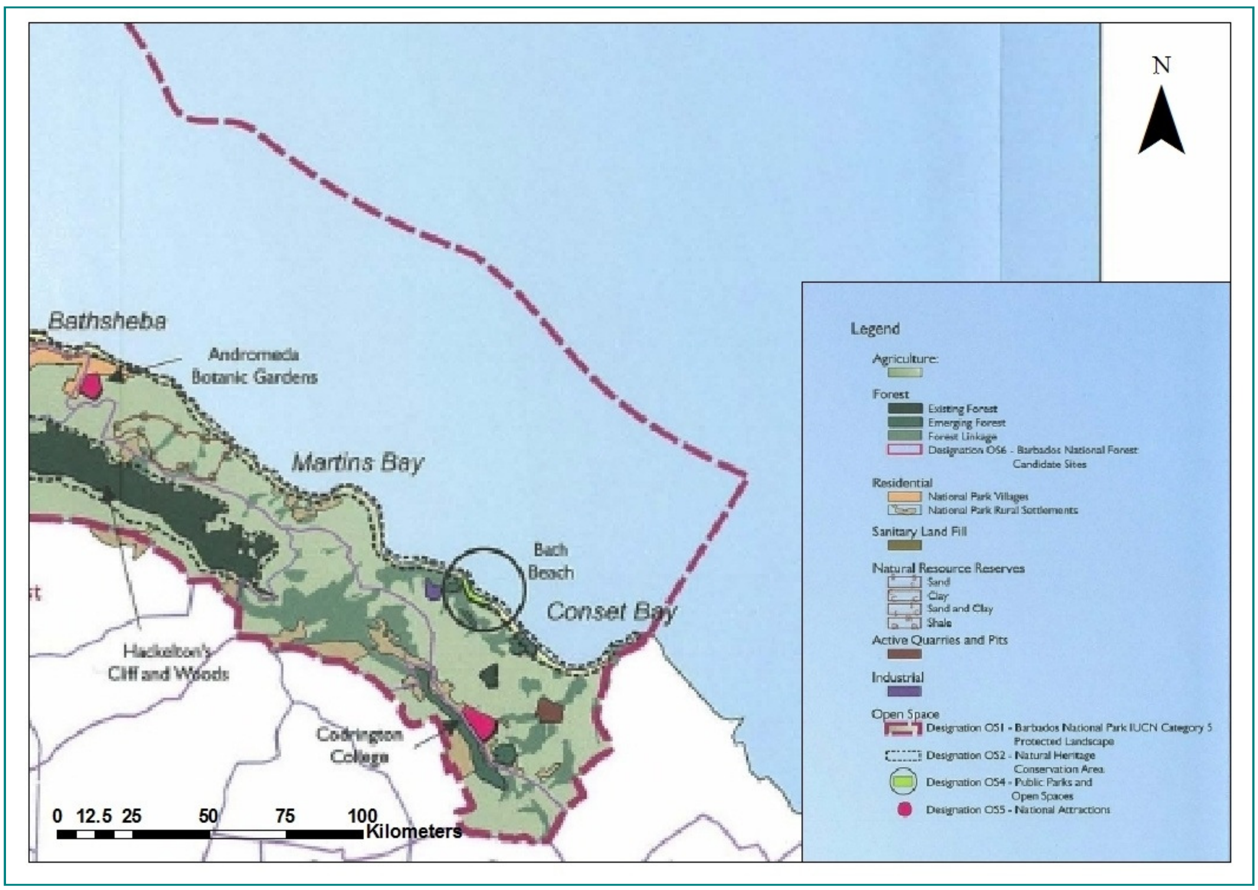

Figure 3 Location of Conset Bay within the Barbados National Park (Government of Barbados 2003)

3.1 Geological setting

Barbados is formed as part an accretionary prism above the subduction zone of the South American Plate and the Caribbean Plate (Quinlan 2008). It is mainly composed of sedimentary rock with 85% of the island covered by a Pleistocene coral reef limestone cap; the remainder is a layer of tertiary rock of marine origin which outcrops in the northeast of the island. This area is referred to as the Scotland District and comprises two formations; the Scotland formation and the Oceanic formation. Conset Bay lies on the edge of the Scotland District (**Error! Reference source not found.**) and comprises six bed deposits (Figure 4):

- Coral rock and middle reef terraces
- Upper reef terraces
- Head and scree
- Marine beach and modern dune deposits
- Oceanic group undivided
- Joe's Rivers beds (Post Mid Miocene)

The coral limestone formation reaches 150 m in depth; it is very porous and so allows rapid infiltration of rainfall (Soil Conservation Unit 2010). The Oceanic group is made up of marly beds several hundred metres thick. When exposed to the surface they appear white and while compressed and waterlogged they appear blue-gray (Soil Conservation Unit 2010). Scotland Formation comprises alternating beds of clay and sand several thousand metres in depth; the lower regions are clayey while the upper regions are sandy (Soil Conservation Unit 2010). Joes River Beds (muds) are up to 150 m deep and consist of variable sandy and clayey silt usually with oil deposits (Soil Conservation Unit 2010).

3.2 Topography

The terrain consists of steep V-shaped valleys formed as a result of erosion of underlying mud, sand, clay and shale. According to EPG et al. (2004), the slope of the eastern coast is about 1% to 3%. The east coast region contains a number of gullies with short flow paths and the resulting catchment areas are small and separated by a series of west to east ridges as is the case in the Conset Bay watershed (EPG et al. 2004a). The gullies that lie within the watershed have been characterised as shallow with a depth of 0-4 m while others have been classified as intermediate, measuring 4-15 m (EPG et al. 2004a). The communities within the area lie approximately 20-100 m above sea level and are primarily concentrated at the top of the ridges.

The map in Figure 5 shows the categories of the land capability and planning guide within the Conset Bay watershed. Areas located at the top of the ridges adjacent to the coral escarpment, on the western side of the major road and The Windy Ridge which lies to the east of Sargeant Street fall under Category 3 which suggests these regions are highly unstable and infrastructural development should be prevented. On the eastern side of the main road running along the top of the ridges, the land begins to slope and consists of steep ridges running west to east; Sealy Hall falls within this region. This area is classified as Category 2 which suggests moderate constraints meaning some areas are suitable for development while others are not. At about the 30 m contour interval the slope of the land begins to decrease, this region falls under Category 1 in which there are minimal constraints on infrastructural development or agriculture and it is considered to be highly stable and not a priority area for the Soil Conservation Unit (Selliah et al. 2012).

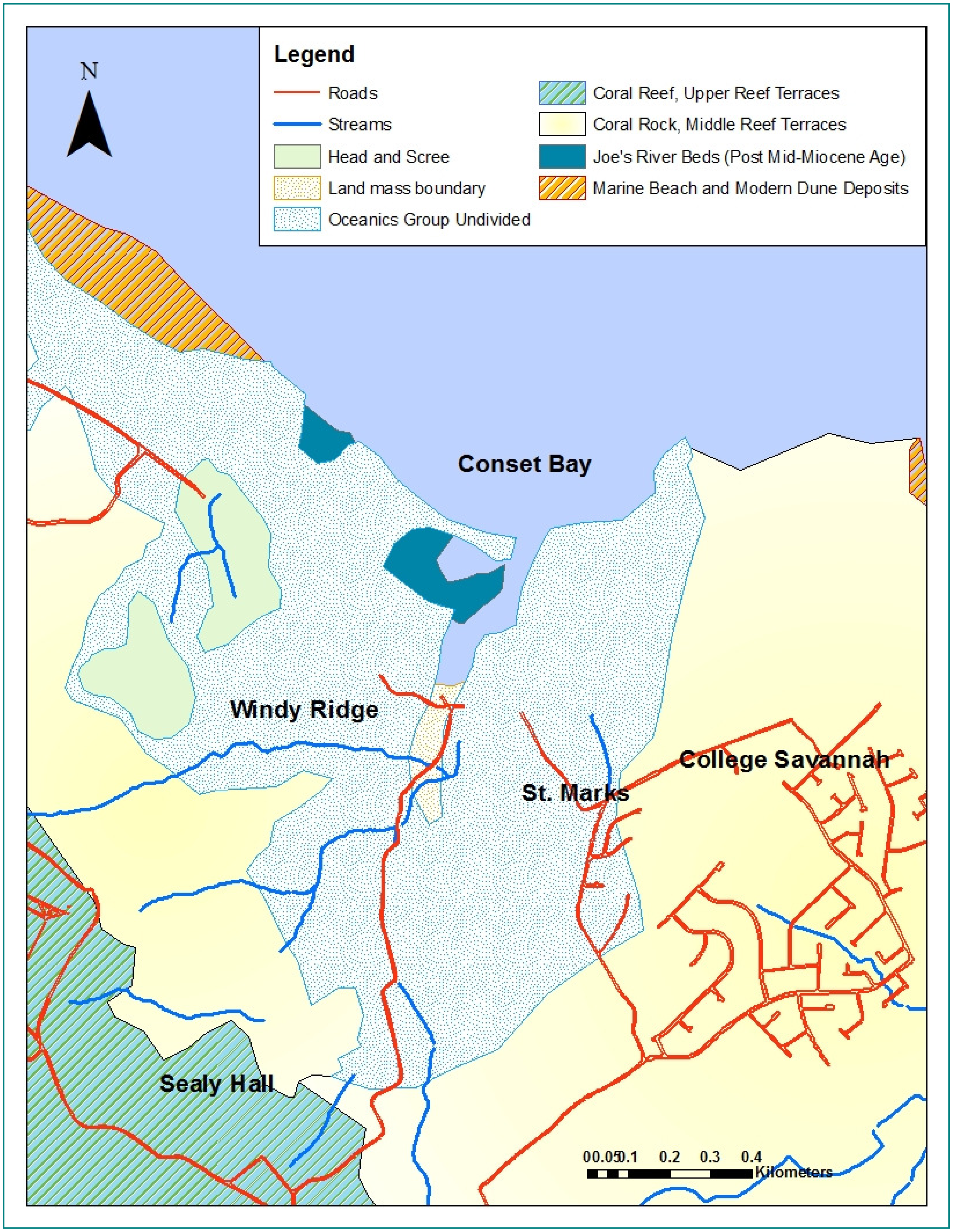

Figure 4 Map showing the geologic composition of the Conset Bay catchment area (Selliah et al. 2012)

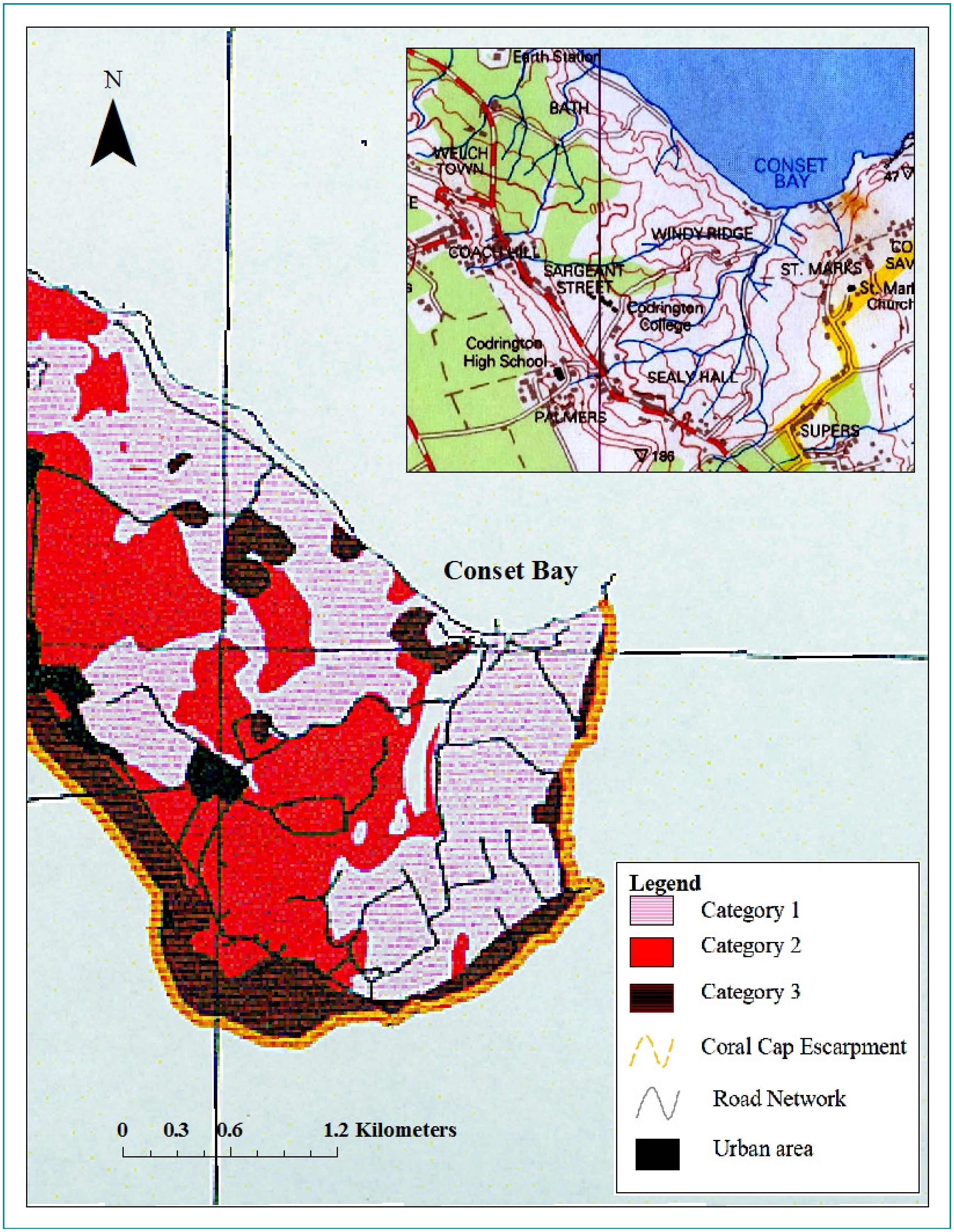

Figure 5 Soil Conservation Unit (2000) land capability and planning guidance map for landslides

3.3 Population distribution

Table 4 shows the population distribution of communities surrounding Conset Bay. The majority of the population is concentrated in the College Savannah area representing 48%. College Land, Sargeant Street and Sealy Hall represent 27%, 15% and 10%, respectively. The map in Figure 5**Error! Reference source not found.** shows the relation of the communities to the drainage basin of the watershed. It can be seen that these communities lie along the head waters of the streams within the watershed.

Table 4 Population distribution in communities around Conset Bay (Selliah et al. 2012)

	Male	Female	Total	Percentage
College Land	120	124	244	26.5
College Savannah	238	207	445	48.3
Sargeant Street	68	74	142	15.4
Sealy Hall	48	43	91	9.9
Total	474	448	922	100.0
Percentage	51.4	48.6	100.0	

3.4 Climate

The climate of the Conset Bay area is similar to the rest of the island, which experiences a moderate tropical marine climate. Rainfall is seasonal and occurs mainly during the wet season from the period June to October. The island also experiences tropical depressions during this time. During December to March, the island experiences the effects of northerly swells which generate long period waves; some of the wave energy is refracted around the northern headland and so initially impacts communities along the eastern coast including Conset Bay (Selliah et al. 2012).

4 METHODOLOGY

The current study was conducted to investigate how land-use practices might affect the quality of water entering the marine environment in Conset Bay. The study aims to link terrestrial activities within the watershed with possible impacts on the nearshore marine environment. In order to pursue this, land cover and land-use within the watershed were characterised using GIS tools and site surveys. The riparian vegetation distribution and spatial extent was assessed and characterised using rapid assessment techniques. Water quality data were collected and analysed for microbial levels, nutrient levels and physical water quality parameters. An activities survey was also conducted to gain a comprehensive understanding of how the location is utilised.

4.1 Watershed mapping

Land cover was assessed via satellite imagery using an Ortho-image licensed by Digital Globe dated 2007. The image was compared to more recent satellite imagery available on Google Earth to determine if any major land-use changes had occurred between 2007 and the present. The image was imported and assessed using ESRI’s ArcView software. The catchment was delineated using watershed mapping data from the Barbados Gully Ecosystem Management Study 2004. Images were analysed at a scale of

1:10000 and a land cover data set was created to categorise usage using the editing tool. Site visits were also conducted for ground-truthing and confirming consistency with that of the imagery.

Land cover was mapped for the entire watershed in order to characterise the landscapes' vegetation cover. Land-use was mapped for the purpose of determining potential contributing areas to non-point source pollution. The spatial arrangement of land cover within watersheds is an important indicator of stream ecosystem health (King et al. 2005). In depth analysis of land cover spatial relation to streams by correlative techniques is covered by King et al. (2005) and addresses a number of considerations while undertaking these analyses. This study only goes as far as to characterise the land cover within the watershed due to time constraints.

Land cover categories were adapted from the Biodiversity Conservation section of the Barbados Gully Ecosystem Management Study (Carrington et al. 2003) categories for vegetation cover/land-use in the broad scale biodiversity survey and consisted of:

- Cropland: land currently in cultivation
- Grassland: natural rangeland, livestock pasture land and agricultural land not in recent cultivation
- Built infrastructure: general areas of settlement
- Forest: closed forest, open forest
- Scattered trees: Less than 25% tree cover
- Scrub: vegetation dominated by shrubs usually less than 5 m tall
- Sand: coastal area

Land-use was assessed via site visit observations and digitised using the Ortho-image utilised for land cover assessment and categorised as follows:

- Agriculture
- Natural vegetation
- Recreation
- Residential
- Commercial

4.2 Identifying potential sources of non-point source pollution due to land-use

In order to identify potential sources of non-point source pollution due to runoff, the ArcView hydrology spatial tool set was used. Using contour data provided by CERMES, a digital elevation model (DEM) was created for the watershed area. The model was then filled to remove any sinks or pockets to create a depression-less DEM. Sinks must be removed as they do not drain within the watershed and hinder the determination of the drainage path network. Using the smooth filled DEM, flow direction was calculated to produce a flow direction raster. The grid created contains an eight directional code for the direction in which each grid cell drains. This is necessary to determine the flow characteristics of each cell in the grid and provide drainage characteristic data for the entire watershed.

> "For every 3x3 cell neighbourhood the grid processor finds the lowest neighbouring cell from the centre. Each number in the matrix below corresponds to a flow direction – that is, if the centre cell flows due north, its value will be 64, if it flows NE its value will be 128. These numbers have no numeric meaning but are simply a coded directional value that indicates the steepest descent based on elevation" (Trent University 2009).

The flow direction raster was created using the Flow Direction Tool. Using the flow direction raster a flow accumulation raster was created using the Flow Accumulation Tool. The geographic extent of a watershed is set by the drainage. A drainage network is created to calculate the definitive drainage path of the cells within the grid. Flow accumulation produces a drainage pattern of cells that experience the highest flow levels which correspond to stream channels and valleys (Trent University 2009). A feature data set was created containing the location of the water quality measurement sites and used for analysis. Key sites were selected and used as pour points throughout the watershed. The sites represented the point at which stream branches met the main channel. The pour points were snapped to the flow accumulation raster using the Snap Pour Point tool. Pour points occur in areas of high flow accumulation within the drainage network and can be utilised to determine the water flow to that given point. In instances where pour point data do not correspond to cells with high flow accumulation due to differences in data sources the Snap Pour Point tool can be used to snap the pour points to the nearest high flow accumulation path using a measured threshold distance. The threshold distance is measured using the measure tool to determine the furthest distance away of the furthest pour point from the high flow accumulation path. Here a threshold distance of 80 m was used. Watersheds were then delineated for each pour point to determine the spatial contribution to each site. This was done using the Watershed tool inputting the flow direction raster grid and the snapped pour point raster data. The percentage of each land-use type within each watershed created was then calculated to determine the relationship between land-use and water quality data at the corresponding water quality sampling site. Correlation was done between the three most abundant land-use types (natural vegetation, residential, and agriculture) and the water quality data to determine any relationship that may exist. Scatter-grams were created to determine the relationship between land-use area contributing zone to corresponding pour point nutrient concentration levels.

4.3 Riparian vegetation assessment

Riparian vegetation was assessed throughout the watershed to map changes in type of vegetation along watercourses. The assessment primarily recorded information on vegetation types, size of channel, dominant tree and shrub species and adjacent land-use. Vegetation was initially observed using the Ortho-image satellite imagery and Google imagery. Secondly, site visits were conducted to (1) collect data along accessible watercourses and (2) view the watershed from vantage points to assess vegetation in inaccessible areas. Data was collected using rapid assessment field sheets seen in Appendix 2. A GPS hand-held unit was used to record data points along the water courses where changes in vegetation were observed or significant observations noted. Vegetation was classified using the vegetation cover/land-use categories seen in the Biodiversity Conservation Section of the Gully Ecosystem Management Study (Carrington et al. 2003).

4.4 Human activities survey

In order to gain a comprehensive understanding of the land-use practices in the area, a human activities survey was conducted during site visits. Surveys were conducted on six days, 10th of August, 11th of August, 17th of August, 18th of August, 24th of August and 25th of August, as well as via online survey techniques. Participants were approached and asked to answer a number of quantitative questions seen in the survey questionnaire in Appendix 3. The survey used was adapted from the Barbados Coastal Conservation Programme (Phase 1), Final Report for Coastal Projects land-use assessment survey (Alleyne et al. 1999).

4.5 Water quality data collection

Water quality data were collected on two occasions at a number of sites within the watershed. Figure 6 shows the location of the water quality collection sites. Sites were selected to reflect the contribution of streams before and after pour points within the watershed as well as at the stream mouth and marine outfall. Two site visits were conducted on the 25th of August 2013 and the 28th of August 2013; sampling took place between 2pm -6pm. The first site visit was conducted after a four-day period of no rainfall to determine dry weather run-off concentrations whereas the second site visit was conducted the day after a torrential rain fall of 6 cm to determine wet weather runoff concentrations. Each site was tested for the nutrients nitrate and phosphate as well as enterococci bacteria concentrations. Physical *in situ* readings were also conducted for pH, temperature, total dissolved solids, salinity, dissolved oxygen and electric conductivity. Apparatus for data collection was obtained from the CERMES water quality lab and included: 1 sterilised glass sample bottle per site, 2x plastic sample bottles per site, YSI meter, Oakton meter, cooler, and ice.

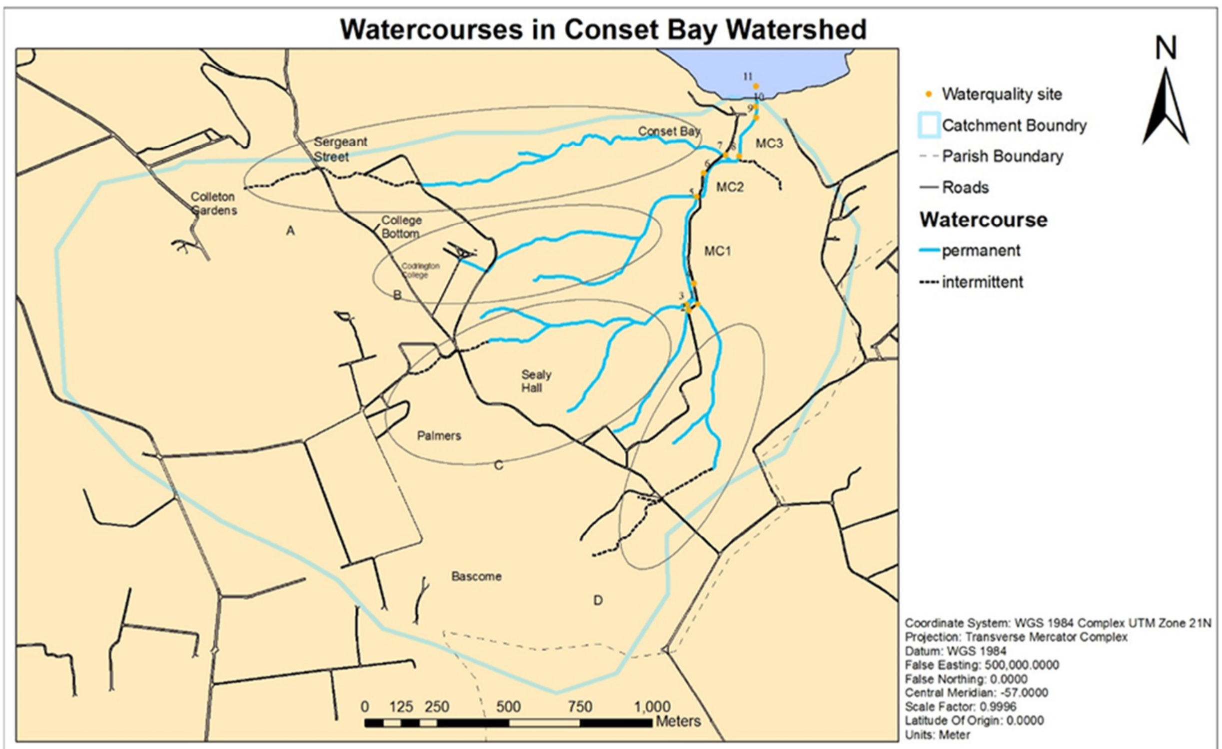

Figure 6. Watercourses within Conset Bay Watershed along with water quality sites, and the main channel sections (MC1, MC2, MC3).

Micro bacteria samples were collected in sterile glass bottles - the first sample set consisted of 500 ml bottles while the second sample set consisted of 100 ml bottles. This was due to the results obtained from the initial sample test; less of the sample was necessary to obtain observable readings. While in the field, bottles were filled using a beaker to collect samples from the stream with care taken to not contaminate the inside of the bottle caps or bottles. Care was taken to not expose the inside of the bottle for extended periods to reduce contamination of airborne bacteria. Nutrient samples were filled in stream, 2 samples were taken at each site. The sample bottle was first rinsed out 2-3 times with sample water and then filled and capped. Samples were kept in a cooler of ice overnight and tested the next day.

In the field, physical water quality parameters were measured using a YSI Model 85 meter. The meter was initially calibrated in the field according to calibration directions. Temperature, dissolved oxygen and conductivity were measured. The Oakton multiparameter tester PCSTester 35 was used to measure pH, electrical conductivity, total dissolved solids and salinity. Care was taken to allow readings to stabilise before values were recorded. In some instances readings proved difficult to obtain from the YSI Model 85 meter as the meter failed to stabilise.

4.6 Water quality sample processing

Samples were taken to the lab on the following day after each collection and placed in the freezer. The micro bacteria samples were pippeted into sterile sample bottles and the Enterolert enzyme added and shaken. For the first sample set 10 ml, 50 ml and 100 ml samples were tested, whereas the second sample set consisted of 10 ml, 5 ml, and 1 ml sample dilutions. Samples were diluted with distilled water to produce 100 ml. For marine water samples at sites 10 and 11 only, 10 ml samples were pippeted and diluted to 100 ml as recommended by test instructions. During both sample collection days, the tide was high and mixing of stream water and marine water was occurring during sampling. The solution was poured into Quanti Trays and sealed in the IDEXX Quanti Tray sealer. Samples were placed in an incubator at 41^{o}C for 24 hours. The samples were then read according to test instructions with a black UV light.

Nutrient tests were also carried out on the day following sampling. Samples were initially filtered to remove any debris and sediment in the bottles. Care was taken to shake each sample before filtering. Samples were measured for turbidity using a Hach 2000P IS Turbidimeter. Samples were then tested for nitrogen and phosphate concentrations using Hach DR.820 Portable Colorimeter according to testing directions.

5 RESULTS

5.1 Land cover

A land cover map was created for the Conset Bay Watershed (Figure 7). The percentage land cover for each type was calculated and can be seen in Table 5. The map shows the various land covers present in the catchment and their spatial extent. Data collected for land cover shows seven categories of land cover throughout the watershed. The major land cover types consisted of Forest which was equivalent to 30%, Grassland 24.6% and Cropland 25.1%. Built infrastructure accounted for 12.8% while Scrub and Sand accounted for 0.78% and 0.05%, respectively. It is noted that much of the Grassland present may have also served as small scale Cropland prior to the survey.

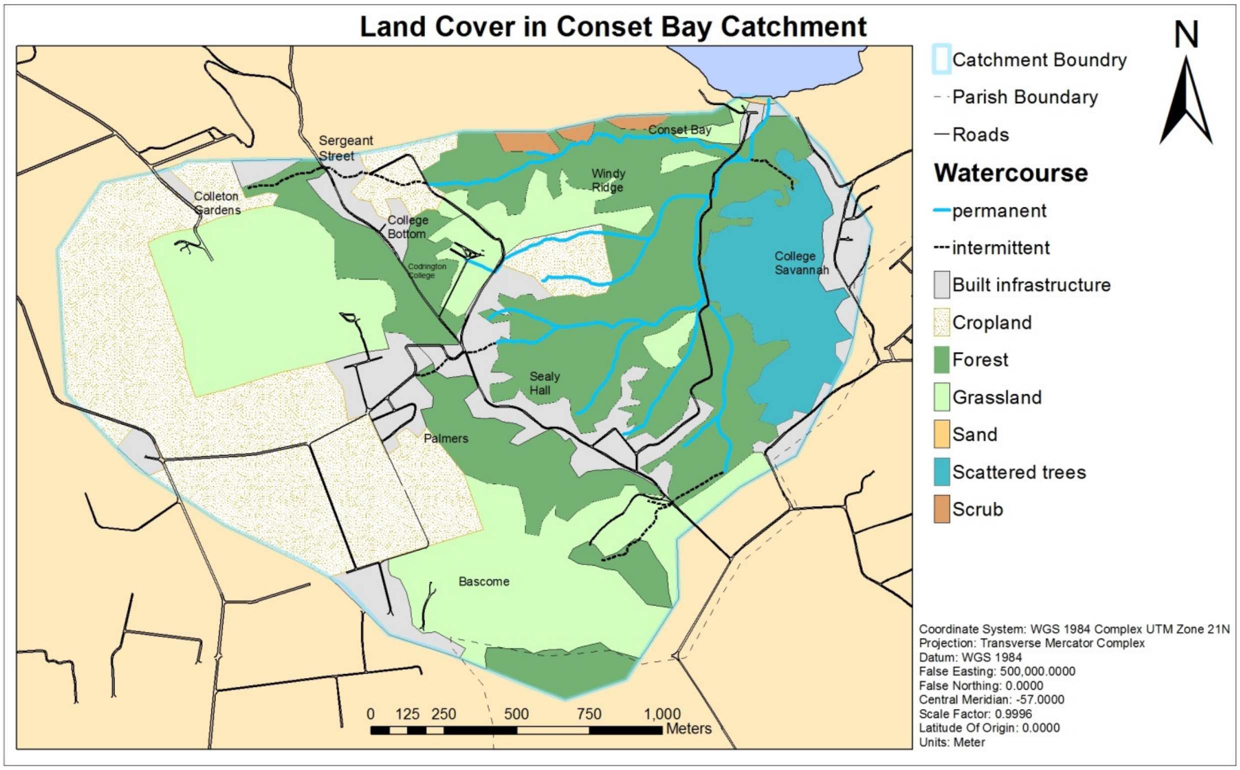

Figure 7 Land cover map of Conset Bay Catchment Area

Table 5. Land cover distribution in the watershed

Land Cover Type	Forest	Built-infrastructure	Grassland	Cropland	Scattered trees	Scrub	Sand
Area km^2	1.17	0.50	0.96	0.98	0.26	.03	0.002
Percentage	30	12.8	24.6	25.1	6.7	0.78	0.05

5.2 Land-use

Land-use data collected was displayed in ArcMap and a land-use map of Conset Bay catchment area was created (Figure 8). The percentage of each land-use type was calculated and can be seen in Table 6 below. The map displays the six land-use types determined and their spatial extent within the watershed. Land-use data shows six categories of land-use in the catchment area. The most prominent land-use types found were natural vegetation 62%, agriculture 26% and residential 12.3%. Commercial accounted for 0.5%, recreational for 1.53% and beach for 0.05%. This data is consistent with the low development associated with area due to topography and accessibility.

Table 6. Land-use distribution in watershed

Land-use Type	Natural Vegetation	Agriculture	Commercial	Beach	Recreational	Residential
Area km^2	2.4	1.0	0.02	0.002	0.06	0.48
Percentage	62	26	0.51	0.05	1.53	12.3

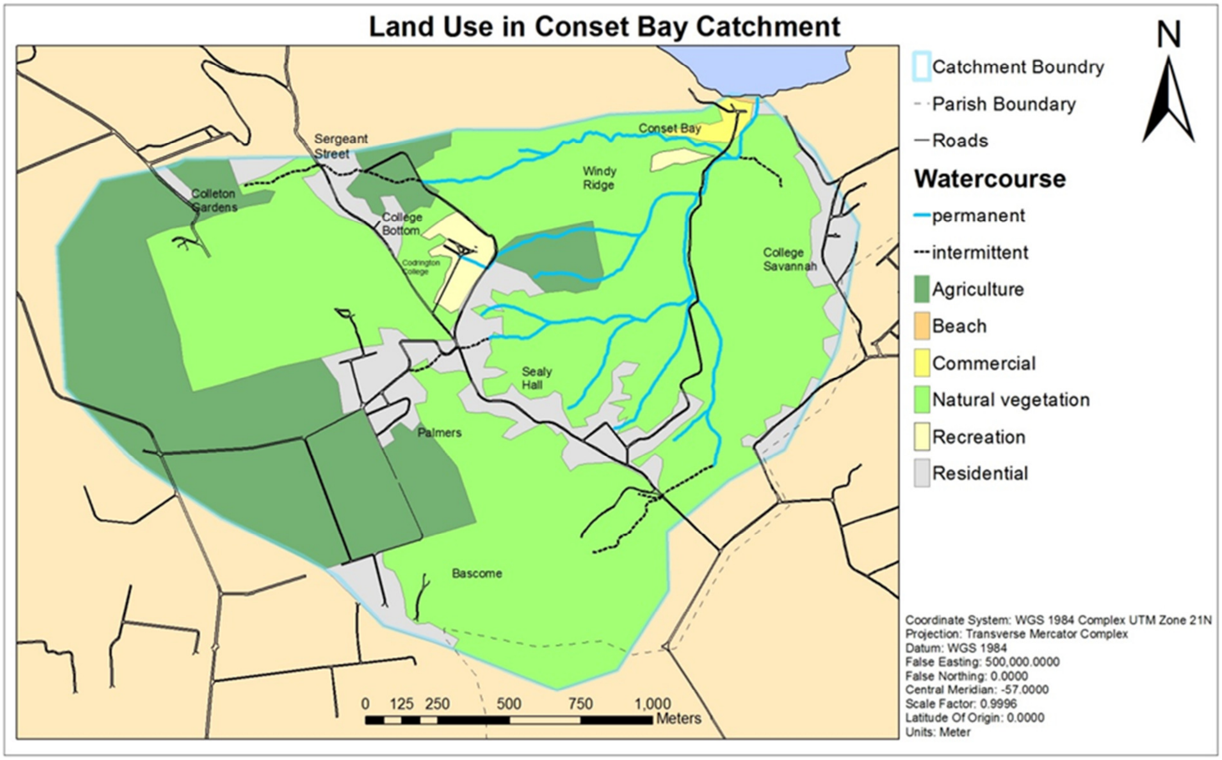

Figure 8 Land-use map of Conset Bay Catchment Area

5.3 Riparian vegetation

A third map (Figure 9) was created displaying the present riparian vegetation cover in the watershed. The map shows the vegetation cover classification throughout the watershed. Stream channels were estimated to be 9.1 km in length with the majority classified as permanent streams; 6.6 km (73%) while intermittent streams were found to be 2.5 km (27%). The intermittent streams were found mainly in the upstream region across the terraced land while permanent streams were found in the lower elevations. During rainy periods it was observed that some streams overflow their banks and water flows over the land particularly in areas where the natural drainage path has been altered for construction of roads and infrastructure in the lower region of the watershed e.g. at main channel sites 2 and 3. It was also noted in the upstream region of the watershed that no definite drainage path exists in many areas. During heavy rainfall, water flows down from the terraced land above through manmade drainage paths and then on to the residential and agricultural lands below. Figure 10A shows the characteristic manmade drainage path leading down from the terraced land above while 10B and 10C shows the change in definitive drainage paths leading to exposed lands below. 10D shows the runoff from diverted waterways in the lower watershed as a result of infrastructure. This flux of water onto large portions of land may carry with it contaminants which contribute to alterations in water quality and ultimately coastal pollution.

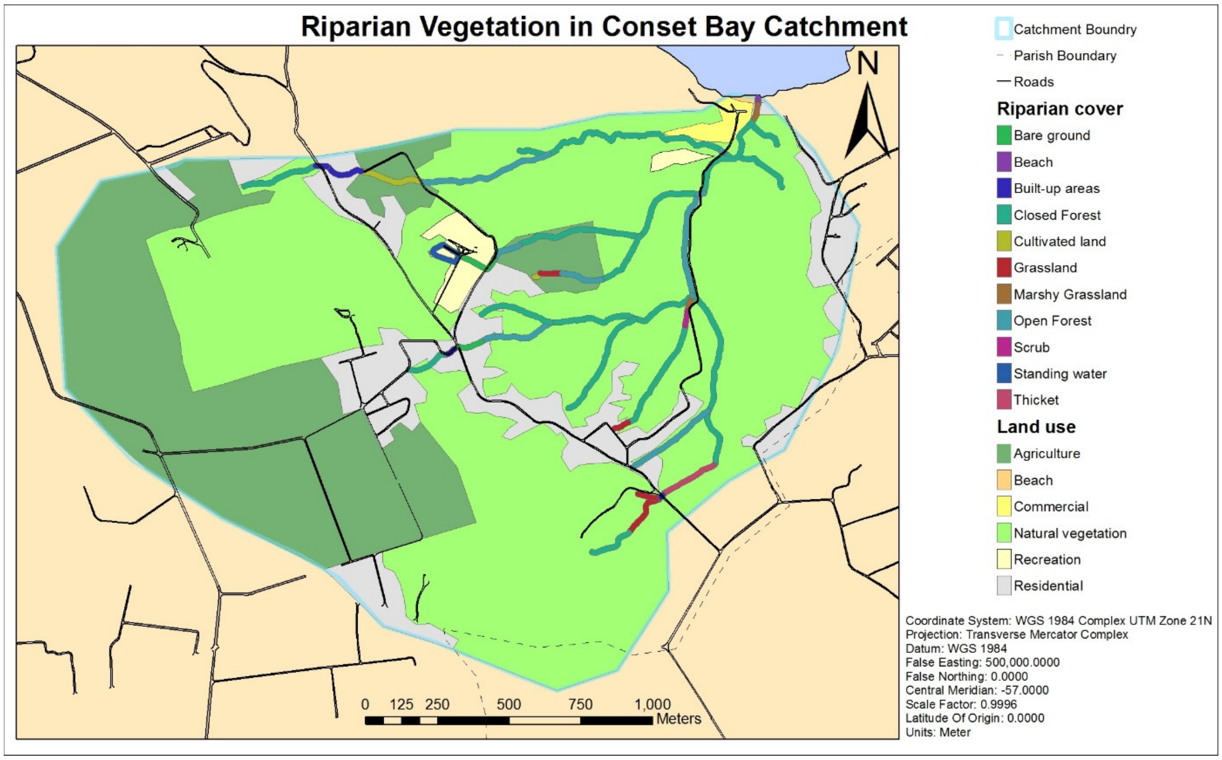

Figure 9 Riparian vegetation spatial distribution in Conset Bay Watershed

Data collected from the riparian vegetation survey shows the extent, distribution and type of vegetation within the riparian zone (Figure 11). Eleven types of riparian vegetative cover were found within the catchment. Riparian vegetation exists throughout the majority of stream network where only 5% flowed through built-up areas and bare ground. Closed forest was the most common representing, 61% while open forest made up 20%. Grassland and cultivated land made up 4% and 3%, respectively. Scrub and marshy grassland made up 1% each. In the lower region of the catchment; MC3 vegetation consisted primarily of coconut trees and marshy grassland. As the streams go further inland along the MC 2 and MC1, changes in vegetation are observed where clammy cherry and river tamarind are the dominant tree type and shrub. As the streams deviate into branches, dominant vegetation also changes. The dominant shrub appeared to be the white willow while the dominate tree appeared to be almond. At the head waters of the streams, vegetation became more closely related to adjacent land-use and human activities. Adjacent lands are cleared for agriculture housing and the extent of riparian buffer is reduced. Dominant tree vegetation ranges from crop trees such as coconuts and bananas while the dominant shrub is river tamarind. In these areas it was also noted that water from the streams was diverted to irrigate adjacent crop lands through pipe fixtures. The pictures seen in Figure 12 show an example of these irrigation fixtures.

A

B

C

D

Figure 10 (A) Characteristic manmade drainage path leading down from the terraced land above. (B) and (C) The change from definitive drainage paths to exposed lands below, (D) Runoff from diverted waterways in the lower watershed as a result of infrastructure.

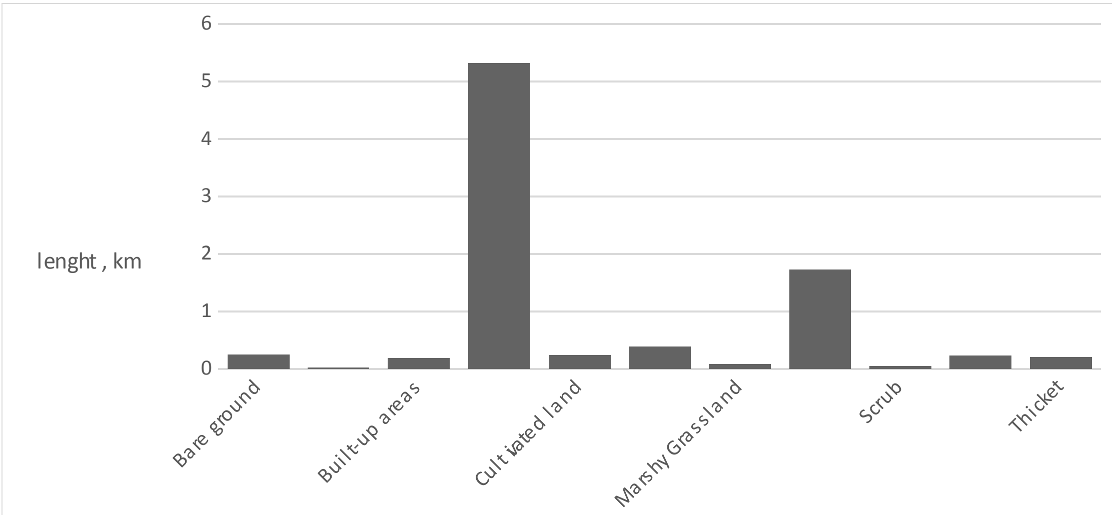

Figure 11 Distribution of riparian vegetation type

Figure 12 Examples of irrigation pipes seen in the watercourse

5.4 Human activities survey

Surveys were conducted to determine anthropogenic activities that may contribute to non-point source pollution. According to population data available for the surrounding communities, a survey sample of 100 would give a 95% confidence interval. Eighty percent of respondents were male while 20% were female. Figure 13 shows the distribution of age groups that were surveyed. Respondents were primarily in the 40-49 age group (35%) and 50-59 age group (30%). The 21-29 and 30-39 categories each represented 15% of respondents while 18-20 represented 5%.

Figure 14 shows the location distribution of respondents. The majority (40%) of those surveyed were from areas other than the surrounding communities of Conset Bay: 30% from College Savannah; 10% from Sealy Hall and 10% from Conset Bay while St. Marks and Sargeant Street represent 5% each. The main activities cited by respondents as taking place in Conset Bay (Figure 15) included swimming (20%), fishing at sea (20%), farming (15%), fishing in rivers for crayfish bait (10%) and kayaking (5%) . Figure 16 shows a small number of respondents utilise the streams directly. The streams are primarily utilised for irrigation of crops and crayfishing.

Dumping of garbage was the primary concern of respondents regarding activities that could harm the watershed (Figure 17). Fertilisers and water runoff from homes also proved to be a concern followed by overfishing and bad farming practices. Of least concern was the removal of vegetation. Others cited the establishment of golf courses and resorts as a threat to the watershed. The majority of respondents agreed with the suggested proposals to help the watershed (Figure 18). Only 60% of respondents agreed with replanting of vegetation as a helpful activity for the watershed. Other respondents suggested educational programs and tours to be another alternative while some suggested upgrades to the fishing complex and fishing facilities.

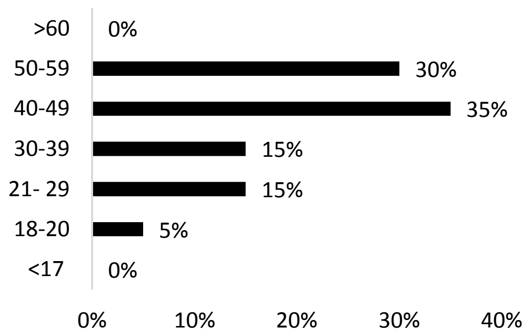

Figure 11 Age distribution of survey participants

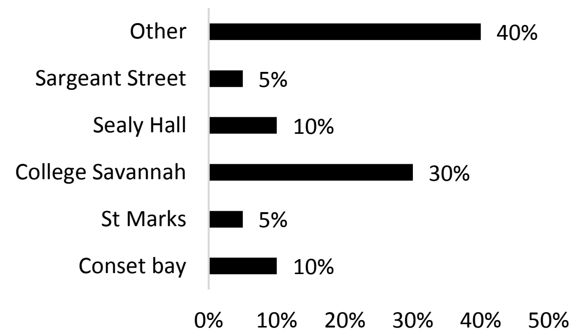

Figure 12 Distribution of communities surveyed

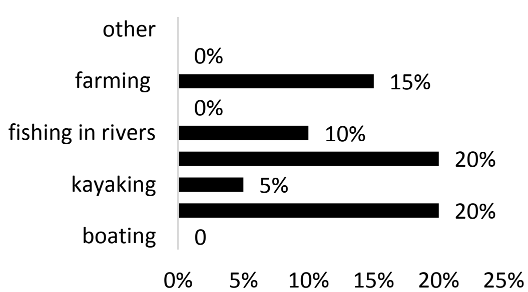

Figure 13 Activities within Conset Bay

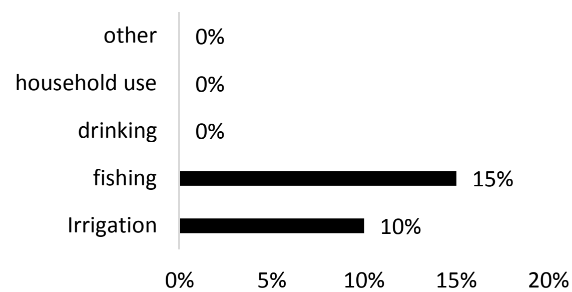

Figure 14 Utilisation of the streams

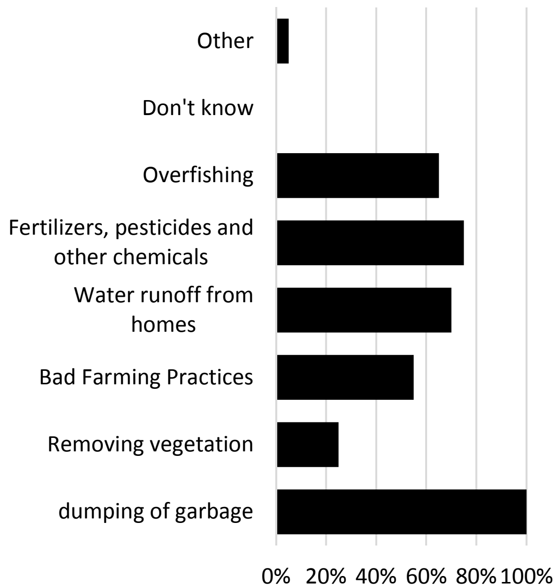

Figure 15 Percentage of respondents who consider these activities harmful to the watershed

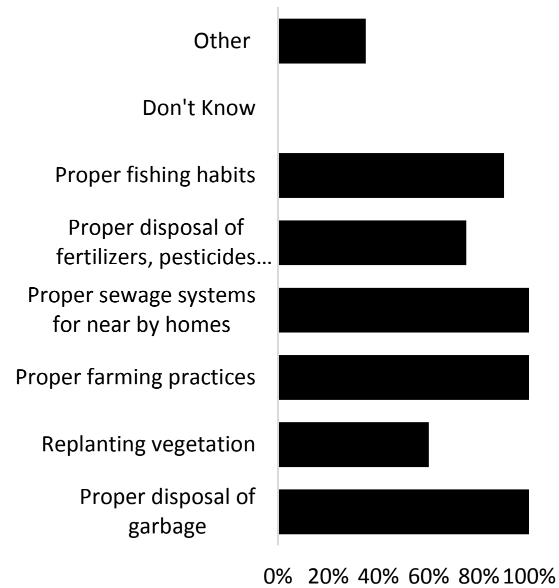

Figure 16 Respondents who agree these activities are helpful to the watershed

5.5 Water quality

The analysis of the water quality data in the catchment shows values of nitrate, phosphates and enterococci to be well in excess of the discharge standards. Tables 8 and 9 show the comparison of nutrient and bacteria water quality parameters with the prescribed discharge standards in Barbados. The tables also shows the comparison of readings for both rainy and dry day sampling at the 11 sites within the watershed. During dry day sampling higher concentrations of nitrates were found when compared to the wet day samples. On average dry day concentrations were 1.4 mg/L higher than on wet days with a 95% confidence interval of between 0.91 and 1.85 mg/L higher than wet days (P-value = 0.00003). Phosphate concentrations showed little variation between rainy day samples when compared to dry day samples; a paired t-test shows that the difference observed is not statistically significant (P-value = 0.5). Enterococci sample readings showed elevated levels in rainy day samples as opposed to dry day samples (P-value = 0.02). Physical water quality parameters whose differences showed statistical significance were turbidity, pH, temperature, total dissolved solids (TDS), and dissolved oxygen (DO). Scatter-grams (Figure 19) show the relationship between the most abundant land-use types and nitrates and phosphates. It can be seen that a nonlinear relationship exists between the area of land-use versus the concentration of nutrients in all instances.

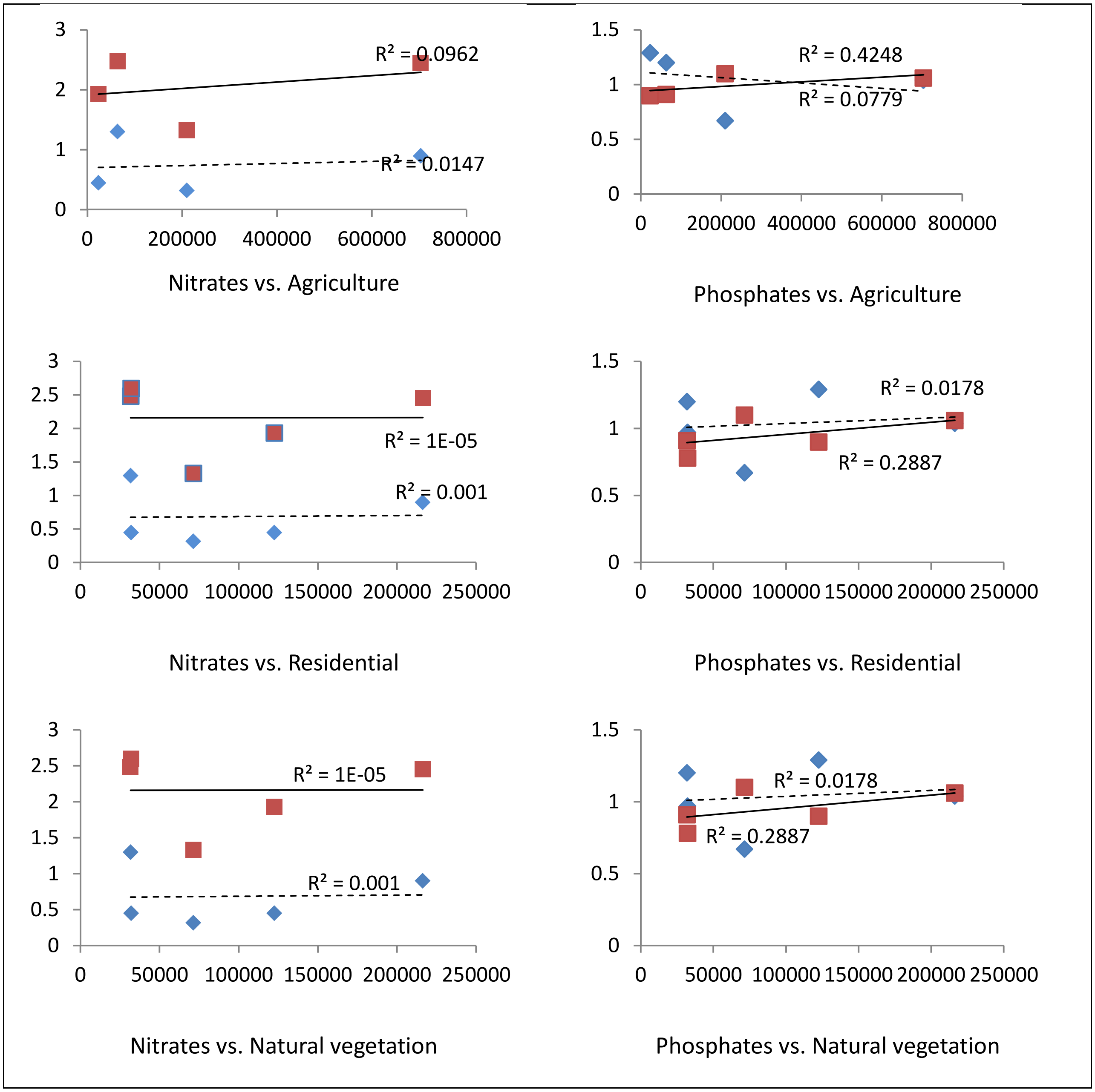

Figure 17 Scattergrams of nitrates and phosphates with most abundant land-use types (concentrations are given in mg/l and area is given in m^2)

Table 8 Comparison of nutrient and microbial water quality results

Parameter	Faecal streptococci / enterococci		Oxides of Nitrogen (nitrate/nitrite)		Phosphate (Filterable Reactive)	
Ambient Water Quality Standard[1]	Geometric mean of min. 5 samples should not exceed 35 colonies/100 ml in any 30-day period (US EPA, 2002. UNEP, 1999 - LBS Protocol)		9.8 (µg N/l) or 0.043 mg/L (Delcan, 1994)		2.48 (µg P/l) or 0.0076 mg/l (Delcan, 1994)	
Site	**Rainy 3 samples**	**Dry 3 samples**	**Rainy mg/L**	**Dry mg/L**	**Rainy mg/L**	**Dry mg/L**
1	11,581	4,039	0.45	1.93	1.29	0.90
2	56,718	2,595	0.93	1.30	1.01	1.18
3	150,075	> measurable[2]	0.9	2.45	1.04	1.06
4	204,766	10,462	0.63	2.33	0.80	1.02
5	7,133	3,602	1.3	2.48	1.2	0.91
6	30,791	2,878	0.45	2.65	1.24	0.92
7	56,271	> measurable	0.32	1.33	0.67	1.10
8	53,213	2,489	0.73	2.78	0.83	0.91
9	13,819	6,131	0.45	2.6	0.97	0.78
10	56,311	6,741	0.45	2	1.145	0.79
11	2,382	28	0.68	0.70	0.21	0.24

[1] Environmental Protection Department 2004

[2] Using laboratory equipment available

Table 9 Physical water quality results

Parameter	Marine discharge standards[3]													
	1.5 NTU		7.0-8.7		<31°C				30-38 psu[2]		90% saturation[3]			
	Turbidity, NTU		**pH**		**Temperature**		**TDS, ppm**		**Salinity, ppt**		**DO, mg/L[4]**		**EC, µS**	
Site	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
1	207.0	23.0	8.6	7.6	26.4	30.9	243	546	0.083	0.376	6.3	4.9	343	769
2	149.3	3.5	8.7	7.4	26.8	32.4	596	1850	0.329	0.1	7.1	5.5	840	2630
3	92.2	20.7	8.7	8.2	26.3	28.7	429	609	0.297	0.421	6.8	5.7	604	429
4	92.7	24.2	9.1	8.2	27.1	27.8	471	627	0.282	0.434	5.8	6.1	665	884
5	29.1	6.7	9.4	8.4	27.1	28.2	417	435	0.278	0.299	5.4	6.7	588	614
6	71.6	13.5	9.0	8.4	27	28.1	422	506	0.245	0.324	6.7	5.7	595	713
7	91.4	17.3	9.1	8.3	26.7	28.1	485	674	0.305	0.464	7.0	5.3	685	950
8	67.9	27.4	9.2	8.5	26.8	28.0	463	532	0.283	0.364	6.5	5.4	650	746
9	81.4	46.1	8.9	8.3	26.9	28.3	505	547	0.323	0.389	5.6	5.4	712	770
10	63.0	37.9	9.1	8.4	26.8	28.0	506	546	0.348	0.376	6.4	5.5	714	770
11	4.6	3.0	9.1	8.5	28.8	29.8			13.4	27.1	6.8	5.6	23,650	46,4000

[1]Practical Salinity Units, numerically equivalent to parts per thousand or grams/kilogram.

[2]Actual concentration varies with temperature

[3]Dissolved Oxygen measured as a concentration the saturation level is calculated based on the Normal Atmospheric Equilibrium Concentration (NAEC). At 35 psu and 24o C the NAEC for oxygen is 5.5 ml/l. Around Barbados 6.5-7 mg/l is typically measured which is approximately 4.6-4.9 ml/l assuming these measurements were taken at standard pressure

[3] Environmental Protection Department 2004

6 DISCUSSION

All activities in coastal areas impact coastal water quality. The water quality data collected from the Conset Bay watershed suggest that levels of microbial and nutrient pollutants entering the marine environment are higher than the prescribed discharge standards. As a result, these pollutants can negatively impact the marine ecosystem and pose significant risks to those that depend upon it. A number of physical water quality parameters were also observed to be in excess of the discharge standards. Turbidity values were observed well in excess of the prescribed 1.5 NTU on dry days and increasingly so in rainy periods. These values could be attributed to the concentrations of nutrients in the water. It can also be indicative of sediment erosion through natural processes and anthropogenic activities; the region in which the watershed is located is associated with high levels of erosion and slippage. Evidence of excess sediment can be seen in the siltation of the nearshore region of Conset Bay. The pH was observed to be in excess of the 7.0-8.7 standard particularly on rainy days, whereas on dry days standards fell within the acceptable range. The pH of aquatic environments is strongly linked to their biological productivity (Carr and Neary 2008). This resulting lowering of the acidity level of the waters can be due to an increase in bicarbonate, carbonates and hydroxides in the water from the dissolution of underlying carbonate rock with the natural acidity of the rainwater. The amount of calcium carbonate, bicarbonate and silicate minerals in sediments that the subsequent run-off comes into contact may also help to buffer acidity. The temperatures and DO levels observed were within the recommended range. While the salinity range was measured below the recommended range; no standard is set for TDS and EC.

The majority of land cover is forest (30%), grassland (25%) and cropland (25%) with a small portion of built infrastructure (13%). The major land-uses were natural vegetation (62%), agriculture (26%) and residential (12%). Forest cover has been associated with a reduction in runoff and reduced nutrient enrichment of water quality, as previous studies have shown a strong negative correlation of forest cover with nitrates and phosphates (Tong and Chen 2002, Basnyat et al. 2000). Though the Conset Bay watershed is primarily forest cover, concentrations of nitrates and phosphates are observed to be well above the proposed standards. Grassland, cropland and built infrastructure combined account for 62% of the watersheds land cover which significantly outweighs forested areas. Agriculture land and urban/built up areas generally generate higher concentrations of nitrogen and phosphorus as opposed to other land-use, these areas make up 38% of the land-use within the watershed (Tong and Chen 2002; Osmond et al. 2002).These concentrations may be attributed to storage in sediment from fertiliser and community waste from upstream which are then transported during rain events as the majority of runoff occurs during rainy season.

Higher concentrations of nitrates were observed during dry day sampling as compared to wet day sampling. This may be attributed to the dilution of nutrients as a result of the heavy rains. Scattergrams of nitrate and phosphates with land-use reveal a nonlinear relationship. This is consistent with other studies which show a nonlinear response of nutrient loadings to different land-use types because of hydro-geochemical processes in the watershed (Tong and Chen 2002; Nikolaidis et al. 1998). Future studies may find it useful to investigate land-use coupled with population characteristics as it can aid in assessing prospective population expansion and changes in land-use over time. Characterising the watershed by evaluating land-use distribution can assist in the development of future management strategies. Information on population distribution and demographics can also aid in determining community needs in the future and help to establish outreach and capacity building programs to help alleviate added stresses to the environment. These techniques provide a basis for development of policy and management programs that are site specific and tailored to the socioeconomic and environmental aspects of the area.

Riparian buffers occur throughout the majority of watershed. At the headwaters adjacent land-use to the rivers is primarily observed to be agriculture-based including both tree crops and short crops. This close proximity to waterways increases the potential for pollutants from fertilisers, and pesticides to enter into water courses. These practices may influence the current water quality. Basnyat et al. (2000) observes that the land-use and land cover adjacent to streams have the greatest influence on water quality and this influence decreases with distance away from the stream (Basnyat et al. 2000). Future studies mapping riparian vegetation may find it worthwhile to determine the relationship between riparian zone extent and water quality to gauge the effectiveness of existing riparian buffers and potential for expansion.

In order to improve coastal water quality several aspects must be considered since the coastal zone involves other coastal issues such as habitats, community development and cumulative impacts (NOAA 2010). For example, coastal habitats such as riparian areas play an important role in filtering pollutants from runoff; protecting these areas helps maintain healthy waters. Encouraging smart community development that limits the amount of impervious or hard surfaces also helps to reduce the amount of polluted runoff (NOAA 2010). By reducing the extent of paved surfaces, storm water can penetrate the ground and reduce the amount of runoff from a location (NOAA 2010). Managing the coastal zone to minimise, or at least mitigate, cumulative impacts is critical for protecting water quality and in turn the marine ecosystem health.

Basin characteristics such as land-use, land cover, slope and soil attributes affect water quality as they help to regulate sediment and nutrient inputs. By managing land-use and land cover it is possible to improve water quality in watersheds and in turn coastal outfall areas such as Conset Bay. In order to reduce the impact of non-point source pollution best management practices should be utilised. The management of these areas requires action at both the community and national levels. Programs such as the GEF funded Integrated Watershed and Coastal Area Management (IWCAM) project provide guidance on establishing IWCAM within Caribbean countries; Barbados is part of this initiative. The general objective of this Project and its successor Integrating Water, Land and Ecosystems Management in Caribbean Small Island Developing States (IWECO), is to strengthen the commitment and capacity of the participating countries to implement an integrated approach to the management of watersheds and coastal areas.

Riparian buffers can effectively limit the potential negative impacts of human activities and land-use adjacent to waterways. They can act as nonpoint source pollutant filters and create a balanced ecosystem for riparian and aquatic life (Osmond et al. 2002). The characteristics of buffers such as width, types of vegetation and management all play a significant role in the efficiency of the riparian buffer system while the size and topography of the watershed determine the amount and rate of surface and groundwater passing through the buffer (Osmond et al. 2002). The width of buffers is an integral part of buffer design. Determining buffer width can be complicated as a number of factors have to be considered; if widths are too narrow they may be ineffective while on the other hand wider riparian extents minimise the usage of neighbouring land. Other factors to consider include topography, hydrology, geology, land-use and the value of water resource and adjacent lands (Osmond et al. 2002).

In riparian buffers, grass and forested sections help to reduce water velocity allowing sediment to settle out of the surface runoff. The grassed portion of the buffer functions as a grass vegetated filter strip (Osmond et al. 2002). Phosphates are in turn removed as they are closely associated with the sediment entrained in runoff. Riparian buffers also help to reduce nitrate concentrations. Though is important to note that not all buffers are effective for nitrate removal and this is primarily dependant on the prevailing hydrology of the area (Osmond et al. 2002).The ideal criteria for nitrate removal by a riparian buffer system suggest that "an aquatard is present at relatively shallow depth (>5 m in upper part of field; <1.5 m in riparian area)" (Osmond et al. 2002). Before the soil water reaches the waterways the water must pass through an area allowing for roots to take up nitrates as well as provide sources of carbon for denitrifying bacteria to act (Osmond et al. 2002). The most ineffective condition for nitrate removal occurs when all of the groundwater passing through the riparian zone has very little or no interaction with the roots of vegetation (Osmond et al. 2002).

7 CONCLUSION

This study demonstrates the value of a quantitative spatial approach to watershed assessment. It shows the major land covers to be primarily forest (30%), grassland (24.6%) and cropland (25.1%) with a small portion of built infrastructure (12.8%); while the major land-uses were natural vegetation (62%), agriculture (26%) and residential (12.3%).Water quality values for nitrates and phosphates together with enterococci within the watershed were found to greatly exceed the proposed standards for Barbados and this can have serious impacts on the marine ecosystem and the health of humans that depend upon it. By managing land-use and land cover it is possible to improve water quality in watersheds and in turn coastal outfall areas such as Conset Bay. In order to reduce the impact of non-point source pollution best management practices should be utilised such as reafforestation to establish an effective system of riparian buffers. Integrated water and coastal area management can help to better manage the interactions and impacts terrestrial activity has on the marine and coastal environment. By developing policies and community-based management strategies to monitor water quality together with implementing mechanisms to control unrestricted development, land-based sources of pollution can be controlled and mitigated.

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APPENDIX 1: WATER QUALITY STANDARDS

Glossary of Terms.

µg/l –	micrograms/litre α 1000 mg/l α parts per billion.
µg P/l or µg N/l –	The mass of the phosphorous or nitrogen in a litre rather than the mass of the atoms they are attached to, e.g. oxygen in nitrates.
% Saturation –	The measured concentration compared with the normal atmospheric equilibrium concentration at that temperature.
Bioaccumulation –	The retention and accumulation of a chemical within the tissues of a biological organism.
Geometric mean –	The list of values are multiplied together and then the taken to the power 1/n, where n is the number of values.
Half-life –	The time period required for a process to remove half of the original quantity.
Organic/inorganic –	Organic compounds contain Carbon. Inorganic compounds do not contain carbon.
psu –	Practical Salinity Units, numerically equivalent to parts per thousand or grams/kilogram.
NTU –	Nephelometric Turbidity Units.
Toxic –	Poisonous to biological organisms.
Volatile –	Prone to evaporate rapidly.
Conductivity	measurement of the ability of water to transmit electricity due to the presence of dissolved ions. It is thought that the source of these ions is often from seawater intrusion.
Atrazine	organic compound widely used in herbicides
SPM	fine particles suspended in either liquid or gas
Total Coliform	The total coliform group is a large collection of different kinds of bacteria.
BOD	a chemical procedure for determining the uptake rate of dissolved oxygen by the biological organisms in a body of water.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
		the recommended level is exceeded.		
Total nitrogen (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well.	Not measured.	Anzecc, 2000 for tropical marine systems.	100
Total phosphorous (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well.	Not measured.	Anzecc, 2000 for tropical marine systems inshore.	15
pH	General indicator of acidity/alkalinity. Change in pH can be either toxic directly or indirectly by changing the toxicity of other pollutants.	Rarely measured.	CCME, 1999	7.0-8.7
Salinity	General parameter describing the total salt content of seawater. An indicator of the presence of freshwater or hyper saline discharges.	Ambient levels generally within the range although not always measured.	Delcan, 1994.	30-38 (psu)
Temperature	Indicator of thermal pollution from, for example, cooling water discharges. Changes in temperature can affect the toxicity of chemicals or kill coral directly through bleaching.	Isolated cases, but typically between 26-29°C.	Delcan, 1994.	<31°C
Total Suspended Solids (TSS)	Suspended solids increase turbidity, reduce light penetration, and decrease photosynthetic activity – the basis of coral growth. Also important in the transport of other pollutants that are strongly associated with the solids, such as metals.	Can be problematic during construction or near freshwater discharges such as drains and gullies. Occasionally exceeds standard.	Delcan, 1994 standard is 4mg/l, but given observations, the standard is set at 5mg/l.	5 (mg/l)
Sedimentation Rate	Indicator of the amount of solids that settles on the seabed. Settling solids can smother a reef. Bank reefs are more susceptible than fringing reefs.	Can be problematic during construction or near freshwater discharges such as drains and gullies. Not frequently measured, but can exceed standard.	Delcan, 1994.	Fringing reefs: 25 $mg/cm^2/day$ Bank Reefs: 5 $mg/cm^2/day$
Turbidity	Aesthetic impact; reduced water clarity; impact on	Typically <1NTU	Delcan, 1994.	1.5 (NTU)

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	photosynthetic capacity of corals. Another measure of the amount of sediment in the water column.			
		Non-metallic Inorganics		
Chlorine (Total Residual Chlorine)	Chlorine is commonly used as a disinfectant in potable water and in sewage treatment, toxic to many marine species.	Not measured.	Delcan, 1994.	2
Cyanide (un-ionised HCN)	Used in metal plating / metal finishing and photo-processing. Toxic. HCN (hydrocyanic acid) is the most toxic form of cyanide as it can cross biological membranes.	Not detected in past samples.	Anzecc, 2000. 95% protection level[a].	4
		Metals		
Cadmium	Used in metal plating, in batteries, and in the manufacture of semiconductors. Toxic. Bio-concentration can be significant for bivalves. If shellfish from the area are consumed an even lower trigger value of 0.2 µg/l is recommended. Causes kidney damage in humans.	Not detected in past samples.	Anzecc, 2000. 99% protection level[b].	0.7
Chromium III (trivalent)	Used in metal plating, leather industry and as a corrosion inhibitor in cooling systems. Toxic. Chromium III less toxic than Chromium VI.	Low values have been detected.	Anzecc, 2000. 95% protection level[a].	27.4
Chromium VI (hexavalent)	Used in metal plating, leather industry and as a corrosion inhibitor in cooling systems. Toxic.	Low values have been detected.	Anzecc, 2000. 95% protection level[a].	4.4
Copper	Commonly used metal, specifically by the rum industry. An essential trace element, but toxic at higher concentrations. Readily accumulated by plants and animals. Copper toxicity to marine species generally increases as salinity decreases. Long-term exposure causes liver and kidney damage in humans.	Detected occasionally.	Anzecc, 2000. 95% protection level[a].	1.3
Lead	Historically added to paint and gasoline; used in old water pipes. Toxic.	Detected occasionally, primarily in Careenage and Port.	Anzecc, 2000. 95% protection level[a].	4.4
Mercury (inorganic)	Used in switches, thermometers, and dentistry. Can be converted by microorganisms in sediment to methyl	Not detected in past samples.	Anzecc, 2000. 99% protection level[b].	0.1

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
General Parameters and Nutrients				
Chlorophyll a	An indicator of the presence of algae, which can be an indicator of high nutrient levels.	Elevated levels detected occasionally, up to 3.23 at the Careenage.	Anzecc, 2000 for tropical marine systems.	0.5
Dissolved Oxygen[1]	Essential for aquatic life. Requirements vary depending on species, life stage, and life processes. Many compounds become more toxic as Dissolved Oxygen decreases; so can have an indirect effect.	Oxygen levels are often supersaturated, but can dip quite low where there is an outfall with high oxygen demand.	Anzecc, 2000 for tropical marine systems.	90 (% saturation) -actual concentration varies with temperature.
Faecal streptococci / enterococci	Public health indicator of sewage pollution in seawater. This is generally the preferred indicator of health risk.	Priority pollutant that has previously been detected at high levels.	US EPA, 2002. UNEP, 1999 - LBS Protocol.	Geometric mean of min. 5 samples should not exceed 35 colonies/100ml in any 30-day period.
Faecal coliform	Public health indicator of sewage pollution in freshwater, but historically used in seawater as well.	Priority pollutant that has previously been detected at high levels.	UNEP, 1999 - LBS Protocol.	Geometric mean of min. 5 samples not exceed 200 colonies/ 100ml in any 30-day period. No more than 10% of samples exceed 400 colonies/100ml.
Phosphate (Filterable Reactive)	Primary nutrient causes high algal growth, which then impacts on coral by blocking light and smothering.	Priority pollutant. The recommended level is often exceeded.	Delcan, 1994	2.48 (µg P/l)
Oxides of Nitrogen (nitrate/nitrite)	Primary nutrient causes high algal growth, which then impacts on coral by blocking light and smothering.	Priority pollutant. The recommended level is often exceeded.	Delcan, 1994	9.8 (µg N/l)
Ammonia	Form of nitrogen most easily used by plants. Causes high algal growth, which then impacts on coral.	Priority pollutant. Not regularly measured, but	Delcan, 1994	9.8 (µg N/l)

[1] Dissolved Oxygen – is measured as a concentration then the saturation level is calculated based on the Normal Atmospheric Equilibrium Concentration (NAEC). At 35psu and 24°C the NAEC for oxygen is 5.5ml/l. Around Barbados we typically measure 6.5-7mg/l.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	mercury. Methyl mercury is soluble, more toxic than inorganic mercury and bio-accumulates.			
Nickel	Used in metal plating, present in batteries. Nickel toxicity increases with decreasing salinity. The 95% protection level not deemed to provide sufficient protection to juvenile mysids and molluscs.	Low values have been detected.	Anzecc, 2000. 99% protection level[b].	7
Silver	Used in the electronics and photography industries. The acute toxicity of silver to marine fish is considerably lower than to freshwater fish. Toxicity to most species increases with decreasing salinity.	Historically present in at least one local industrial effluent. Low values have been detected.	Anzecc, 2000. 95% protection level[a].	1.4
Vanadium	Occurs in 4 valency states. Vanadium +5 (Vanadate) is the most common in water and the most toxic.	Low values have been detected.	Anzecc, 2000. 95% protection level[a].	100
Zinc	In greater than trace concentrations, harmful to aquatic organisms. Zinc uptake and toxicity generally decrease as salinity increases.	Low values have been detected, primarily in Careenage.	Anzecc, 2000. 95% protection level[a].	15
Organotins				
Tributyltin	Highly toxic to marine bivalves. Present in marine antifouling paints and wood preservative.	Used in Barbados, but not detected.	Anzecc, 2000. 95% protection level[a].	0.006
Organic Alcohols				
Ethanol	Present in alcohol distillery waste. Volatile and completely mixable with water. Large inputs can significantly reduce Dissolved Oxygen levels. Limited marine toxicity data. Anzecc present a low reliability value taken from the freshwater value, which should be considered only as an interim working value. It is recommended for inclusion due to the known presence of ethanol in marine waters off of the west coast of Barbados.	Not measured.	Anzecc, 2000. 95% protection level[a] in freshwater.	1400
Chlorinated Alkanes and Alkenes				
1,1,2- trichloroethane	Volatile and relatively soluble in water. Commonly used industrial solvent. Not expected to bioaccumulate significantly.	Not measured.	Anzecc, 2000. 95% protection level[a].	1900
1,1,2,2-tetrachloroethylene	Commonly used in the dry cleaning industry in	Not measured.	Anzecc, 2000. Low	70

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
(perchloroethylene)	Barbados. Not expected to bioaccumulate or to bind to sediment. Volatile with a half-life of 1-6 days in water. Due to its known use in Barbados the Anzecc marine low reliability value is recommended as an interim working value. Anzecc considers that there is insufficient data to generate a marine medium reliability trigger value.		reliability value.	
Aromatic Hydrocarbons				
Benzene	Benzene, toluene, ethyl benzene and xylene (BTEX) are the simplest aromatic hydrocarbons. Products of oil refining and important common aromatic solvents. Commonly associated with contaminated petroleum sites (e.g. Needham's Point). BTEX compounds are highly volatile, have low water solubility and have low bioaccumulation potential. However, water managers should be aware of possible additive effects (mixture toxicity). Anzecc 99% protection level is recommended to provide protection against chronic toxicity to crabs.	Rarely measured. Below detectable limits.	Anzecc, 2000. 99% protection level[b].	500
Toluene	Insufficient data. Low reliability value recommended as an interim value.	Rarely measured. Below detectable limits.	Anzecc, 2000. Low reliability 95% protection value.	180
Ethyl benzene	Insufficient data. Low reliability value recommended as an interim value.	Rarely measured. Below detectable limits.	Anzecc, 2000. Low reliability 95% protection value.	80
Xylenes	Insufficient data. Low reliability value recommended as an interim value for m-xylene.	Rarely measured. Below detectable limits.	Anzecc, 2000. Low reliability 95% protection value.	75
Naphthalene	Naphthalene is the simplest polycyclic aromatic hydrocarbon (PAH), used as an insect-proofing agent for stored materials and clothes. Will absorb strongly to sediment. UV light increases the toxicity. Only PAH that Anzecc considers there are sufficient data to generate a moderately reliable guideline value. Due to chronic toxicity to the crab *C. magister*, the Anzecc 99%	Rarely measured. Below detectable limits.	Anzecc, 2000. Moderate reliability 99% protection level[b].	50

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	protection level is recommended.			
Polychlorinated Biphenyls				
PCBs	Used as a dielectric fluid in transformers and capacitors. No longer used by the Barbados Light & Power Company Ltd. High persistence and potential to bioaccumulate. Moderate reliability trigger values have been derived for Arochlors 1242 &1254 in freshwater. These numbers have been converted to marine low reliability figures and should be considered as interim values.	Not detected.	Anzecc, 2000. Moderate reliability 99% protection level[b] in freshwater.	Arochlor 1242: 0.3 Arochlor 1254: 0.01
Phenols				
Phenol	Commonly used raw material in the manufacture of a wide range of products. A common by-product of oil refining. Readily soluble in water and low bioaccumulation potential. Imparts taste and odour in fish and shellfish at low concentrations. Variable toxicity.	Not detected.	Anzecc, 2000. Moderate reliability 95% protection level[a].	400
Pentachlorophenol (PCP)	A biocide, disinfectant, pesticide and wood preservative. Found in chlorinated effluents from sewage treatment plants. Impair taste, more toxic at lower pH. The Anzecc 99% protection level is recommended in the absence of local bioaccumulation data.	Not detected.	Anzecc, 2000. Moderate reliability 99% protection level[b].	11
Pesticides, Insecticides, Herbicides and Fungicides				
All organochlorine (OC) pesticides	The use of OC pesticides was phased out in Barbados more than a decade ago. However, the compounds are persistent with high bioaccumulation potential. The detection limits for most OC's are greater than the standards, so it is recommended that OC's should not be detectable in marine waters.	Some have been detected at low levels, but not in exceedance of guidelines.	Anzecc, 2000.	Not detectable, based on a detection limit of 0.005.
All organophosphate (OP) pesticides	Commonly used in Barbados. Toxic to most species. Detection limits in the order of 0.02 µg/l in water. Recommended standards are lower. Therefore, it is	Some have been detected at low levels, but not in exceedance of	Anzecc, 2000.	Not detectable, based on a detection limit of 0.05.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	Ambient Water Quality Standard (µg/l) unless otherwise stated.
	recommended that OP's should not be detectable in marine waters.	guidelines.		
Other Insecticides, Herbicides and Fungicides	Insufficient data currently exists to allow Anzeoc to generate moderate reliability trigger levels for other pesticides at this time. To be precautionary, it is recommended that a No Detection limit be used as a default in the absence of other data.	Some have been detected at low levels, but not in exceedance of guidelines.	Anzeoc, 2000.	Not detectable, based on a detection limit of 0.01.

[a] The 95% protection level means that at this concentration it is expected that 95% of species will be protected.
[b] The 99% protection level means that at this concentration it is expected that 99% of species will be protected.

Parameter	Rationale	Current Status in Barbados	Basis of Standard	End of Pipe Standard
Biochemical Oxygen Demand	When there is a large quantity of biological matter in the water bacteria will break it down but use up oxygen at the same time. This is a measure of that oxygen demand and will lead to a drop in dissolved oxygen levels.	This can be high for specific types of discharge such as sewage effluent and rum distillery waste.	UNEP, 1999 - LBS Protocol.	Class 1 – 30mg/l Class 2 – 150mg/l
Total Suspended Solids (TSS)	Suspended solids increase turbidity, reduce light penetration, and decrease photosynthetic activity – the basis of coral growth. Also important in the transport of other pollutants that are strongly associated with the solids, such as metals.	Can be problematic during construction or near freshwater discharges such as drains and gullies. Occasionally exceeds standard.	UNEP, 1999 - LBS Protocol.	Class 1 – 30mg/l Class 2 – 150mg/l
Total nitrogen (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well. The end-of-pipe standards have been set to meet the ambient standard in Class 1 waters within a 50:1 mixing zone.	Not measured.	Class 1 based on 50:1 dilution with nutrient removal. Class 2 based on no or advanced preliminary treatment.	Class 1 – 5mg/l Class 2 – 45mg/l
Total phosphorous (inorganic and organic)	Better indicator of nutrient loading as measures organic load as well. The end-of-pipe standards have been set to meet the ambient standard in Class 1 waters within a 50:1 mixing zone.	Not measured.	Class 1 based on 50:1 dilution with nutrient removal. (CEHI, 1998) Class 2 based on no or advanced preliminary treatment.	Class 1 – 1mg/l Class 2 – 10mg/l
pH	General indicator of acidity/alkalinity. Change in pH can be either toxic directly or indirectly by changing the toxicity of other pollutants.	Rarely measured.	EEC, 1976 and World Bank, 1999.	6-9 in Class 1 and 2 waters.
Faecal streptococci	Public health indicator of sewage pollution in seawater. This is generally the preferred indicator of health risk.	Priority pollutant that has previously been detected at high levels.	US EPA, 2002. UNEP, 1999 - LBS Protocol.	Class 1 - Geometric mean of min. 5 samples should not exceed 35 colonies/100ml in any 30-

Parameter	Rationale	Current Status in Barbados	Basis of Standard	End of Pipe Standard
				day period.
Faecal coliform	Public health indicator of sewage pollution in freshwater, but historically used in seawater as well.	Priority pollutant that has previously been detected at high levels.	UNEP, 1999 - LBS Protocol.	Class 1 - Geometric mean of min. 5 samples not exceed 200 colonies/ 100ml in any 30-day period. No more than 10% of samples exceed 400 colonies/100ml.
Total Residual Chlorine	Chlorine is commonly used as a disinfectant in potable water and in sewage treatment, toxic to many marine species.	Not measured.	CEHI, 1998.	Class 1 - 0.1mg/l
Fats, Oils and Grease	Found in urban runoff and domestic waste. Smothers shoreline ecosystems. Can be toxic.	Not measured as a general group. Generally below detectable limits.	UNEP, 1999 - LBS Protocol.	Class 1 – 15mg/l Class 2 – 50mg/l
Floatables	Plastics and other materials that are not easily removed by natural processes. They can smother or be ingested by organisms.	An important problem.	UNEP, 1999 - LBS Protocol.	Not visible in Class 1 and 2 waters.

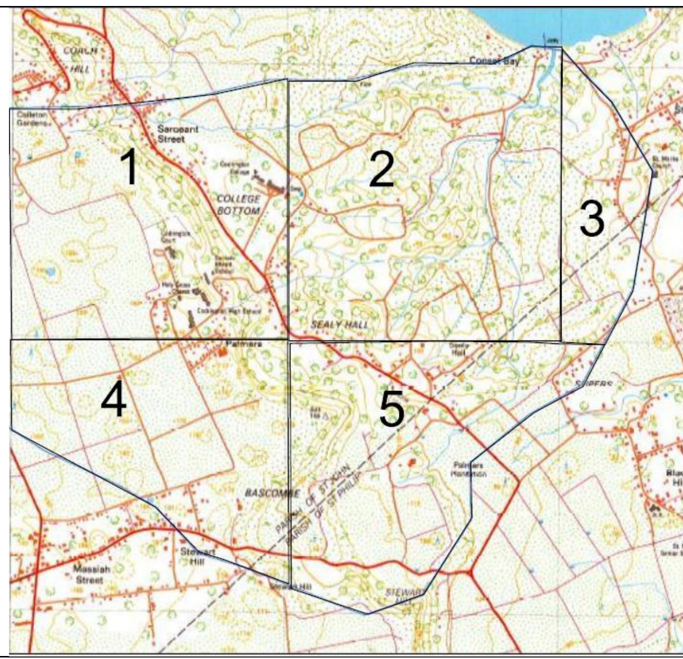
Parameter	Rationale	Current Status in Barbados	Basis of Standard	End of Pipe Standard
Total Petroleum Hydrocarbons (TPH)	Important chemicals used in the production of oils and fuels. Found in industrial discharges and urban runoff. Smothers shoreline ecosystems. Lighter fractions are most toxic.	Not measured as a general group. Generally below detectable limits. Longer chain hydrocarbons found at detectable limits in Careenage and at tanker moorings, but below standards.	Max - State of Wyoming, 2000. Av. Daily value is interim value recommended by consultants to allow some flexibility.	Max. daily discharge (mg/l): 10 Av. Daily concentration over 30 consecutive days (mg/l): 5
Total Oils & Greases	Found in industrial discharges and urban runoff. Smothers shoreline ecosystems. Can be toxic.	Not measured as a general group. Generally below detectable limits.	Max - World Bank, 1999. Av. Daily value is interim value recommended by consultants to allow some flexibility. Based on US EPA, 1995.	Max. daily discharge (mg/l): 10 Av. Daily concentration over 30 consecutive days (mg/l): 5
Total Organic Carbon	The level of organic carbon can influence the availability of other pollutants. Directly non-toxic.	Not measured.	Max - US EPA, 1995. Av. Daily value is interim value recommended by consultants to allow some flexibility.	Max. daily discharge (mg/l): 110 Av. Daily concentration over 30 consecutive days (mg/l): 55

[2] Petroleum Hydrocarbons – consistent standards are difficult to find. The daily average over 30 days is included to allow some flexibility for dischargers, but may be more difficult for regulators to monitor. The values are at this stage based on the 50% difference seen for oils and grease, but are certainly up for discussion. It may be preferable to use a standard for BTEX rather than TPH etc.

APPENDIX 2: FIELD ASSESSMENT SHEET

fid	X	Y	width	depth	btype	v type	dom tree	dom shrub	adjacent land use	comments
1	232671	1458255	10		water	marshy grassland	cocnuc		boat yard/fishing complex	
2	232505	1458031	2		water	open forest	corobl	leuleu	forest	abandoned road runs along river, gabions present
3	232500	1458000	2	2	water	open forest	corobl	leuleu	forest	
4	232443	1457775	1	0.5	water	open forest	corobl	leuleu	bareground/abandoned road	vegetation cleared
5	232491	1457629	1		water	closed forest	tercat	leuleu	continous scrub	
6	232441	1457776	2		water	open forest		wwillow		
7	232340	1457568	3		water	closed forest		wwillow		
8	232317	1457545	5	4	water	closed forest		wwillow		
9	231650	1457776	2		water	running water			institutional	drainage outflow from building to stream, sparse vegetation planned along stream
10	231778	1457770	2		water	running water	banana		residential	irrigation lines connected in stream leading in various directions
11	231815	1457813	5		water	open forest	almond	elephant ears	agriculture	small scale agri of bananas; river is terraced
12	231956	1457841	5		water	closed forest	pride of india	wwillow	agriculture/ forest	argiculture of bananas and coconuts mixed with forest veg
13	231999	1457849	5		water	closed forest	tercat	wwillow	forest	signs of irrigation
14	232074	1457864	5		water	closed forest	tercat	wwillow	continous scrub	
15	232094	1457866	10		water	open forest	tercat	ginger lilly	residential/agriculture	manmade concrete drainage
16	232264	1457825	10	10	water	closed forest	tercat	wwillow	forest	some bamboo seen along river
17	232272	1457040			earth	scattered trees	corobl		forest	beginning of river at bridge
18	232254	1457128			earth	scattered trees	corobl		pig pen	
19	232378	1457197			earth	scattered trees	cocnuc	leuleu	agriculture/housing	cultivated bananas
20	232378	1457197			earth		almond	leuleu		
21	232493	1457623					corobl	leuleu		
22	232576	1458141	1				corobl	leuleu		man made drainage
23	232339	1458197	1		water		corobl	leuleu		
24	232339	1458197								
25	232097	1458013								
26	231794	1457876				closed forest	corobl	leuleu		
27	231084	1458199								
28	231121	1458233								
29	231207	1458234								
30	232363	1456946	2	1			sunburn tree	leuleu	grassland	man made drainage, mahogany and flamboyant passed grassland
31	231684	1457402								
32	231656	1457464	1		rocks		delreg	leuleu	residential	concrete drainage, bananas growing along side river
33	231473	1457386			earth		delreg	leuleu	residential	
34	232108	1457760					corobl	leuleu		bananas grown near river near houses, small farming plots
35	231950	1457655				scattered trees	cocnuc	banana	residential/grassland	start of river
36	231240	1457957	0.5					leuleu	residential	

APPENDIX 3: LAND-USE ACTIVITIES QUESTIONNAIRE.

Gender of respondent:	( ) Male ( ) Female
Age of respondent:	( ) 11 – 18 ( ) 19 – 30 ( ) 31 – 45 ( ) 45 – 65 ( ) 65 +
Do you know what a watershed area is? *(If yes)* Please tell me in your own words what the words “watershed area” means to you	( ) Yes ( ) No
In which community do you live?	Conset Bay[] St. Marks[] College Savannah[]Sealy Hall[]Sargeant St.[] Other[] (if Other please specify in which parish) …………………………..
What types of activities do you do in the area?	( ) Boating ( ) Fishing ( ) Swimming ( ) Farming ( ) Staking out animals ( ) Hunting ( ) Other (please specify) …………………………………
What types of activities do you use the streams in the watershed for?	Irrigation[] Fishing[] Drinking Water[] Household Uses [] Other [] (please specify)
In which of the numbered areas do your activities take place? Please list activity in corresponding area Area1:...................................... Area2:...................................... Area3:...................................... Area4:...................................... Area5:......................................	
What types of activities do you think could be harmful to Conset Bay?	Dumping of garbage [] Removing vegetation [] Bad farming practices [] Water run-off from homes [] Agro-chemicals, pesticides and other chemicals [] Don’t know [] Other [] (please specify)…......................
What types of activities could be helpful to Conset Bay?	Proper disposal of garbage [] Re-planting the vegetation [] Proper farming practices [] Proper sewage systems for the nearby homes [] Proper disposal of agro-chemicals, pesticides and other chemicals [] Don’t know [] Other (please specify)…………………………………