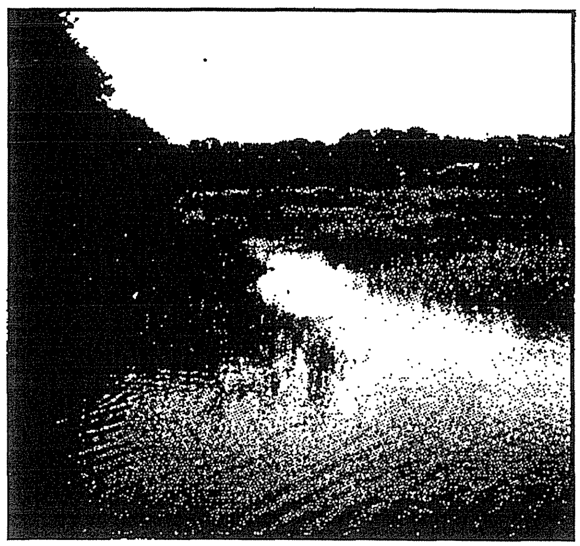
Working Draft

Barbados Tourism Development Programme Subprogramme C

Part 1: Graeme Hall Swamp Today



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Acknowledgements

Many professionals and scientists in the consulting, government, university and private and not-for-profit conservation sectors have contributed to this report and to the studies upon which it is based. Their assistance in contributing materials and insights is gratefully acknowledged.

The study team has also consulted with several stakeholders: the Ministries in the Barbados government responsible for the tourism, environment and health, as well as public works; the NGOs with involvement in nature conservation and protection issues, and with the people of Barbados. A significant level of interest in the issues related to Graeme Hall Swamp has been evident throughout the course of the project, and the input resulting from these consultations has been invaluable in formulating the recommendations contained in this document.

Early in the study, the Graeme Hall Swamp Education Committee, with the support of the Ministry of Foreign Affairs, Tourism and International Transport, and the Ministry of Health and the Environment, hosted a public meeting to solicit input from the residents and property owners in the vicinity of the swamp. Comments received at this meeting underscored strong public attachment to the swamp, concerns about the state of its environment, and the desire to initiate a plan of action to remedy current and historical problems.

The study team extends sincere appreciation and thanks to all those who took the time to attend meetings and/or share insights, ideas, advice and information. In Particular, the Graeme Hall Swamp Project Working Group that guided the study process and acted as a sounding board for the various ideas proposed over the course of the study program. To the NGOs and government agencies that devoted valuable time to meet with us, provide us information and serve on committees, we owe a special thank you. Finally, we wish to express a special thanks to the Project Steering Committee under the enthusiastic direction of Mr. Charles Holder and Mr. Rudolph Hinkson.

$800,000 U.S. IADB Study

Note to Reader

For Convenience during the review process, this document has been produced in three parts:

- Part I: Graeme Hall Swamp Today
- Part II: Graeme Hall Swamp's Future
- Part III: Appendices and Background Documents

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effective management strategy was formulated that sets the ground rules for the long term protection, enhancement and maintenance for Graeme Hall Swamp.

1.4 Work Plan

Graeme Hall Swamp is one of the few remaining examples of a complex wetland ecosystem in Barbados. The work plan for GHS study included relevant biophysical parameters and identification of the swamp's long history of development to arrive at a realistic judgement on how the swamp should be used and managed. The management objectives included recommendation on the swamp's potential role in the country's nature-based tourism programme.

Specifically, the GHS work plan focused on:

- A realistic investigation of the swamp's biophysical characteristics
- Documentation of historical, current and planned use
- An assessment of the swamp's current biophysical status
- Development of a comprehensive management plan
- Development of a realistic implementation plan.

The major components of the work program are summarised below and detailed in Appendix Section 12.1 .

1.4.1 Characterise the Swamp Area

The characterisation of the ecological boundaries of Graeme Hall Swamp provides the ability to evaluate and make recommendations for the swamp as a functional unit. A biophysical reconnaissance identified the relevant physical, biological and infrastructure characteristics of the swamp. This reconnaissance, together with compilation of other relevant studies formed the basis for a working site plan which was used for the biophysical recommendation and the potential development options for the swamp as a functional unit.

1.4.2 Management and Use

Graeme Hall Swamp and its surrounding habitat have been heavily influenced by human activity for over 300 years. Documentation of these human activities that have effected the swamp; such as ownership, human use, education and scientific projects, and agriculture are all important to understand the swamp's current characteristics. The central causeway, the sluice gate operation, and the redevelopment of Highway 7 have all influenced the swamp's characteristics, and the historical and on-going effects of these developments were investigated and evaluated. An assessment of the development and operation of the South Coast Sewerage Treatment Facility provides an understanding of the long-term viability of the swamp and its potential for nature-based tourism. Ongoing and planned government programs, such as the mosquito control program, also affect the viability and management options for the swamp system.

More than half of the swamp is in private ownership, and the entire southern fringe of the swamp is surrounded by residential and commercial development. Existing and planned uses of these

- loss of ecologically important marine/terrestrial/coastal habitat
- sustainability of existing flora and fauna
- introduction of non-native species of flora and fauna
- agricultural pesticide and fertiliser runoff
- leachate from indiscriminate litter and garbage dumping
- water quality/quantity and "rush water" flooding issues resulting from inadequate drainage/tidal flow control.

Graeme Hall Swamp could offer visitors a unique and exciting natural experience if these issues can be resolved, and become a welcome respite from the bustle of the densely populated and busy tourism areas of South Coast Barbados.

Government proposed developing the area as a nature reserve and tourist attraction as far back as 1981; however, lack of funds, jurisdictional uncertainties, and land tenure entanglements inhibited any significant actions regarding the status and management of the swamp. The time has now arrived for decisions and definitive action on the future of Graeme Hall Swamp before outside forces preclude any realistic future options.

1.2 Project Objectives

Subprogramme C has a number of common objectives for resource protection and sustainability, public awareness, linkages to tourism and revenue generation, and creation of appropriate institutional structures. Within these overall programme objectives, the Graeme Hall Swamp Programme is designed to formulate a strategy for the protection and management of Graeme Hall Swamp and evaluate the development of its key features and attractions. Specifically, this includes:

- Assessing the ecological, recreational, educational and scientific resources of Graeme Hall Swamp
- Assisting the Government of Barbados to define the objectives, goals and values of a reserve at Graeme Hall Swamp
- Examining the feasibility of developing and managing Graeme Hall Swamp as an economically viable nature reserve.

1.3 Methodology and Approach

Graeme Hall Swamp has been subjected to well-intended physical interventions over a long period of time, and its natural resources have been studied for the past 40 years. Many of these studies have been reasonably well documented. Graeme Hall Swamp has not, however, been subjected to a holistic scientific evaluation, and the ecological and hydrologic regimes of the swamp are not very well understood. Hence, the focus of these Graeme Hall Swamp investigations was to develop a sound natural profile of the area and, from that, to identify the preservation/management options for the area. Based on these options, a recommend for a costprivate developments will be a major determinate in identifying and evaluating realistic options for long term management of Graeme Hall Swamp.

1.4.3 Existing Environment Evaluation

Current data provides the basis for determining the existing status and "health" of Graeme Hall Swamp and this information, together with previous studies, provides the basis for formulating the recommendations necessary to management the swamp as a natural, sustainable resource for the foreseeable future.

Current biophysical data on GHS provides an understanding of the complexity of this ecosystem, allows for a comparison with similar mangrove ecosystems that have not been impacted by human activities, and provides the understanding of how to maintain the swamp as a functioning ecosystem. These biophysical data include water and nutrient flows, water quality and quantity, nutrients, plankton and invertebrates that form the basis of the swamp food chain, the structure and composition of vegetative communities, and the species of birds and other wildlife all provide an understanding of the swamp ecosystem. Recommendations for the biophysical management of the swamp are based on an understanding of swamp dynamics derived from these data, and these recommendations will, in turn, provide the basis for overall development and management recommendations GHS.

1.4.4 Management Plan

The comprehensive management plan developed for Graeme Hall Swamp is based on government's objectives for the swamp, current and planned use, and results of the environmental assessment and modelling of the swamp ecosystem. This management plan focuses on measures required to protect and maintain Graeme Hall Swamp a functional coastal wetland ecosystem, and the appropriate development of its unique features for nature-based tourism.

Protection and sustainable management of the swamp as a functioning ecosystem is not only important as a national priority of protecting the country's natural heritage, it is critical for developing any nature-based tourism in the swamp. The management plan specifically addresses management of the swamps resources, water movement and exchange issues, reclamation and restoration of the area's resources, resolution of existing or planned incompatible uses, and development on adjacent areas.

The management plan also specifically addresses viable tourism development themes and activities, with significant emphasis on visitor capacities and Limits of Acceptable Change monitoring. These monitoring plans are designed to maintain product quality, and develop a realistic and focused organisational and management structure that includes adequate training programs and visitor management systems.

1.4.5 Implementation Plan

As in any major project development, the success of the Graeme Hall Swamp protection and management plan will be primarily depend upon a well thought out implementation plan. This plan must include a legislative and policy framework and capacity that supports the plan objectives. It must also include a realistic evaluation of funding sources available for site development, the tourism potential of the site, the projected revenues from tourism and the procedures to maximise revenue retention for site operation and maintenance. It must also include a business plan with sound financial planning and controls and, most importantly, it must include practical mechanisms to maximise local economic development linkages and maximise economic returns to the local area.

Last, and probably most importantly, the implementation plan must recognise that protection and maintenance of the site and the success of any nature-based tourism products developed at the site will be completely dependent upon the awareness and support of the public, particularly in the local area. The implementation plan will contain, therefore, specific recommendations on a public awareness and education program, and on a program to actively involve the local communities in site development and operation.

2. Defining Graeme Hall Swamp

Graeme Hall Swamp, located on the South Coast of Barbados, is the last remaining major coastal wetland area in Barbados. The majority of the swamp has two different owners, and functionally is being operated as two separate units. The portion of the swamp West of the causeway (Figure 2-1 is owned by the Graeme Hall Bird Sanctuary, Inc. which has submitted an application to Town & Country Planning for development of the property as a Nature Centre. The East section of the swamp remains under government ownership. There are a number of government agencies with jurisdictional authority for this portion of the swamp, however financing has been not specifically directed for the swamp in recent years and no development or management activities have occurred.

The main body of the swamp, comprising approximately 91 acres, has been designated as the GHS Management Unit for the purpose of this study, and for the management and development recommendations contained in later sections of this report. Reference to "GHS" or "the swamp" in subsequent portions of this report refers to this GHS Management Unit, unless otherwise designated.

The boundary of this GHS Management Unit includes the property boundary of the private property in the western section of the swamp and assumes that the CLICO lands currently under negotiation with Graeme Hall Bird Sanctuary Inc. will be added to the private holdings of the swamp. The Northwest boundary borders the residential development of Amity Lodge, and the northern boundary borders the footpath on the South side of the Ministry of Agriculture experimental fields. The East and South boundary of the government property borders the marl road being constructed for laying the sewage effluent pipe.

The northeast portion of the government portion of the swamp, within the area designated in this report as the GHS Management Unit, is currently being developed for the South Coast Sewage Treatment Plant. This treatment plant will occupy about 5 acres of the swamp, and the project also includes construction of a 24-foot wide marl road along the South and East property boundary that is being used as a work pad to lay the sewage discharge pipe. This work pad will cover about 2 acres of the swamp, but will be reduced to about an 8-foot footpath along the swamp boundary after the sewage pipes are installed.

The entire drainage basin for Graeme Hall Swamp is about 1156 acres (Cattaneo et. al. 1988). The land immediately South and West sides of the swamp contains relatively intense urban development; along Highway 7 on the South side in Worthing and St. Lawrence, and along the West side along Rendezvous Road in Amity Lodge and Rendezvous Gardens. The North and East sides of the swamp are surrounded by undeveloped land, primarily in agricultural experiment fields or in pasture.

These lands immediately adjacent to the swamp significantly influence the biophysical viability of the swamp and, because of this influence, have been identified as a GHS Management Buffer Zone for the purposes of this study (Figure 2-1). This Management Buffer Zone includes approximately 183 acres surrounding the GHS Management Unit, or about 10 percent of the entire drainage basin of the swamp. The Buffer Zone is roughly bounded by Highway 7 on the South, Rendezvous Road on the West, the escarpment containing the old plantation property [Ministry of Agriculture] on the North, and the extension of the Harmony Hall Road to the Sewage Treatment Plant on the East. This buffer zone area served as the primary focus of investigation and examination of associated land use in this study, and as the focus of recommendations for future management and development of the swamp.

The western portion of the St. Lawrence Gap immediately South of Graeme Hall Swamp also contains another wetland area, the St. Lawrence Swamp. This well-defined wetland area is completely enclosed by the developments bordering Highway 7 and the St. Lawrence Gap drive. It is not directly connected to Graeme Hall Swamp, and does not appear to affect or by affected by Graeme Hall Swamp. For this reason, the St. Lawrence Swamp was not included in the investigations or recommendations for Graeme Hall Swamp. Many of the conclusions and recommendations applicable to Graeme Hall Swamp will, however, also be applicable to the St. Lawrence Swamp.

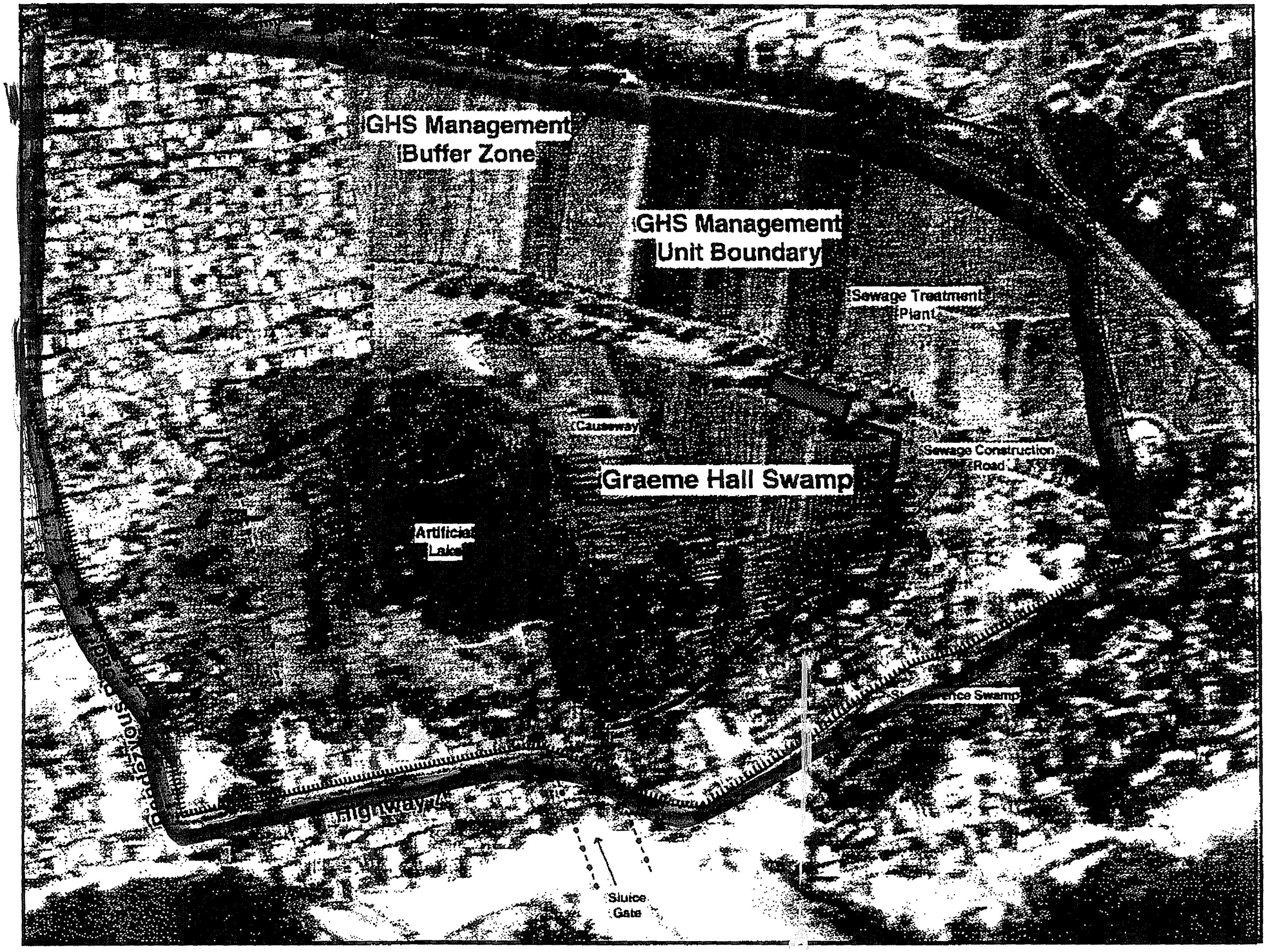
The bridge on Highway 7 crosses the last remaining direct connection between Graeme Hall Swamp and the ocean. This connection is now a canal running along the West Side of the Causeway draining the artificial lake on the western portion of the swamp into the ocean. Water movement between the swamp and the ocean is controlled by a sluice gate located at the beach The operation and effects of this sluice gate have been the subject of considerable controversy in recent years.

St. Lawrence Bay, immediately offshore from the beaches adjacent to Graeme Hall Swamp, contains one of the most extensive seagrass beds remaining in Barbados (Vermeer 1997). These seagrass beds have historically interacted with Graeme Hall Swamp by receiving nutrients from the drainage through the swamp into the bay, and by providing faunal diversity from the seagrass beds to the swamp. There has been a substantial loss of these seagrass beds in the last 40 years, and a reduction in the diversity and abundance of marine fauna. These reductions in the seagrass beds adversely affect the faunal diversity and abundance of the offshore coral reefs, endangered species such as the green turtle, and the sources of faunal diversity and abundance for the swamp.

The seagrass beds, and specifically effects of the Sewage Treatment Plant on the beds, were included as a specific component of this study of Graeme Hall Swamp. A review of the aquatic fauna of Graeme Hall Swamp and the effects of the bay and the seagrass beds on this fauna was also conducted as a component of the Graeme Hall Swamp studies. These studies are included as appendices in their entirety in Section 12.4 and Section 12.5. The interaction of the swamp and the bay, and the resulting inter-relationships, were important considerations in the subsequent recommendations for management and development of Graeme Hall Swamp in this report.

This report, therefore, focuses on the GHS Management Unit as Graeme Hall Swamp, "the swamp". The GHS Management Buffer Zone is included in this report as the major source of external influences to the swamp. The canal and the sluice gate are given attention because of their role in connecting the swamp with St. Lawrence Bay and because of their influences on the tourism and recreation on the beach. The bay and its coral reefs and seagrass beds are addressed because of their interdependence with the swamp. St. Lawrence Swamp is not addressed because of its lack of direct connections and inter-relationships with Graeme Hall Swamp.

Figure 2-1. Graeme Hall Swamp Project Area.



3. Historical Setting

3.1 Introduction

Developments and modifications undertaken by its owners over the past three centuries have been significantly influenced how Graeme Hall Swamp exists today. Sugar cane production dominated island activities for most of this period. In addition to sugar cane, other activities at GHS have included cultivation and harvesting of grass for mule feed, cutting mangroves to build fence posts, extracting peat, a bird shooting club, fishing and crabbing (Kinas 1982; Hutt 1983; Arnott 1984). A number of these activities have significantly changed the biophysical characteristics of the swamp.

In addition to these commercial activities, other physical alterations and developments initiated over the last century have also significantly changed the biophysical characteristics of the swamp. These developments include constructing three sluice gates in 1920 on Worthing Beach and constructing a central embankment 1947 that bisected the swamp. Large tracts of mangroves in were also removed and para grass was introduced in the eastern section, and an artificial lake was dredged for an aborted development in the West Unit in 1972.

Recent developments include construction of the South Coast Sewage Treatment Facility and associated sewerage system in 1997, and major landscape revisions on the western section in April 1997. The following Sections describe the nature and significance of these changes to GHS.

3.2 Ownership and Developments

The recorded history of Graeme Hall Swamp ownership dates to shortly after the island was colonised by English settlers in 1627 (Kinas 1982). The first recorded owners of the swamp and surrounding lands were the Kirton family, in the late 1600's. Graeme Hall Plantation originally included 373 acres, and was cultivated primarily for sugar. A Greeme or Grame family owned a large portion of the Plantation for most of the 18th century. The land changed ownership frequently during the first few decades of the 19th century, with at least three different owners (Mayers, Belgrave, Roach) of the 243 acres estate and swamp.

J. Belgrave purchased the estate in 1820, and managed it until his death in 1828 as a 'shooting swamp' where bird hunting were permitted for a fee. Belgrave modified the swamp for this purpose by developing rows of banks and canals to attract birds to the site. These canals still remain in the eastern section of the swamp.

Ownership records are unclear between 1829 and 1842. Thomas Perch sold the estate to Thomas Spencer in 1861, who increased the size to 276 acres. Thomas Jones bought it in 1887, and sold it to the plantation's manager, Edwin Clarke, in 1892. His two sons acquired the estate upon his death in 1931, expanded it to 340 acres and retained ownership until 1945.

The stone bridge over the remaining channel to Graeme Hall Swamp was built in 1871. Construction of the original bridge and previous coastal road (1700's) probably took advantage of filling of the area. The road narrowed and reduced tidal flow into the swamp, which had long existed at the tidal interface with the freshwater flow from the surrounding basin. Building activity continued to take advantage of any dry land in the area.

The Clarke family developed the eastern section of the estate for grass cultivation by cutting mangrove trees in rows, dredging channels, and using the spoil to create banks for growing para grass (*Panicum muticum*) to feed tram mules in Bridgetown. Peat and mangrove poles were also harvested (Parker and Oxenford 1994). When tram service ended in 1924, coconut palms (*Cocos nucifera*) were planted along the banks (Stoute 1980; Hutt 1983). Para grass and coconut palms still exist in the eastern section of the swamp.

The Clarke family also constructed three sluice gates on Worthing Beach about 1920 to control water flow to and from the swamp (Hutt 1983). Only one sluice gate remains. Maurice Wexler, who acquired the estate in 1945, bisected the swamp in 1947 with a large central embankment that may have changed swamp drainage patterns by creating a water flow barrier between the western and eastern sections (Kinas 1982).

George Manning purchased 29 acres in the western section in 1947, and established the Graeme Hall Gun Club. Five wooden shooting huts were erected around the pools in the western section, and mangroves were regularly slashed to promote visibility for incoming birds. The Gun Club was closed on the western section about 1970, when adjacent residential property encroachment reduced the site's attractiveness to migrating shorebirds (Hutt 1983). The Gun Club continued in the eastern section until 1981, when Government banned hunting in the swamp.

Mr. Gooding purchased Mr. Wexler's property in the 1950's, and sold it to the Government of Barbados in the 1960's. Government acquired 289 acres, which included 189 acres of arable land, 48 acres of swamp, and 3.5 acres encompassing the sluice gate. The Barbados Agricultural Development Corporation held ownership until the early 1970's (Kinas 1982) when the estate was sectioned and distributed among various Government Ministries.

3.3 Vegetation

Historical vegetation analysis of Graeme Hall Swamp's[1] freshwater and brackish areas must consider the swamp's vegetation within context of the island's vegetation. This analysis includes the following assumptions:

- species composition and diversity is limited because of being an island, and this limitation must be recognised when comparing GHS vegetation to similar continental plant associations
- many historical plant associations within GHS will have resulted from similar influences and actions occurring within the Caribbean basin, and can be compared to other Caribbean islands and peninsular swamps

[1] Any discussion of Graeme Hall Swamp refers to the inland, tidal influenced wetland which includes fresh and brackish water containment and associated vegetation.

GHS plant composition and diversity analysis must incorporate the significant human actions on the island since the early 1600's.

Barbados' flora probably arrived in from the northern tropics and general Caribbean via the Guadeloupe-St. Lucia-St. Vincent chain and from South America via Trinidad, the Grenadines and St. Vincent (Gooding 1974, Watts 1966). Some species would have arrived via winds and currents from Africa and South America. Most of the island's 532 plants identified by Gooding (1974) and Watts (1966) came from Caribbean islands or tropical continental America (Table 3-1). Carrington (1993) recently described about 700 flowering plants growing in Barbados.

Table 3-1. Sources of Barbados Flora (Gooding 1974).

Source	Species
NORTH CARIBBEAN: species mainly north of Barbados (Florida, Greater Antilles)	55
SOUTH CARIBBEAN: species mainly in area of Trinidad and South America	90
TROPICAL /CARIBBEAN: species Caribbean and/or tropical continental America	204
PANTROPICAL: species throughout the topics world-wide	124
INTRODUCED BY HUMANS: intentionally brought to area	54
ENDEMIC: confined to Barbados	5

3.3.1 Historical Vegetation

Recent floral studies from Hardy (1934), Gooding et. al. (1965) and Watts (1966) contain similar Barbados botanical histories with little contradiction, and provide a basis for describing the possible makeup of pre-settlement vegetative communities, particularly in less utilised wetlands like mangrove communities. Barbados vegetative communities that existed before English settlement, compared to post-settlement vegetative, would probably appear to be flora of two different islands.

3.3.1.1 Pre-colonisation

Barbados was reportedly uninhabited when the English arrived in 1627, and the native vegetation reflected West Indies flora, particularly the Lesser Antilles and northeastern South America. Like many West Indies islands, pre-colonisation flora was probably affected by plants introduced either by early Amerindian residents or other visiting peoples (Arawaks, Caribs or Indians of the Saladoid-Barrancoid period) from South America or other islands.

Drewett (1991) reported that a number of early writers described fruits common in Barbados today that, whether native or introduced, may have been present prior to colonisation. These included Speed's reference to *Annona* (Momin) in 1676 and Ligon's mention of Sour Sop (*Annona muricata*) and pepper (*Capsicum frutescens*), as well as fruits such as custard apple (*Annona reticulata*), clammy cherry (*Cordia collocoa*), juniper apple (*Meliococca bijuga*), guava

(*Psidium guajava*), calabash (*Crescentia cujete*), pawpaw (*Carica papaya*), true pineapple (*Ananas comosus*), gully plum (*Spondias purpurea*), and wild plantain (*Heliconia caribea*).

Drewett (1991) obtained pollen samples of different historical periods from deep sediments taken at Chancery Lane and Graeme Hall Swamp. These core samples contained organic deposits and sediments with an organic deposit of not less than 175 cm at one location. Mangrove pollen was dominant in the samples, indicative of the long presence of mangroves in those locations. Watts (1966) concluded that in GHS the "littoral changed only slightly, except for a thinning of the valuable mangroves and whitewood, the quick dispersal of *Cocos nucifera*, and the introduction of tolerant grasses (*Paspalum distichum*) with long stems for growth in sand-dune marginal areas".

3.3.1.2 English Colonisation

The English immediately began harvesting timber, clearing native vegetation for planting, and introducing non-native cultivated plants and landscape species upon arrival. The original forest cover was estimated at 29,600 hectares. It was reduced to only 20 hectares at Turner's Hall Woods by 1657, and it was necessary to import firewood by the 1660's.

The settlers learned farming techniques from Arawak Indians from Guiana who introduced them to cassava, yams, maize, pulses, plantains, bananas, oranges, lemons, limes, pineapples, tobacco, cotton, annatto and melons (Scott 1667). Breadfruit (*Artocarpus communis*), ginger (*Zingiber aurantifolia*), and nutmeg (*Myristica fragrans*) were also subsequently introduced. Sugar cane was introduced from the Guianas at about the same time by the Arawaks but was not cultivated as a commercial plant until reintroduced by Peter Brewer of North Holland in 1637 (Powell 1656). Cane cultivation in Barbados began to dominate agriculture in the late 1640's when Portuguese-Jewish refugees from Brazil arrived with new sugar refining techniques (Watts 1966).

Details on specific plant species are difficult to extract from early studies that pre-date standardisation of scientific names. Drawings and descriptions provide some clues but much remains unknown. Ligon's (1657) reported dramatic changes occurring when sugar cane was introduction. Hutt (1983) described numerous introduced species including numerous garden herbs (brought by Ligon in 1647), the Shaddock (*Citrus maxima*) brought by Captain Shaddock in 1684, and some more notable introductions by unknown persons such as the mango (1690), the tomato (1720's) and the avocado (1750). mahogany introduced in 1780, spread across the island to uncultivated areas and gullies (Gooding 1974).

Dramatic changes in both flora and soil characteristics occurred between 1627 and the 1700's. Hardy (1934) noted "As regards the soils of Barbados, it may be remarked that over the larger part of the surface of the Island the soil has been tilled and manured for several generations. After all the natural virgin soil (which was laid bare as the primeval forest was cut down) had been brought under cultivation, the planters had to rejuvenate the land in order to make it continue to produce crops successfully. Hence considerable changes have been brought about in the composition of Barbados soils as a result of the influence of man".

Forest clearing for firewood, particularly in gullies, continued through the 1950's (Carrington 1993). Coastal wetlands and vestiges of original forest on sheltered cliffs or in gullies eventually served as the only potential refuge for native species. Gullies often served as the boundaries between estates and were usually cleared; though regeneration and development of secondary forests in some places occurred once this practice ceased (James 1991).

Since vegetative associations reflect soil, moisture, and climatic conditions; it is not unexpected that these associations were affected not only by forest clearing, but also by changes in soil characteristics and drainage patterns from agriculture and buildings. In addition to soil chemical changes. extensive soil erosion in the 1700's led to rapid sedimentation of downstream swamps and inlets, and changes to aquatic and vegetative communities such as Graeme Hall Swamp (Watts 1966). A coastal roadway in the 1700's took advantage of the developing sandbar near GHS, further separating the mangrove swamp from the sea.

3.3.1.3 The Twentieth Century

20th century botanists have deposited Barbados specimens in Kew, the British Museum of Natural History, the New York Botanical Gardens, the US National Herbarium in Washington, the Department of Agriculture (Barbados Museum and Historical Society) in Bridgetown, and in herbariums of a number of universities involved in West Indies studies, including the University of the West Indies in Jamaica. The most recent comprehensive work on Barbados vegetation is the multi-volume, *Flora of the Lesser Antilles* (1974-1989) which includes among the 3000 species (native, naturalised, cultivated) of the Lesser Antilles, the approximately 700 species of flowering plants known from the wild in Barbados (Howard 1988).

3.3.1.4 Graeme Hall Swamp

Early accounts reported littoral species including manchineel (***Hippomane macinella***), sea grape (*Coccoloba uvifera*), and mangroves in southwestern coastal Barbados (Colt (1631) and Ligon (1657) *in* Watts (1966)). Ligon (1657) wrote, "it has not been often that…fish, or any other, have been taken in that place, by reason the whole lake is filled with trees and roots". Watts speculates that Ligon may have been referring to the old Bridgetown Harbour. Colt's narrative reveals that mangrove bark was dried and used to fire cannons and, since Colt only travelled the western littoral zone, Watts (1966) postulates that at least one species of mangrove had to have been present in that area.

Hardy (1934) described Barbados' true hydrophyte (fresh water plants) and xerophytic (saline water plants) as plants that may live totally submerged in water or in soil that is very wet (Table 3-2). These hydrophytes including simple filamentous algae like Spirogyra commonly found in freshwater ditches at GHS. Soil anchored hydrophytes including hornwort (*Chara* sp.), a green alga and pond weed (*Ruphia maritima*), and a flowering plant in the Potamogatonaceae were typically found in brackish waters at Graeme Hall Swamp and at St. Lawrence swamp. The swamp at the turn of the century also contained a number of grasses and other swamp plants commonly found in fields that can tolerate being submerged from time to time.

3.3.2 Recent Vegetation Studies

Gooding (1974), Hutt (1983), Riven-Ramsey (1988), and Parker and Oxenford (1994) provided recent historical descriptions of mangrove and associated freshwater vegetative communities at Graeme Hall Swamp, including human actions affecting the swamp's vegetation.

Hutt (1983) described management practices at the Graeme Hall Gun Club from 1954 through 1967. These practices included cutting mangrove North of the main open water to a 5-foot high hedge each June and July. Large mature white mangrove (*Laguncularia racemosa*) along the eastern shore of the lake were cut in 1965, and the red mangroves (*Rhizophora mangle*) extending East and West from the eastern shore of the lake to the property limits along the drainage channel were cut to the ground.

Rapid re-growth of mangrove occurred in the western section of the swamp after cutting ceased in 1970. Cutting North of the pool ended earlier, and by 1972 trees were 20-25 feet high and hosting the first nesting of cattle egrets. Mangroves continued to grow un-checked, except in the Northeast corner of the lake toward the artificial hunting trays. White mangroves lined the South and West banks of the pool. The 1972 dredging of the lake in the West Unit provided fill for the shallow hunting trays South and West of the lake. This fill produced mostly dry or occasionally flooded land consisting of an old-field or coastal scrub type vegetation often dominated by cure-for-all (*Pluchea carolinensis*).

Graeme Hall Swamp is the main brackish water region still remaining in Barbados (Gooding 1974)--"Behind the Mangrove swamps the water - if it is still swampy- will be less brackish or virtually fresh". This Sedge Swamp association (locally often called "rushes") is now only seen in Barbados at the swamp. The main species are rush (*Eleocharis mutata*) growing to a height of 2-3 feet; grass rush (*Eleocharis monostachya*) which is small and tufted, club rush (*Albilgaardia monostachya*), and rusty club rush (*Fimbristylis ferruginea*) (Table 3-4). There are patches of crab grass (*Sporobolus virginicus*) and the pink-stemmed trailing *Philoxerus vermicularis* among the sedges. The flora of this brackish water itself is sparse, except for patches of floating Algae. Chara, one of the green algae, forms dense masses and is rooted in mud on the bottom of the swamp. The only other plant of any significance is the Tassel Pond Weed (*Ruppia maritima*).

In addition to extensive species list from the late 1970s and early 1980s, Hutt (1983) also documented storm damage to white mangroves in the eastern swamp during Hurricane Allen in 1980. Many trees were blown down, and young sucker shoot saplings subsequently developed along their trunks to create thickets of maturing trees.

Hutt (1983) found button mangrove (*Conocarpus erectus*) at Chancery Lane but not at GHS. He reported that the northeast portion of the eastern swamp was dominated by rush (*Eleocharis mutata*), along with a variety of more freshwater species including the grass rush (*Eleocharis geniculata*) and the rusty club rush (*Fimbristylis ferruginea*).

Table 3-4. Mangrove and Associated Freshwater Plants of Graeme Hall Swamp (Gooding 1974).

Scientific name	Common name
Rhizophora mangle	Red Mangrove
Laguncularia racemosa	White Mangrove
Avicennia nitida	Olive or Dwarf Mangrove Black Mangrove
Conocarpus erectus	Button Mangrove
Eleocharis mutata	Rush
Albilgaardia monostachya	Club Rush
Fimbristylis ferruginea	Rusty Club Rush
Sporobolus virginicus	Crab Grass
Philoxerus vermicularis	
Ruppia maritima	Tassel Pond Weed
Chara sp.	Hornwort

A varied assortment of coastal strand and wayside plants had begun to overtake the raised banks and some areas created to grow para grass. The higher and drier areas of the swamp periphery included the introduced casuarina (*Casuarina equisetifolia*), the tamarind (*Tamarindus indica*) and the shak-shak or woman's tongue (*Albizzia lebbeck*). Hutt (1983) also included specific reference to the "eastern pool"; an open freshwater area northeast of the white mangrove and south of the freshwater sedge marsh lining the base of the northeastern ridge.

The generalised 1988 vegetative cover map in Riven-Ramsey (1988) provided an overview of swamp vegetation communities as they appeared nearly a decade ago (Figure 3-9 (a)). This map showed expansion of mangrove and other vegetative changes compared to vegetative mapping conducted during the 1960's and 1970's. The cattle egret nesting colony was well established by 1988; developing amid one of the most densely populated and developed areas of the island. The filled land South of the lake was becoming well covered with scrub vegetation.

Parker and Oxenford's (1994) generalised vegetative cover map of Graeme Hall Swamp updated vegetation mapping from Riven-Ramsey's (1988) report, and included additional descriptions of additional management changes. The absence of the eastern pond or "eastern lake" that appeared on Hutt's 1983 sketch and Riven-Ramsey's 1988 vegetative map of Graeme Hall Swamp is noteworthy, as is the absence of extensive areas of casuarina shown South and West of the "western lake". Parker and Oxenford (1994) described these areas as grassland with white mangrove along the wet creek, and much reduced areas of "dry woodland" with no *Casuarina*. They do show the distinctly separate northeast patch of casuarina woodlands also included by Riven-Ramsey (1988); although that map shows much more casuarina between the eastern canals that is not reported in Parker and Oxenford (1994).

Parker and Oxenford (1994) also noted that red mangrove dominate much of the western lake shoreline, while white mangrove dominate the northeast shore and form isolated clusters along the southern boundary of the swamp. They also noted the now mature white mangrove in the East Unit, the continued spread of shrub land onto the filled areas in the West Unit, and the network of human-created drainage canals containing lotus water lilies, water lettuce, and filamentous green algae. The periodic cutting of mangroves in recent years by the Ministry of Health has seemingly reduced the spread of red mangroves in the areas that they are best adapted to colonise.

3.4 Wildlife

Barbados, because it is an oceanic island, would be expected to have a limited faunal diversity compared to tropical continental areas. Historically, animal migrations may well have mirrored arrival of plants from the North and along island chains; from the East on currents and winds from Africa, and from the South. The most obvious wildlife colonisers would have been birds, sea turtles and vertebrate and invertebrate life of the littoral zones on currents and tide.

Historical documents suggest substantial wildlife, particularly birds, on Barbados; including some species that would be expected in a Caribbean mangrove community (Ligon 1657, Hughes 1750, Schomburgk 1847). Ligon makes particular note of land crabs and bats, "sparrows, haysocks, finches, yellow hammers, titmice" and "Lizards we had in great plenty". Ligon also reports drastic habitat changes even within the first 30 years of colonisation, and notes at least ten species introduced by Europeans, including turkeys, goats, rabbits, hares, and camels.

Drewett (1991) reported 51 faunal species, primarily fishes, in pre-historic samples from Barbados. He suggested the rice rat (*Oryzomys*) may have been Barbados' only prehistoric native land mammal; and that snakes also appear to have been present. He observed that "Although Barbados probably never had an extensive land-based fauna it is surrounded by a warm sea with shallow water, reef habitats and close by deep water" a wide range of fish and shellfish were available for human use. Hutt (1983) also provided extensive anecdotal material on Barbados wildlife, including a list of 187 bird species and observations made in Graeme Hall Swamp and Chancery Lane Swamp.

3.4.1 Wildlife in Graeme Hall Swamp

Very little information is available on pre-colonisation wildlife species within the swamp. The Historical wildlife biodiversity of the swamp was probably comparable to similar Caribbean mangrove ecosystems. The size and location of Graeme Hall Swamp's mangrove and associated habitats may have made it increasingly attractive for wildlife habitat in light of continually decreasing habitats in other areas of the island.

Geologic records of peat deposits suggest GHS has been a mangrove swamp for several hundred years. It probably provided habitat for the now extinct Barbados racoon (*Procyon gloveralleni*) and a wide variety of birds that occur throughout the Caribbean. It was originally a marsh and mangrove system that included St. Lawrence Swamp and other surrounding wetlands open to or fringed the St. Lawrence Bay. This interconnection was important for fish and invertebrate exchange, and for tide and storm flushing for inland water quality. Water exchange between the swamp and the bay is still a key element influencing wildlife biodiversity in Graeme Hall Swamp. As the area between the bay and the mangrove was raised or filled; natural exchange between the bay and the swamp has gradually become limited to the remaining sluice gate and some sub-surface water movement. These changes have greatly curtailed exchange of water and marine vertebrate and invertebrate species within the swamp.

Very few scientific wildlife collections have been made in the swamp, and only 9 of 51 species identified in fossil records or Amerindian use analysis for Barbados appear to be from Graeme

Hall Swamp (Drewett 1991). Local ornithologists and amateur enthusiasts indicate that at least 100 species of birds use the swamp for nesting, a temporary stopover, and/or feeding area. However, recent reports (Watson 1997) and a survey of written materials and notes on Graeme Hall Swamp could not verify these claims. Reviews of written and anecdotal material indicate that few if any wildlife species have been totally eliminated from Graeme Hall Swamp.

Carrington et. al. (1993) included an overview of wildlife species commonly seen on Barbados. Lack of any on-going, systematic observations of birds and other species in the swamp may be the reason why some migrants are not reported for one or more years. In addition, the lack of shallow mud pans in the swamp has reduced its attractiveness to these birds.

3.4.2 Human Impacts on Wildlife Diversity

It appears that the diversity of nesting and migratory birds has remained fairly constant in Barbados following European colonisation, however, the number of birds has been greatly influenced by habitat manipulations over the last 300 years.

Mangrove swamp complexes frequently have shallow mud flats washed by tidal action that attract shorebirds, and include freshwater marshes inland from the mangroves that are also attractive to a diverse bird population. The shallow feeding trays constructed at the swamp have been in use since the 1800's, and were maintained by various shooting clubs until 1977. The periodic building and maintenance of shallow feeding trays or ponds mimicked the natural marsh conditions, attracted migrating shore and wading birds and significantly increased avian biodiversity. Historical reports of large numbers of a variety of bird species killed during each hunt indicated that these pans were significant attractions to birds (Watson 1997, Hutt 1983). A recognisable decline in shore and wading bird diversity at the swamp occurred immediately after the last bird pans were filled. Reports indicate that more than a dozen species are still being killed in large numbers in pans at the northern end of the island.

There are definite signs that fish and marine invertebrate fauna have been negatively impacted by operation of the sluice gate and siltation and waste water discharge into the swamp during construction of the South Coast Sewage Treatment Plant (see Sections 4.6, 4.8.3).

3.4.3 Exotic Species

Barbados has a long history of introducing wildlife species from many areas of the world, starting well before European settlement. In fact, it appears that there are currently more exotic species of mammals, and possibly reptiles, on Barbados than there are native species. All mammals found in Barbados and in the swamp, with the probable exception of bats, have been introduced over the past 300 years. Animals like the mongoose (an introduced predator of small vertebrates) can strongly influence other wildlife populations, and the existence of these predator species may have caused extinction of some ground nesting birds, reptiles, and amphibians. The mongoose is the most commonly encountered mammal in the swamp, along with the African green monkey (*Cercopithecus aethiops*) and the black rat, (*Rattus rattus*). The reportedly native racoon (*Procyon gloverallení*) may have inhabited the swamp before it became extinct.

There have been many reports of people releasing exotic species of fish, birds, and reptiles in Barbados, some into the swamp (Table 3-5). Most releases are unwanted pets or unintentional "hitch hikers" but others have been intentionally released in hopes that they would reproduce and provide stock for future collections, or add to the rather limited fauna of the island. Gilbert (personal communication) indicated that there are so many fish species from other areas of the world introduced into the swamp that there actually may be some hybridisation taking place, making it difficult to identify some fish species.

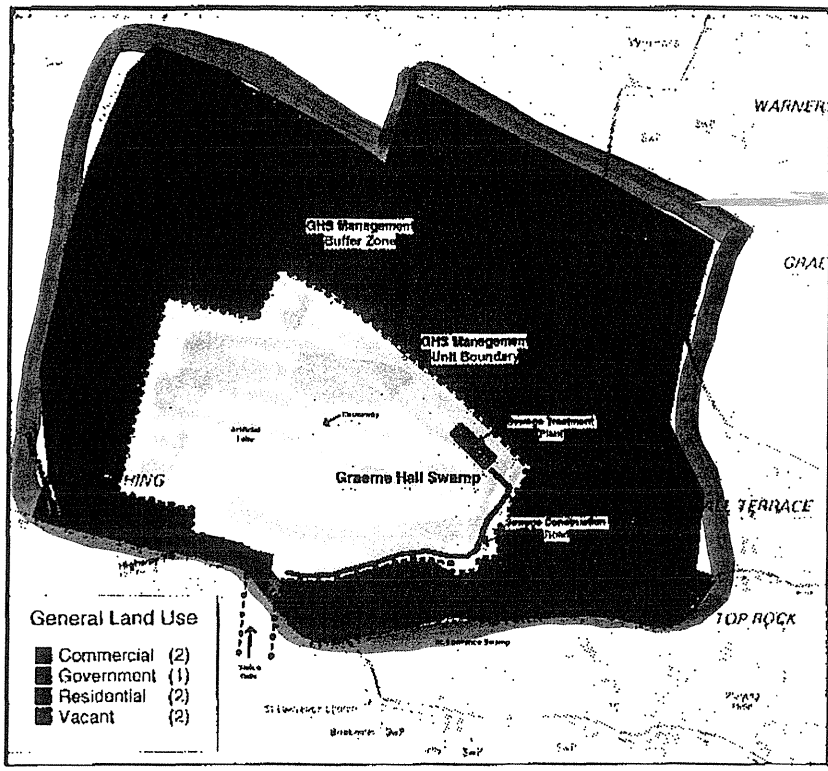
Table 3-5. Historically introduced Wildlife in Graeme Hall Swamp.

Group and Scientific Name	Common Name
Fish	
Cyprinus carpio	Carp
Polycentropsis abbreviata	African Leaf Fish
Oreochromis aureus*	Tilapia
Oreochromis mossabicus*	Tilapia
Poecilia sp*.	Molly
Barbus sp.	Barb
Cichlasoma spp.*	Cichlids
Colisa sp.	Gouramis
Reptiles	
Podocnemis unifilis	Yellow-headed Sidenecked Turtle
Kinosternon scorpiodes	Scorpion Mud Turtle
Pseudemys sp*.	Slider
Chelydra serpentina	Snapping Turtle
Amevia sp.*	Ground Lizard
Crocodylus sp	Crocodile
Birds	
Sicalis lutenola*	Lowland Yellow Grass Finch
Dendrocygna bicolor (restocking native species)*	Fulvous Whistling Duck
	Muscovy Duck
Cattaneo et. Al. (1988); Johnson (1986); observed in this study (*).	

4. Existing Land Use Conditions

The land surrounding the swamp is intensively developed with a mix of predominantly residential and commercial (Appendix Table 12-22, Figure 4-1). Approximately 78 acres of the area studied includes Graeme Hall Swamp. Only five lots, totalling 40.69 acres on the periphery of the swamp, are vacant and, according to the Barbados Land Tax Department (1996), have not been developed due to their marshy conditions. Commercial developments around Graeme Hall Swamp include small, medium and large hotels, restaurants and shopping outlets.

Figure 4-1. General Land Use Surrounding Graeme Hall Swamp.



The Barbados Physical Development Plan (Amended 1986), produced by the Town and Country Development Planning Office (1988), stated "plans are underway to develop Graeme Hall as a nature reserve…as well as positive action for the implementation of the plans, including statutory protective measures." The Plan further states that "within and outside the National Park, few remaining wildlife sanctuaries are suggested to be designated as nature reserves. These are … Graeme Hall Swamp … " and "it is anticipated that wildlife research activities will be intensified in the designated reserves. To ensure the implementation of the proposed designations and a proper management of the reserves, the necessary legislation must be introduced."

Currently, the majority of the swamp is designated as Major Recreational and/or Open Space in the Barbados Physical Development Plan (TCDPO 1988). West along Rendezvous Road and Southeast, around Highway 7/Harmony Hall Road the designation is predominantly Urban Residential. Southwest along Highway 7 Special Environmental Control designation appears to include the Southwest margins of the swamp. It is unclear, however, what legislative backing this designation enjoys to ensure its implementation.

The Barbados Physical Development Plan (1988) notes that the Graeme Hall area is proposed to be maintained as an agricultural area and as an urban open space in order to create an environmental break between the two urban areas. Sports and recreational are proposed for parts of the open spaces.

A review of available documents and discussions with the Town and Country Planning Office revealed that, other than the Sewage Treatment Plant, there are no Government of Barbados or public sector planning applications pending before Town Planning that are expected to affect Graeme Hall Swamp. Town and Country Planning Office also advised that there are also no development initiatives concerning Highway 7 that will affect the swamp.

4.1 Ownership and Management

4.1.1 Government Ownership

The entire property considered Graeme Hall Swamp for the purposes of this analysis encompasses 91 acres (Section 1.4.1). The current land under Government ownership comprises just over 254 acres; 48 of which are parts of Graeme Hall Swamp (personal communication, Barbados Land Tax Department 1996).

The government ministries involved in management of Graeme Hall Plantation include:

- Ministry of Housing and Lands to oversees tenantry along the seafront
- Ministry of Agriculture, head-quartered on the property to manage cultivation of the arable land
- Ministry of Public Works responsible for operation of the sluice gate.

Other ministries and agencies with management responsibilities at the swamp include:

- National Conservation Commission, under the Ministry of Health and Environment, currently has jurisdiction for the swamp, although it is not actively involved in management operations on the site
- Ministry of Health has conducted a mosquito control programme at the swamp since 1989 (a mosquito eradication programme was successfully completed from 1928-1930 by the Department of Sanitation during a malaria epidemic)

- Environmental Unit of the Ministry of Health and the Environment has responsibility for Graeme Hall Swamp in the context of the swamp's potential as a protected area or nature reserve

Ministry of Tourism has responsibility for Graeme Hall Swamp in the context of its potential for nature-based tourism

Coastal Zone Management Unit of the Ministry of Health and the Environment has responsibility for the St. Lawrence lagoon, which includes the seagrass beds, rubble barrier and offshore coral reefs which form part of the Worthing Beach/Graeme Hall Swamp ecological unit.

4.1.2 Private Ownership

The privately owned western section of Graeme Hall Swamp was sold in 1969 to South Coast Development Ltd., a land development company, which proposed to develop a 'lake-side' apartment complex. In 1972, a number of shallow pools were dredged, and fill used to increase the elevation of the uplands in the western section to prepare for the proposed development (Kinas 1982; Hutt 1983; Arnott 1984). The Town and Country Planning Office never approved the development, and the development was never completed.

The current owner of the western portion of the swamp, Graeme Hall Bird Sanctuary Inc., acquired the property in 1995, and submitted a proposal to the Town and Country Planning Office to develop the 29-acre property. Town and Country Planning action on that proposal is pending recommendations from the current study (personal communication, Lionel Nurse 1996).

4.2 Planned and Development Initiatives

Submitted Management Plan in 1998 — couldn't get gov't to respond - 6 hrs then given development approval - Does this mean they accepted the final draft in substance if not formally?

4.2.1 Government Initiatives

The Ministry of Health has conducted an ongoing mosquito eradication programme at Graeme Hall Swamp since 1988 to control the spread of the *Anopheles aquasalis* mosquito. A component of this program was to remove vegetation from the East Unit channels, cut mangroves to 'thin out' the woodland in the East Unit, and burn accumulated piles of vegetation and mangroves to facilitate debris removal.

The practice of cutting mangroves and burning inside the mangrove woodland was discontinued in 1994 after it was brought to the Ministry's attention that cutting mangroves was not necessary to eradicate the targeted mosquito population. In addition, cutting mangrove reduced the available mangrove habitat, and burning debris was a hazard to the viability of the entire woodland area.

A section of red mangrove prop roots were 'selectively removed' by the Ministry of Health in the West Unit of the swamp in September 1996 in an attempt to improve water flow in the central channel. Ministries involved in management of Graeme Hall Swamp agreed, in October 1996, that this practice would continue only direction of the Department of the Environment.

The Ministry of Tourism and the Ministry of Health and the Environment have been engaged in a public education programme for Graeme Hall Swamp to raise awareness of locals, tourists and hoteliers to the benefits of preserving the swamp as an 'ecological treasure' of Barbados.

The Ministry of Public Works is responsible for operating the sluice gate at Worthing Beach and for clearing any clogged drainage channels in the Graeme Hall area. The sluice gate used to be opened three times per week during low tide periods to allow floodwaters to drain to sea. This schedule has not been regularly adhered to in recent years. In October 1996, responsible Ministries agreed that the sluice gate would be opened twice a week, and the possibility of opening it at the end of every day would be discussed with the Sewerage Project Unit.

The South Coast Sewerage Project Unit of the Ministry of Health and the Environment is responsible for management of the Sewage Treatment Plant located in the East Unit of the swamp. The impact assessment completed for that project's pre-feasibility study predicted a small adverse impact to the swamp through disruption to wildlife during construction and a small reduction in available wildlife habitat. There was no predicted effect on wildlife during operation of the plant (South Coast Sewerage Project 1991). Approximately 5 acres of wetland will be modified to accommodate the project works, and sewage pipes running from the facility to highway 7 are being located along planned for location along the margins of the swamp.

Documents and discussions with staff from the Town and Country Planning Office revealed that there are no other Government of Barbados or public sector planning applications, other than the Sewage Treatment Plant, pending at the Town and Country Planning Office that are likely to affect the Graeme Hall Swamp.

4.2.2 Private Sector

The margins of the swamp comprise primarily of small-scale commercial private developments on the west and Southwest, residential on the Southeast, agricultural on the North and primarily residential in the Northwest.

Over 50 applications have been received for developments in these areas, the majority being for private commercial or residential upgrading/extensions. Two applications stand out from these, one for the public sector development of the Sewage Treatment Plant (ref. TCPO application no. 1696/10/95) and the other for a private sector ecotourism centre (ref. TCPO application no. 772/96).

The latter application was submitted in April 1996; and encompasses a bird sanctuary and aviary display with support facilities, a restaurant, a shop, and parking for 48 cars. The proposal covers a site area of 29.3 acres in the West Unit of the swamp and incorporates the western lake (17.5 acres) and two land parcels to the west and south of 6.8 acres and 5.0 acres respectively. Of the land area, 8 acres is stated as having been dredged from the swamp in the early 1970's, of which 3.5 acres is for tourist infrastructure.

The planning history of the site reveals that a previous application for residential and commercial uses including a hotel and apartment complex was approved in c.1969. The current application has been held over at the request of the Chief Town Planner, pending the outcome of the present study.

4.3 Recreation and Leisure Use

A 2-week survey in October 1996 investigated current human uses at the swamp. Three observation sites were used-- the Southwest bank of the lake, the central causeway, and the Northeast section of the swamp. Observations were taken during three time periods [8:00-11:00 a.m., 11:00 a.m.-2:00 p.m., 2:00 p.mm-5: 00 p.m].

A total of 80 individuals were recorded using the swamp during these observation periods (Table 4-1). These observations exclude workmen involved in construction of the Sewage Treatment Plant, and government employees engaged in management activities in the swamp. The West Unit of the swamp was more heavily used than the central or East Unit, and pedestrian 'traffic' was more frequent during the mid-day and evening periods than in the early morning period.

Table 4-1. Local Use of Graeme Hall Swamp in October 1996.

Survey Periods	8:00-11:00	11:00-2:00	2:00-5:00
Fishing	W18	W3	W5 C4
Hiking	W7	W8 E1	W11
Educational Visits		W21	
Wood Gathering			W2

(Numbers preceded by E, C, or W indicate the total individuals observed in the eastern (E), central (C), or western (W) sections of the swamp.)

Flooding obstructed access into the central section via the central footpath, and de-watering associated with sewage facility construction obstructed access during the rainy season. Construction of the Sewage Treatment Plant in the East Unit may also have deterred use of that area of the swamp.

The major deterrent to local use from the South side of the swamp was the erection of a fence by the Sewage Treatment Project on the pathway off Highway 7. This fence was erected midway through the observation period, and was combined with 'Private-No Trespassing' signs within the private property.

Use of the swamp is essentially unregulated. Although human traffic was not excessive during the survey; recreation use, particularly fishing and crabbing in season, can be relatively intensive. These activities appear to be focused in the area immediately surrounding the lake and the footpath along the central causeway. The fencing and security guards severely limited recreation use and resource harvesting.

Domestic animals such as cows and black-belly sheep were found tethered in the swamp in both the East and West Units. These animals will eat, trample or destroy vegetation; and during grazing they can create depressions in waterlogged soils that fill with water and become potential breeding sites for mosquitoes. Until the security was put in place on the West Unit, crab harvesting by digging out burrows was also a major source of water filled mosquito-breeding areas.

Interviews with six local residents during the survey indicated they were all concerned about the swamp being used as a "criminal hide-out". Complaints about mosquitoes and flooding during heavy rains were noted in five of the six interviews. Local hoteliers have also expressed concern about the reportedly objectionable watercolour entering the sea at Worthing Beach when the sluice gate is opened, and would prefer that the gate only be opened when absolutely necessary.

4.4 Agriculture

The Ministry of Agriculture headquarters has been located in Graeme Hall Plantation on the ridge overlooking the swamp since 1981. In addition to Ministry offices, the complex also contains Entomology and Plant Pathology Unit and a Central Agronomic Research Station, the latter in operation since 1972. The Research Station is responsible for cultivation of approximately 97 acres of land at Graeme Hall. Crops cultivated on these lands include potatoes, corn, cassava, pumpkin, butternut squash, beets, okras, sweet/hot peppers, onions, pigeon peas, beans, cotton and carrots (Appendix Table 12-24). Note that plot numbers 1-11 are at swamp level (i.e. 66.7 acres), while plots 12-19 are located on the ridge above the swamp (30.4 acres). Crops are rotated regularly as part of the ongoing programme of crop diversification at Graeme Hall.

When Government initially purchased the Graeme Hall Plantation in the 1960's, sugar cane was the primary crop being cultivated. The site was used for sugar cane variety testing in conjunction with Groves Plantation in St. Thomas. Crop diversification has been developed over the past 2 decades. There were at least nine different crops being cultivated by 1985, with only 40% of the estate used to cultivate sugar cane. At present, 16 different crops are planted at Graeme Hall and sugar cane is no longer grown.

Chemicals are used to control pests affecting crops at Graeme Hall. A list of chemicals that have been used at the Graeme Hall Plantation is presented separately for the years 1985 and 1996 in Appendix Table 12-25. Chemicals used at the Graeme Hall Plantation by the Ministry of Agriculture.). Tambo and Jupiter are the insecticides currently in use, and chemicals are usually rotated and varieties alternated over time.

Fertilisers are also applied to cultivated crops at Graeme Hall during the growing stages so that each crop receives a minimum of one fertiliser application harvested. Fertilisers used include 12-12-17-2, 24-018, Salt of Ammonia, Urea, Potassium Nitrate and Triple Superphosphate.

There is an ongoing programme to test biological control of target pest species at the Graeme Hall Plantation. These tests are being conducted on an experimental basis on a number of fields, and results are expected in the near future.

Soils in the swamp were tested for pesticides during this project's water quality investigations, and all samples tested showed levels below Method Detection Limits (Section 5.4). These limited and preliminary tests indicate that historical applications of pesticides within the agricultural properties have not adversely affected the swamp soils.

A number of 'fish kills' has been reported at Graeme Hall Swamp since the 1980's. One incident in April 1985 was attributed to a drop in oxygen levels due to water stagnation (Nation Newspaper, April 1985). Impacts of chemical pollution from the surrounding agricultural fields needs to be further investigated and monitored to determine if flora and fauna in the swamp are at risk from watershed chemicals.

4.5 Education and Scientific Research

Graeme Hall Swamp has long been recognised as a unique area of scientific interest and significant educational value (Riven-Ramsey 1981; Hutt 1983; Arnott 1984; CCA 1985; NACC 1992; Delcan 1993). Several scientific studies have been conducted at the swamp in recent years, and the swamp has been used to promote the study of wetland ecology for primary, secondary and tertiary level students in Barbados.

Undergraduate students at the Biology Department of the University of the West Indies Cave Hill Campus (UWI), and Bellairs Research Institute of McGill University use Graeme Hall Swamp to conduct ecological investigations as part of their practical course of study. In addition, post-graduate students at the Marine Resources and Environmental Management Programme (MAREMP) of UWI study measurement and monitoring techniques at the swamp and associated coastal zone as part of their practical course in environmental research.

The few scientific investigations conducted at the swamp have provided only limited baseline to describe its biological characteristics. The Caribbean Coastal Marine Productivity (CARICOMP) program has selected the swamp as the Barbados component of the CARICOMP program. This regional scientific program currently studies tropical land-sea interaction processes through a network of 31 laboratories in 23 countries in Latin American and the Caribbean Region. The program involves long term study and monitoring of coastal ecosystems; including mangroves, seagrass beds and coral reefs. The mangroves at Graeme Hall Swamp have been monitored since 1990 (Parker and Oxenford 1994). Bellairs Research Institute of McGill University is providing the technical expertise for this component of the program.

Two additional scientific studies were also completed at Graeme Hall Swamp in the late 1980's. The Department of Biology of McGill University (Cattaneo et al. 1988) conducted a limnological and ichthyological reconnaissance, and the Biology Department of the University of the West Indies, Cave Hill (Riven-Ramsey 1988) conducted an investigation of the population dynamics of the Cattle Egret (*Bubulcus ibis*) with specific reference to Graeme Hall Swamp.

Aspects of Phase I of the Barbados Coastal Conservation Project, completed in 1995, contributed information on the role of Graeme Hall Swamp as a viable coastal ecosystem with mangroves, seagrass beds and coral reefs as the salient elements (Delcan 1993).

4.6 Sluice Gate Operation

Sluice gate operations are discussed in several other sections of this report, including Section 4.2.1.

4.7 Highway 7 Development Options

The Chief Technical Officer of the Ministry of Public Works, Transport and Housing, Mr. Cedric Archer has indicated in writing that there are no immediate plans for any major development of Highway 7. However they are investigating the possibility of a side walk programme along Highway 7. This would involve improvement and construction of sidewalks between the Graeme Hall Sluice Gate Canal and Harmony Hall Road. Town & Country Planning informed study team members that they have no about development options on highway 7 that will affect Graeme Hall Swamp.

4.8 Mosquito Control Program

The Ministry of Health manages the East Unit of Graeme Hall Swamp for mosquito control. This management includes (1) periodic clearing of the vegetation from the freshwater canals and adjacent banks, (2) cutting of mangroves which overhang the embankment and clog the exit canal to the sea, and (3) through fogging with malathion (Spielman and Nathan, 1990).

4.8.1 Program History

The last malaria epidemic in Barbados occurred in 1929. The *Anopheles aquasalis* mosquito vector for malaria was abundant in Graeme Hall Swamp then, and was eventually eradicated after an aggressive control programme by the Sanitation Department in the early 1930's. Water ditches in the East Unit of the swamp were stocked with thousands of fish (e.g. *Tilapia* species), and arsenic was also used to kill mosquito larvae (Stoute 1980).

In 1988, an isolated population of *A. aquasalis* was discovered in Graeme Hall Swamp by a team of PAHO entomologists. No more than a few larvae were present in any sample of water, and the majority of samples contained none. Over a 15-month observation period, no more than 50 *A. aquasalis* mosquitoes were ever collected at one time, and this number of mosquitos was recorded only twice. Since *A. aquasalis* was found to be limited in its dispersal beyond Graeme Hall Swamp. Their biting activity was restricted to 30 minutes at dusk. it was concluded that there was only a small risk of humans being bitten and environmental conditions necessary to perpetuate malaria transmission did not exist (Spielman and Nathan 1990). These findings were reported to the Government of Barbados, and a mosquito control programme was initiated through the Ministry of Health.

There have been no reported cases of malaria since the discovery of the *A. aquasalis* mosquito at Graeme Hall Swamp in 1988.

4.8.2 Current Control Program

The current mosquito control programme conducted by the Ministry of Health consists of research and control. Research involves two separate sampling and analysis programmes carried out in 22 sampling sites in five distinct zones within and adjacent to Graeme Hall Swamp (Table 4-2).

The first Research sampling programme involves extraction of mosquito larvae from water in different sites and determining the number of *Anopheles* larvae present. The second sampling programme involves counting adult *Anopheles* mosquitoes that alight on a human positioned at dusk in the different sampling sites (Table 4-2). Results of man-baited captures during sampling in October 1988 to June 1990 indicate that biting rates are higher in October to January than in March to June.

Table 4-2. Mosquito Control Programme Sampling Zones (Ministry of Health 1996).

Site Number	Site Location
A1 - A6	western section of swamp, adjacent to Amity Lodge residential area
B1 - B5	Central/eastern section of swamp
C1 - C3	Harmony Hall and Pepperpot complex
D1 - D4	Divi Southwinds to Sluice Gate
E1 - E4	West of western section of swamp, and Big B Supermarket complex

Mosquito Control consists of using a 'cutlass gang' to remove vegetation from the 153 channels in the East Unit. Thinning mangrove woodlands ceased in 1994 but was recommenced in 1996, and chemical treatment with a larvacide (Abate or Baytex) and a thermal fogger that sprays a mixture of Malathion and diesel to target the adult mosquito population.

Vegetation clearing appears to primarily consists mangrove cutting in random areas of the swamp. Secondary cleaning involves grass and sedge from canal banks and, at times, removal of aquatic vegetation from some of the fresh water canals. The clearing program has no apparent pattern or relationship to reproduction of disease producing mosquitoes. Discussions with work crews leave the impression that there has been no sampling for mosquito larvae for some time and that vegetation clearing is done focussed clearly on mosquito control objectives.

The scheduled use of chemicals is based upon results of the ongoing Research programmes. When rates of larvae and adult mosquitoes reach a Ministry of Health threshold of greater than 50 larvae or 100 adults, chemicals are applied.

PAHO has suggested that the measures adopted by the Ministry of Health in their mosquito control programme at Graeme Hall Swamp are highly aggressive and may be unnecessary (personal communication M. Nathan 1990, 1994, 1996). Moreover, the current status of the *A. aquasalis* population at Graeme Hall Swamp is not as well understood as it was in 1990, since man-baited captures have not been sampled consistently. The analysis of dip rates of mosquito larvae has been more consistent, however, predictions based on dip rates are not as reliable as those based on man-baited captures. Control programmes should be based on man-baited capture rates that are consistently and reliably sampled over time (M. Nathan, PAHO personal communication 1996).

The mosquito control programme has been limited recently due to budgetary constraints and the problems associated with flooding. The Ministry of Health personnel are having difficulty accessing the East Unit of the swamp due to excessive and consistent water intrusion since construction of the sewage treatment facility began in 1995.

Removal of vegetation to un-block channels is predicated on providing fish freer access to mosquito larvae. Mangrove control reduces density of the mangrove habitat, and studies outside Barbados have indicated that *A. aquasalis* has a preference for sunny locations (Faran 1980). If true in Barbados as well, the practice of thinning mangrove and increasing sunlight penetration into wooded areas may, in fact, enhance conditions supporting increased *A. aquasalis* populations at Graeme Hall Swamp.

The current mosquito control programme is also focusing on garbage dumping in and around Graeme Hall Swamp. A comprehensive programme of solid waste management may be a critical factor in the attempt to eradicate the *Anopheles* mosquito at Graeme Hall Swamp.

4.8.3 Impact on Current Environment

The IFAS at the University of Florida has reviewed the control programs and has recommended that mosquito control should be concentrated on trash removal and on filling holes left by crab harvesting. The *Anopheles* mosquito reproduce in stagnant water, including standing water in old cans, tires, or puddles generally inaccessible to the mosquito fish *Gambusia sp.* and other insectivorous fish and aquatic life. Observations at Graeme Hall Swamp during wildlife surveys verified that mosquito larvae were commonly seen in standing water in trash, usually near the houses and school, and in extensive and numerous land crab holes created during crab harvest efforts. No larvae were collected during dip netting exercises in vegetated canals or mangrove stands.

The current vegetative clearing program has considerable impact on both vegetation and wildlife in the swamp. Clearing and burning around canals in the East Unit has often been done during the nesting season of gallinules, potentially causing habitat and nest loss during nesting. This may also adversely affect yellow warbler nesting in white mangrove. Removal of aquatic vegetation also reduces habitat for insectivorous fishes and dragonflies and has nearly destroyed various species of water lilies and other aquatic plants once common in the swamp.

4.9 Sewage Treatment Plant

The Sewage Treatment Facility, located on the Northeast margin of Graeme Hall Swamp, is accessed off Harmony Hall Road through a predominantly residential area to Highway 7. The facility occupies land under Government ownership and abuts the Ministry of Agriculture land to the North. Although partially hidden by a small ridge to the North, it is still visible from the Ministry of Agriculture buildings and passing traffic on the link road between the ABC Highway and Highway 7.

Manhole construction began in July 1997 along Highway 7 near the sluice gate, and a raised marl workpad is almost completed along the East and South margins of the swamp to the manhole near the sluice gate. This workpad will be used as a platform from which to bury the effluent sewerage pipe from the plant along the margins of the swamp to the manhole near the sluice gate and thence to Needham Point for deep ocean disposal. This main effluent line will be the only sewerage line within the swamp, since a emergency overflow disposal pipe will not be necessary for safe plant operation (Matt McTaggart, personal communication).

The Sewage Treatment Plant has affected GHS primarily by:

- physical location of the plant within the swamp boundaries
- location of a large construction workpad and storage area on the Southeast corner of the West Unit
- construction of a marl workpad/road from the plant to the manhole near the sluice gate along the East and South margins of the swamp
- extensive de-watering during plant construction.

The plant site proper takes about 1.02 acres from the swamp, although it is located on higher elevations on the Northwest margin of the swamp. An additional 2 acres will be required for access road and future expansion. The plant site is not located in any known critical habitats, and its subsequent operation is not expected to adversely affect the overall viability of the swamp fauna or flora. Its location does, however, obviously interfere with existing groundwater flows and underground streams given the magnitude of de-watering that was required during plant construction {see below}. The plant does present a visual physical intrusion into the swamp, and subsequent development and management plans must accommodate or mitigate for this intrusion by protective landscaping and careful planning of activities.

The construction workpad and storage area on the Southeast corner of the West Unit exists on the upland areas that were created by the lake construction in 1972. This facility is on the private property location that is planned for facilities and parking. When construction is completed, the area will be rehabilitated for the planned facilities.

The construction of the marl workpad along the East and South margins of the swamp has been a major physical intrusion into the swamp, and has adversely affected swamp fauna and flora. While the effects of workpad construction will be relatively short-term, retention of all or part of this workpad has significant planning implications for swamp management and development. Although the workpad will provide efficient and relatively low impact access to the effluent pipe in the event of emergency repairs, it can also provide a major access point into the swamp. This access can be successfully developed to provide foot access to the swamp, however, the access must be carefully controlled and managed consistent with the long term plans for the swamp.

The extensive de-watering program conducted during plant construction had significant effects on both the swamp and the St. Lawrence Bay. The water volumes increased water levels and changed the water quality parameters of the swamp throughout its duration. The large water volumes also contained relatively high concentrations of sediments, and the resultant sedimentation of the cut channels on the East Unit These effects are discussed further in Section 8.7.

The volumes of water discharged from the swamp to the sea also had a significant effect on the seagrass beds in St. Lawrence Bay. The potential effects of this de-watering on the seagrass beds of St. Lawrence Bay was investigated between March and May 1997 (Section 13.3). The study measured the shoot density, areal biomass, leaf productivity, leaf growth rate and leaf area of *Thalassia* (turtle grass). This species is a relatively long-lived and slow growing seagrass that is a climax species in seagrass bed development. Its presence indicates a seagrass bed that has been able to retain viability for extended periods of time.

All of the *Thalassia* parameters measured decreased between during the study, with areal biomass decreasing by 80 percent during the study. These results indicate a strong negative effect of increased flushing of swamp water on *Thalassia* beds in St. Lawrence Bay, and suggest that management measures to improve water quality in GHS will have a positive effect on seagrass beds in the bay.

5. Existing Biophysical Conditions

5.1 Geomorphology

Barbados is situated over two overlapping tectonic plates that move together from the Caribbean Sea and the Atlantic Ocean and cause a build-up of sedimentary layers. Coral reefs develop when these layers rise to a sufficiently shallow ocean depth. The reefs surrounding Barbados date to the Pleistocene era, about one million years ago.

Barbados literally pushed up from the sea and subsided more than once. The coral cap covers about 86 percent of Barbados; averages about 200 feet thick; and varies in hardness, density, uniformity and porosity. Oceanic Series soils [typically white earth and chalks] below the Coral Limestone overlay soils of the Scotland Series [typically sandstone and dark sandy clays].

Bore holes from Graeme Hall Swamp indicate that as the layer of coral extends outward under the sea, its permeability produces an interface between sea water infiltrating inland and fresh rainwater percolated through coral to the underlying oceanic deposits, with hydraulic pressure causing flow to the sea. In equilibrium, lower density fresh water floats on underlying denser sea water and escapes at shallow depth along the coastline. Because of the very gentle gradient of the coral layer, this fresh water layer or lens [" sheet water "] can extend from 1 mile to several miles inland (Senn 1946).

The land in Christ Church slopes generally southward in terraces until it dips below sea level. The land surface dips below sea level at the swamp, which is approximately the same as the sheet water level, which is the source of the water body known as Graeme Hall Swamp. The ground surface rises above water level to form a low, flat, natural embankment separating the swamp from the sea. The shallow channel to the sea, controlled by the sluice gate, permits water flow seaward at low tide and landward at high tide. The dredging in 1972 in the western section created the shallow lake, and the dredged materials spread over the Southwest portion of the swamp built up the elevation to about 2 feet above water level.

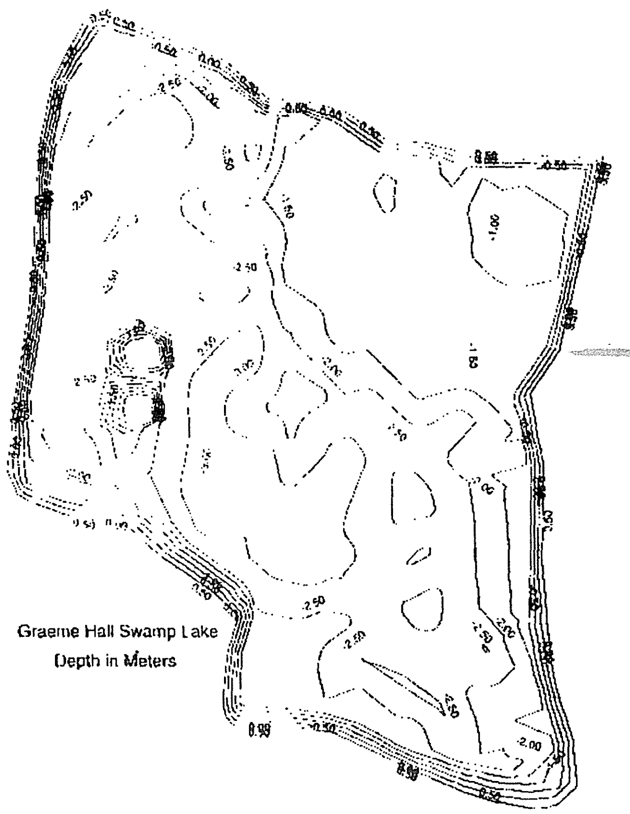
5.2 Bathymetric Profile

The bathymetric profile of the lake in the West unit of Graeme Hall Swamp was determined by sounding measurement from a small boat, with location determined by a geographic positioning system. Godson Associates conducted the hydrographic survey on 23 December 1996. The mean sea level was +0.32 metres; using LAMONT datum the lake water level was 0.6 metres (i.e., about 0.28 metres above sea level) above datum.

The lake bathymetric profile was established at 0.25 metre contour intervals (Figure 5-1). At the height of the rainy season, the lake is only about 0.3 metres above sea level, is fairly shallow and is relatively heavily silted in comparison to water column. The lake bottom consists of a layer of silt varying from 0.3-1.7 metres in thickness and exhibiting no apparent pattern of distribution. The maximum depth of the lake is 3.18 metres immediate East of the existing small island egret rookery. Several other deep "pockets" (approximately 3.0 metres) occur in at least three locations, particularly in the Northwest and Southeast corners of the lake. The shallowest depth of the lake is

0.76 metres at the Northeast corner. Lake depth is very unevenly distributed, but it appears that the average depth is approximately 2.0 to 2.5 metres. The entire perimeter shoreline (where the majority of the mangrove drops off steeply from the edge of the hard ground to the edge of the water.

Figure 5-1. Baythmetric Contours of Graeme Hall Swamp Lake, 1996.



5.3 Hydrology

Graeme Hall Swamp hydrology is a mixture of upland runoff, limited ocean exchange through the sluice gate, and groundwater recharge and exchange. The groundwater exchange is the most important determinate of salinity levels in the swamp over the course of a year. Under certain conditions, however, tidal exchange through the sluice gate can contribute to the swamp salinity and water quality.

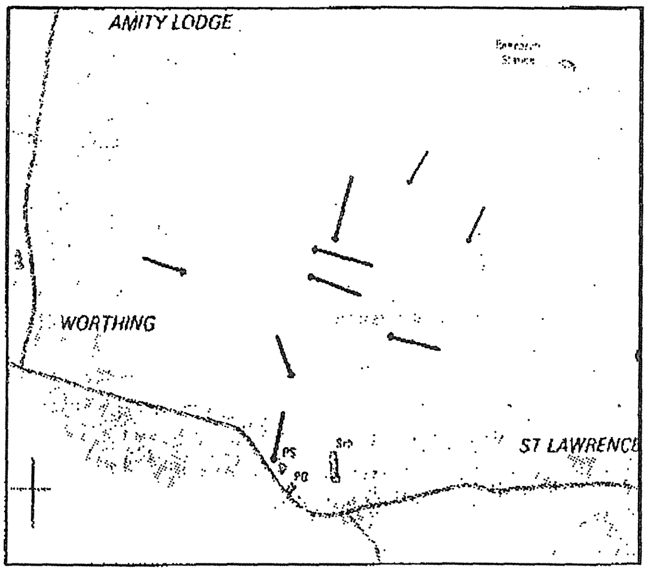
5.3.1 Overland Flow and Groundwater

The upland drainage basin for Graeme Hall Swamp is approximately 4.68 square kilometres (Cattaneo et. al. 1988). The drainage basin extends "in a narrow band from the southern extremity of the swamp to the height of the Christchurch Dome, lying at about 100 meters a.s.l. near the border of Christchurch with the parishes of St. George and St. Michael." Lands immediately adjacent to the swamp that provide direct runoff include:

- agricultural fields maintained by the Ministry of Agriculture
- urban neighbourhoods with roads to the Northwest, East, South, and Southwest
- spoil lands used as pastures to the South
- upland grass areas to the East.

Drainage within the swamp flows from the higher agricultural uplands and the freshwater springs, from the cut channels in the East Unit into the lake or the main drainage channel, and from the lake to the main drainage channel to the sea (). These general runoff and flow pathways were observed during a site reconnaissance in December 1996 under generally high water conditions. Sheet flow was observed from the North end of the red mangrove East of the lake to the lake. During the wet season, the central causeway appears to act as a restriction to flow nearer to the highway.

Figure 5-2. Drainage Flow Pathways and Spring Fed Pools, December 1996.

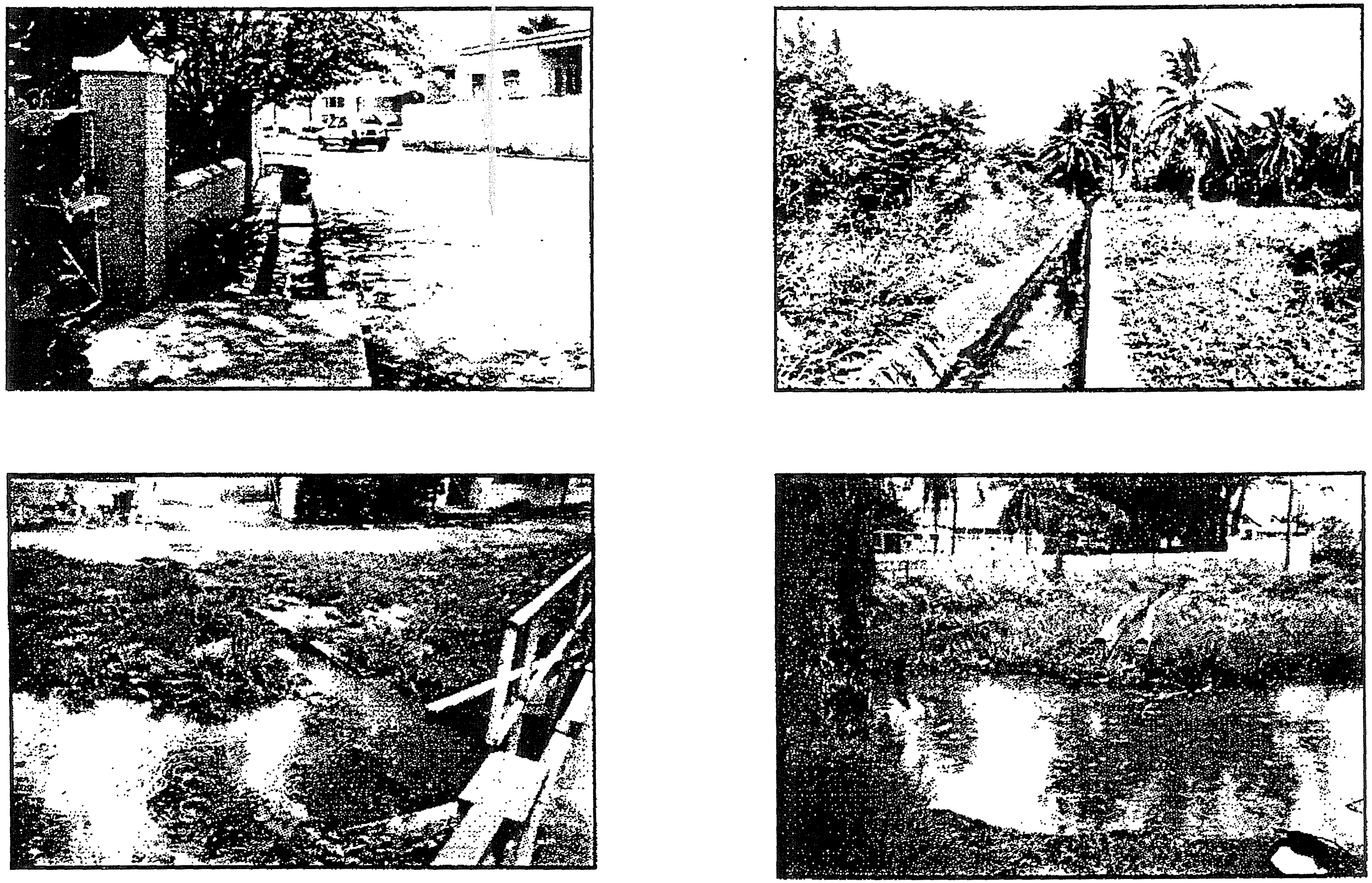


Flow within the main drainage channel along the central causeway is determined by the operation of the sluice gate. When the gate is opened, flow may either be out to the ocean or into the swamp depending upon offshore tide levels. In addition to upland runoff, groundwater recharge provides freshwater to GHS through springs that feed pools near the East Side of the causeway.

The commercial and residential developments surrounding Graeme Hall Swamp have developed structures that drain the developed uplands. The waters flowing into the swamp from these drains provides substantial potential for uncontrolled pollution of the swamp's waters (Figure 5-3).

The South Coast Sewage Treatment Project measured water levels at various locations within the swamp between March and September 1996 while the de-watering associated with plant construction was ongoing. Water level elevations of 0.67-87 meters a.s.l. within the swamp during the period sampled reflect approximately 3 million gallons of water per day being pumped into the swamp [all readings were corrected to government datum prior to reporting].

Figure 5-3. Examples of Urban Drainage into Graeme Hall Swamp.



The low values reported for sample site SP1 occurred when the sluice gate was open. These levels represent the water level gradient during outflow between the channel opening at the beach and the remaining swamp. These water level readings were taken during both a wet (June-December) and dry (January-May) season, however, these water levels cannot be considered "normal" given the large-scale water inputs from the construction project.

5.3.2 Tidal Exchange and Sluice Gate

Water level within the swamp is normally controlled by the sluice gate in the main drainage channel. This sluice gate, installed in 1930, is currently operated by the Ministry of Public Works, Transport and Housing.

Figure 5-4. GHS water levels during construction de-watering.

Note: Remaining Figures in this Section Printed in Black and White to expedite draft Product. Final Version in colour, where appropriate.

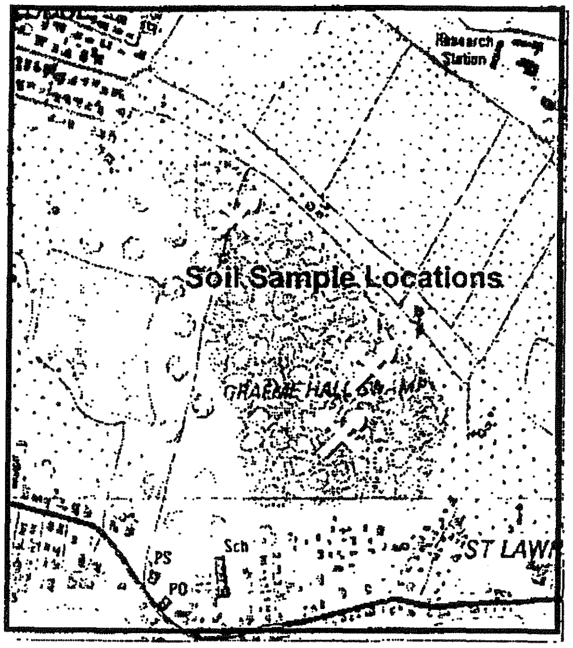
The sluice gate allows swamp water to discharge to the ocean when it is opened during low tide. During periods of sufficiently high tide (primarily meteorological events combined with high astronomical tides), ocean waters can pass into the system through the drainage channel. During these periods, ocean water mixes and interchanges with swamp water at a point where the channel crosses Highway 7. Existing elevation data for the swamp is not accurate enough to estimate the frequency of ocean water exchange if the sluice gate is open during these high tide events. It is estimated that this mixing could occur about 5-6 days per month (Gerald Proverbs, personal communication).

The sluice gate has historically been operated frequently to manage water levels within the system, and this frequent operation provided flushing of upland runoff as well as some inflow of clean saline ocean waters during periods of high tide. This operational practice has become less and less frequent in recent years due to deterioration of the gate structure. This infrequent operating schedule has resulted in complaints from neighbouring hotel owners on the coloured quality of water released from the swamp. In addition, movement of sand along the beach rapidly blocks the canal between the sluice gate and the sea, and this sand buildup requires frequent and extensive excavation to provide proper outflow.

5.4 Soils and Pesticides

The upland agricultural areas along the Northeast side of the swamp are positioned to provide a direct source of runoff from the fields to the swamp. Soil samples were collected at stations PS-03,

Figure 5-5. Soil Samples for Pesticide Testing, December 1996.



PS-04, and PS-05 for analysis of pesticide contamination (Figure 5-5).The preliminary screening for various pesticides was based upon a list of recent pesticide use at the experimental fields on the Ministry of Agriculture.

All samples tested showed levels below Method Detection Limits (Table 12-9). Although this is a limited sample, results indicate that historical applications of pesticides within the agricultural properties have not adversely affected the swamp soils.

5.5 Water Quality

The water quality and hydrologic monitoring program developed for this study of GHS was designed to:

- investigate existing water quality conditions
- provide a basis for historical comparisons
- provide a baseline for analysis with other Caribbean mangrove systems
- provide a baseline for long term monitoring program
- provide the information for a water quality restoration program (if necessary).

This water quality program was designed for, and premised on a relatively "natural" hydrologic system currently existing at the swamp. In fact, construction programs at the South Coast Sewage Treatment Plant during 1996 and 1997 have significantly altered the water quality at the swamp. In addition to these externalities, major landscape alterations on the private property in the western section of the swamp during April 1997 also affected water quality parameters. These development activities severely affected water quality field investigation and the relevance of the water quality investigations. The effects of these programs on water quality results are discussed further in Section 5.5.4.

5.5.1 Sampling Program

Graeme Hall Swamp has a variety of hydrologic characteristics that, for the purpose of providing a representative sample, were characterised into five distinct hydrologic regions:

- the trays and sedge swamp within the eastern side
- the lake
- the central causeway dividing the eastern and western swamp
- the uplands
- the discharge canal and sluice gate.

Ten primary and seven secondary surface water quality monitoring stations, and three groundwater monitoring stations were established within the swamp for the water quality program (Figure 5-6) as follows:

- 3 primary and 2 secondary surface water stations within dug channels east of the central causeway
- 2 primary and 2 secondary surface water stations along the Central Causeway
- 1 primary and 1 secondary station along the discharge canal upstream of the sluice gate
- 3 primary and 2 secondary stations within the lake
- 1 primary station in the drainage channel entering the west side of the lake
- ground water stations within uplands along the southern, western, and northern side of the swamp.

The following parameters were measured at both the primary and secondary surface water stations using hand held instrumentation:

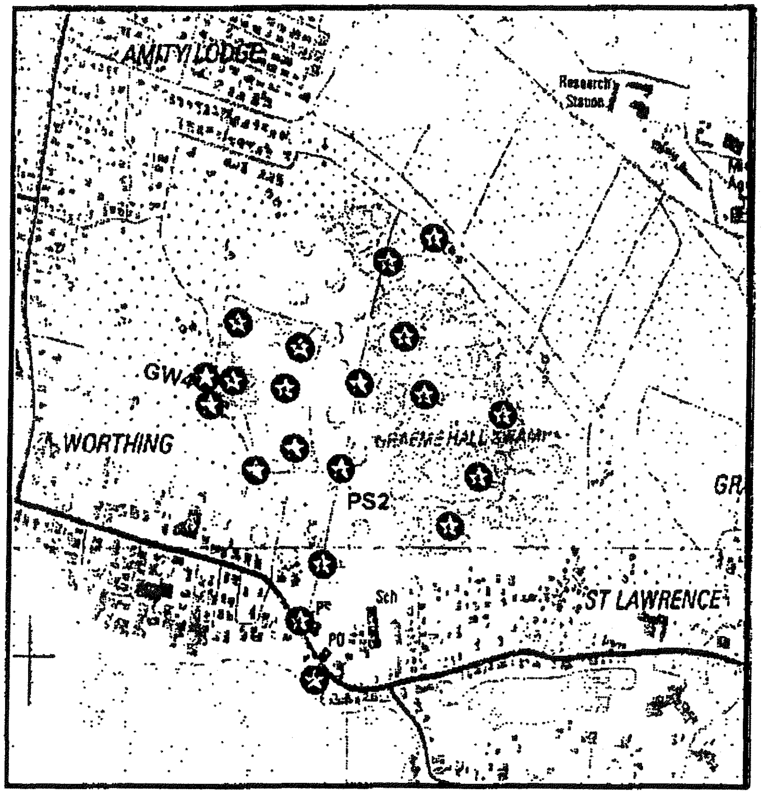
- Temperature
- Conductivity
- Dissolved Oxygen
- pH

Samples at fixed stations were taken at 0.5 meter intervals starting at 0.3 meters below the surface where water depth was greater than 1.0 meter. Samples were taken at mid-depth where depths were at, or less than, 1.0 meter.

Water quality grab samples were collected at the primary stations and analysed for:

- BOD5
- Total Phosphorus
- Ortho Phosphorus
- Nitrate/Nitrite
- Total Coliform
- Faecal Coliform
- Faecal Streptococci
- Total Suspended Solids.

Figure 5-6. Water Quality Sample Sites at GHS, December 1996.



Grab samples were collected at 1 meter below the surface depths were water depths were greater than 2.0 meters. Samples were collected at mid-depth where water depths were less than 2.0 meters.

A total of four sampling events were planned, two during a typically wet period (late fall and early winter), and two during a typically dry period (early spring). Only two of the four sampling events were completed; on 12 and 17 December 1996. The planned dry season samples were not collected because the construction and de-watering associated with the plant and the sewer line construction for the South Coast Sewage Treatment Plant precluded meaningful water quality sampling at the selected sample sites (See 5.5.4).

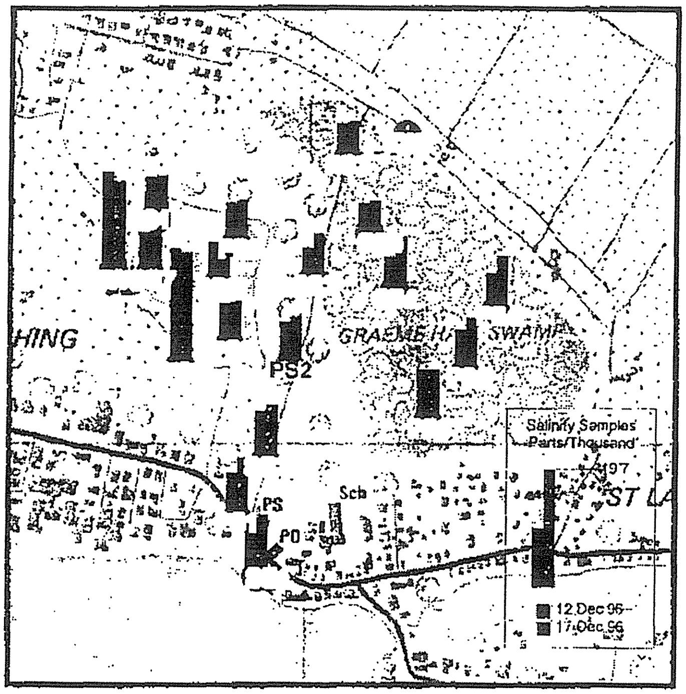
5.5.2 Results

Table 12-3and Table 12-4 in Appendix Section 12 presents results of the water quality sampling for salinity, pH, temperature and dissolved oxygen for stations sampled on 12 and 17 December 1996. The sample results reflect the effects of the de-watering program for Sewage Treatment Plant construction that was underway during the sampling period for water quality. The aberrations of water quality results during the December samples negated any potential value from additional samples while construction de-watering was underway, and the remaining scheduled samples were cancelled. The results of the December 1996 samples are summarised below.

5.5.2.1 Salinity

The highest salinity measured at GHS was recorded at groundwater stations (GW-03 and GW-04) located immediately South and West of the lake. The other groundwater site (GW-02), located at the North end of the swamp just below the escarpment, recorded the lowest salinity (Figure 5-7. Salinity Samples at GHS, December 1996.). Senn (1966) (see Section 5.1) postulated that the primary mechanism providing saltwater to the swamp (under the conditions measured) was

Figure 5-7. Salinity Samples at GHS, December 1996.



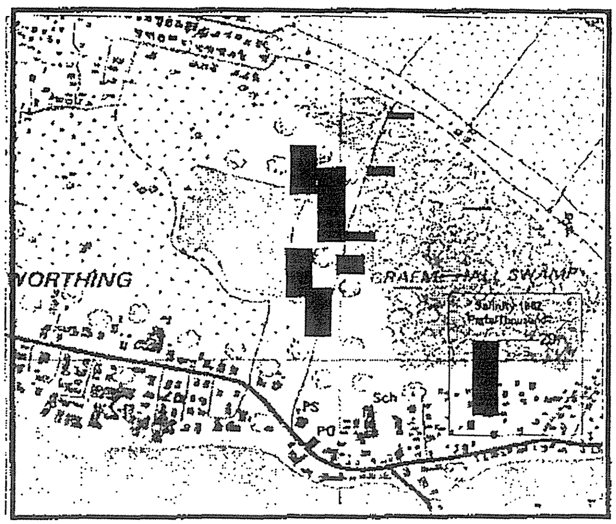
saltwater intrusion through porous geological formations separating the ocean and the swamp. The general results from the December 1996 samples are consistent with that conclusion.

The December 1996 sample sites in the lake, the channel and the uplands, although displaying some tendency for lower salinity levels away from the ocean, provided decidedly mixed results that probably demonstrated the influence of water being pumped from the Sewage Treatment Plant construction site. Extensive de-watering of the Sewage Treatment Plant during December 1996 provided a significant, but artificially high and transient, amount of fresh water entering the swamp. Lower than anticipated salinity in the lake samples may reflect the dilution capacity of these large volumes of water were pumped into the swamp (see 1987 results, Figure 5-8).

The 1996 lake samples, for example, were consistent at about 7.3 ppt [parts per thousand]. Samples from the cut channels in the eastern section of the swamp, which historically have demonstrated lower salinity levels, averaged about 2 ppt higher than the lake. These anomalies are clearly the result of the Sewage Treatment Plant pumping program, and the higher salinity levels in portions of the swamp closer to the Sewage Treatment Plant may reflect pumped water that includes more saline groundwater.

Salinity and pH were previously sampled in the swamp in April 1987. These samples were taken in the western lake, the western side of the causeway, and the trays east of the causeway swamp (see 1987 results, Figure 5-8).

Figure 5-8. 1987 Salinity Samples in GHS.

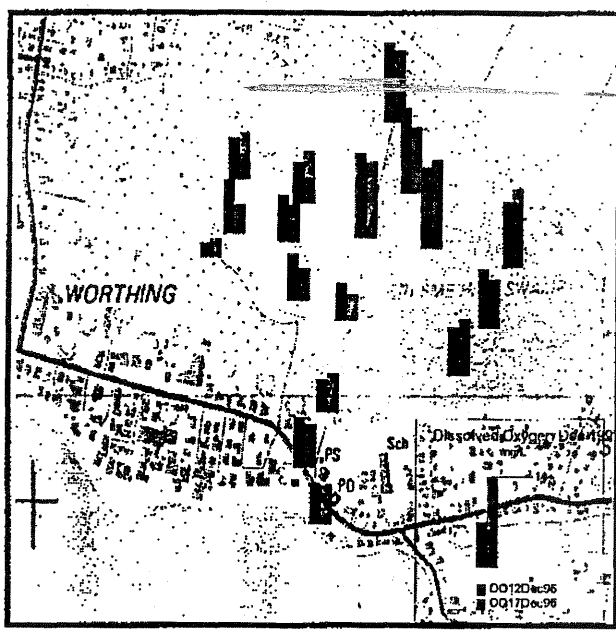


These measurements, taken during the end of the dry season, show salinity of 19 ppt within the lake compared to 7 ppt measured during December 1996. The 1987 salinity measurements also show salinity of 4-8 ppt along the causeway and salinity of less than 1 ppt in the dug channels in the eastern section of the swamp. The 1987 measurements clearly demonstrate salinity differences on each side of the causeway: salinity West of the causeway ranged from 19 to 30 ppt, while salinity East of the causeway ranged from near zero to 12 ppt. These 1987 salinity levels compare to an average salinity of about 16 ppt at a natural mangrove swamp monitored in Florida (Table 12-8)

Given these significant differences between 1987 and the 1996 samples, the 1996 samples and the planned 1997 samples can not be used to provide a realistic baseline for long term evaluations of GHS water quality. Adequate water quality monitoring will need to be re-established when the Sewage Treatment Plant has been completed and the swamp hydrology has stabilised.

5.5.2.2 Dissolved Oxygen

Figure 5-9. Dissolved Oxygen Samples, December 1996.

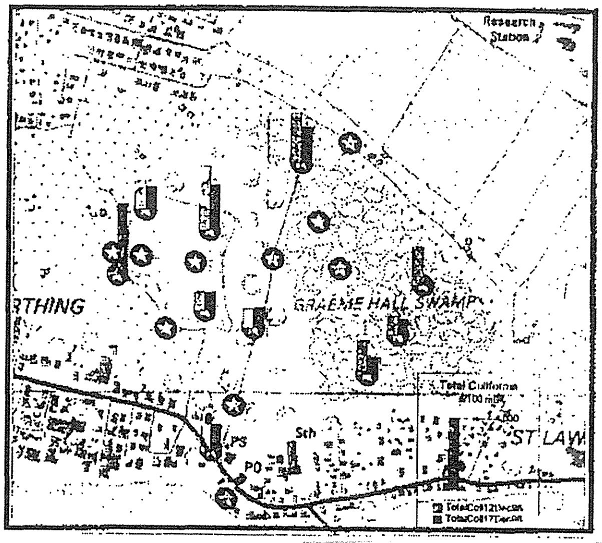


Samples collected at the swamp during December 1996 produced variable dissolved oxygen results ranging from 2.2 to 13.6 mg/L (Figure 5-9). The data indicate a general tendency for higher levels of dissolved oxygen on the East side of the swamp, and a slight tendency for higher levels of dissolved oxygen on the North side of the lake. These findings would be consistent with the hydrologic observations that the source of fresh water is from underground streams and springs on the North side of the swamp. The data also indicated slightly lower dissolved oxygen levels at greater depth in the lake, which would also be consistent with normal lake conditions.

The dissolved oxygen measurements taken in December 1996 were comparable to measurements taken during about a decade ago that were focussed within the lake and also showed decreasing values from the surface to the bottom (Cattaneo et. al. 1988). Although a very limited sample, these dissolved oxygen levels compare to average dissolved oxygen recorded at a natural mangrove swamp in Florida.

Given the shallow nature of the areas sampled (i.e., shallow ditches etc.) and the high degree of biological activity within those areas, it is not unexpected for dissolved oxygen levels to be highly variable and range from near hypoxia to supersaturated conditions. The 1972 dredging increased lake depth, and the increased depth probably contributed to longer and more frequent periods of low dissolved oxygen within the lake bottom due to reduced aeration.

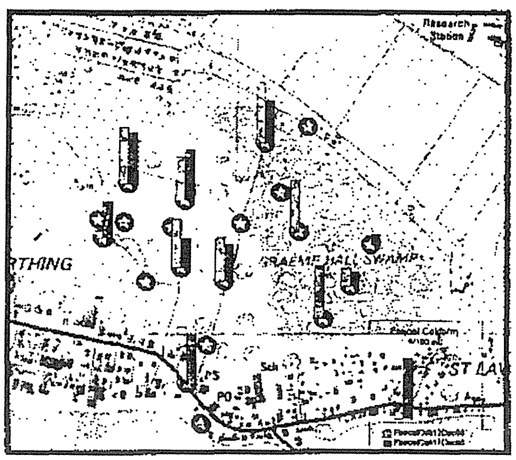
Figure 5-10. Total Coliform Sampling, December 1996.



5.5.2.3 Coliforms

Grab samples taken in December 1996 were also tested for total coliforms, faecal coliforms, and faecal streptococci (see Appendix 12.3). Coliforms are associated with vegetation, soils, slimes, sewage, storm-water drainage and surface water runoff. Positive tests for faecal coliforms, E. coli, and faecal streptococci indicate the presence of human or animal faeces because they are found in the intestinal tract of warm-blooded animals, including man. Most faecal streptococci organisms die off quickly outside the host, and their presence is, therefore, an indication of recent pollution.

Figure 5-11. Faecal Coliform Samples, December 1996.



US Environmental Protection Agency (EPA) standards for total and faecal coliform levels in recreation waters are:

- Total Coliform: mean not to exceed 50-2400 MPN/100 ml depending upon location
- Faecal Coliform: mean not to exceed 200 MPN/100 ml.

Total coliform counts from December 1996 samples were 160-4,000 MPN/100 ml. Faecal coliform results were 120-900 MPN/100 ml, with an average of 700 MPN/100ml for both samples.

Total coliform counts from December 1996 samples were 160-4,000 MPN/100 ml. Faecal coliform results were 120-900 MPN/100ml, with an average of 700 MPN/100ml for both samplings. Three of the sites (PS01, PS03, PS04, PS07, PS09) had total coliform levels that were near or exceeded EPA standards. Two of these sites were at the lake in the West Unit. These high coliform counts indicate external contamination from warm-blooded animals; a supposition supported by high faecal streptococci levels. These high levels also occurred outside the lake, indicating the loads are not primarily from the Cattle Egret Rookery on the northern end of the lake.

A possible explanation for high faecal and streptococci levels was the ongoing de-watering associated with construction of the sewage treatment facility. This de-watering included groundwater possibly contaminated by faulty septic tanks bordering the swamp. Because the de-watering occurred throughout the testing period, it was not possible to make projections on "natural" coliform contamination in GHS.

5.5.3 Nutrients

Total phosphorus in the December 1997 samples was 0.072-1.331 mg/L (Table 12-6, Table 12-7). These results are substantially higher than the average total phosphorus recorded at a natural mangrove swamp in Florida (Table 12-8).

Total nitrogen recorded in the two samples in GHS was 0.13-10 mg/L, with the highest reading occurring at the same station as the high phosphorus level. Again, these results are substantially higher than the average total nitrogen recorded at a natural mangrove swamp in Florida (Table 12-8).

These levels indicate that nutrient loading, particularly total phosphorus and total nitrogen conditions within GHS is substantially higher than that expected from a natural mangrove swamp at the Rookery Bay site in Florida (Table 12-8). Long term monitoring will be required to determine the location, source, and amounts of the nutrient loadings in the swamp, and develop a management strategy that addresses nutrient controls and/or increased freshwater and seawater flushing into the swamp.

5.5.4 Validity of Results

A number of extensive construction works associated with the Sewage Treatment Plant and other developments on private property on the West Unit of GHS were initiated between the time the GHS sampling plan was designed and sampling was completed. These included:

- de-watering of groundwater into the East Unit during construction of the wastewater treatment plant
- de-watering of the manhole adjacent to Highway 7 and the sluice gate, and discharge into the channel upstream of the sluice gate
- construction of an elevated 24-foot road/workpad for installing sewage pipes along the South and East margins of the swamp
- runoff of suspended material from the workpad as a result of limited siltation control
- construction of an extensive workpad and storage area with extensive heavy equipment operation and storage in areas immediately adjacent to Highway 7 and West of the central causeway

- extensive landscape modifications including vegetative clearing, dredging of shallow ponds, and landform shaping within almost the entire upland area between the large pond and the South and West sides of the western section.

The early 1997 Sewage Treatment Plant construction activities (primarily de-watering) on both the West and East Units of GHS produced large volumes of questionable quality water to the swamp. These large discharges into the swamp invalidated the use of the two December 1996 "wet season" samples as background samples of water quality for GHS. These two samples should, more appropriately, be considered representative of the impacts of Sewage Treatment Plant construction on Graeme Hall Swamp.

The early 1997 construction activities also precluded effective sampling during the scheduled "dry season" in 1997. The continued de-watering created unseasonably high water table water elevations within the swamp, created hydrologic and water quality conditions unrepresentative of a dry season, and nullified the value of continuing with plans for the two "dry" season samples.

The landscape construction on the private property on the West Unit also affected the hydrologic and water quality sampling program. A series of new ponds were created in April 1997 and most of the remaining vegetation was eliminated. These ponds and the runoff from the areas cleared of vegetation were directly accessible to the existing lake. Until the vegetative cover is re-established, water samples from the lake cannot provide a reliable base for planning and long term monitoring.

The hydrologic and water quality sampling program at GHS was designed to provide, in addition to baseline analysis and long term monitoring, a comparison between Graeme Hall Swamp and a relatively "natural" mangrove system in the tropics. This comparison model was to aid in defining restoration parameters for hydrology and water quality management of GHS. The December 1996 water quality samples cannot provide reliable background conditions for detailed comparisons and evaluation, and only subjective evaluations can be made. For the purposes of this comparison, some historical data will be used to provide comparisons between Graeme Hall Swamp (as it was prior to construction) and a "natural" mangrove system.

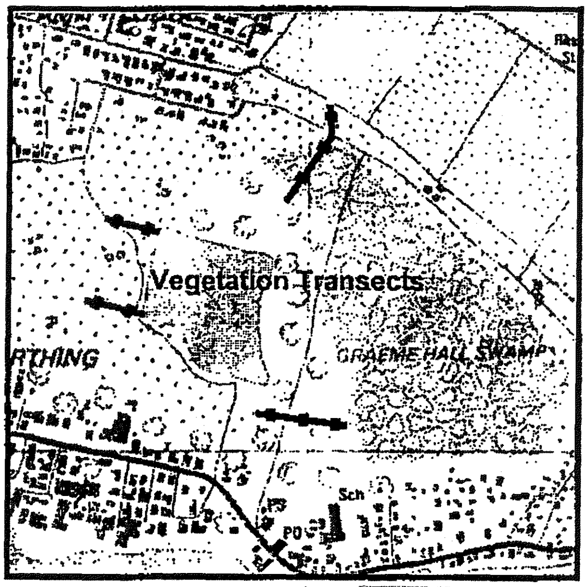
5.6 Vegetation

The area generally referred to as Graeme Hall Swamp is, in fact, not true "swamp". It contains a brackish shallow lake and canal, a sedge marsh, and a series of man-made freshwater canals within a 4.68 square kilometre drainage basin (Cattaneo et. al. 1988). The vegetative communities found in the swamp associated with these features are not uniform, and do they represent an assemblage of "climax" communities reflective of an on-going, uninterrupted succession. The swamp is rather an assemblage of highly diverse and disturbed land parcels. Some parcels have standing water or year-round wet soil that includes remnants of what was once a natural tidal mangrove community backed by a natural freshwater sedge marsh.

Each unique vegetative area contains salient physical conditions and corresponding dominant vegetative species. Some vegetation can be loosely characterised by community types; however, the amount and timing of human disturbance varies from area to area and disrupts the continuity of vegetative features.

The vegetation sampling protocol for this study encompassed both wet and dry season species. The four sampling transects (Figure 5-12) were originally located and designed to become permanent sampling stations for monitoring changes and making appropriate management decisions regarding the long-term vegetative of the swamp.

Figure 5-12. Vegetation Sample Transect, 1996.



Vegetation surveys were conducted on these transects from December 1996 to March 1997. A second sample was conducted on two transects during June 1997. During all field visits a general walking survey of the area was made and a list of all species observed was compiled (Table 12-10, Table 12-11, Table 12-12, Table 12-12). A total of 111 species were identified during these samples (Table 12-14). These sample results together with general observations recorded during site visits provided the information for a current general vegetation cover map of the swamp (Figure 5-13).

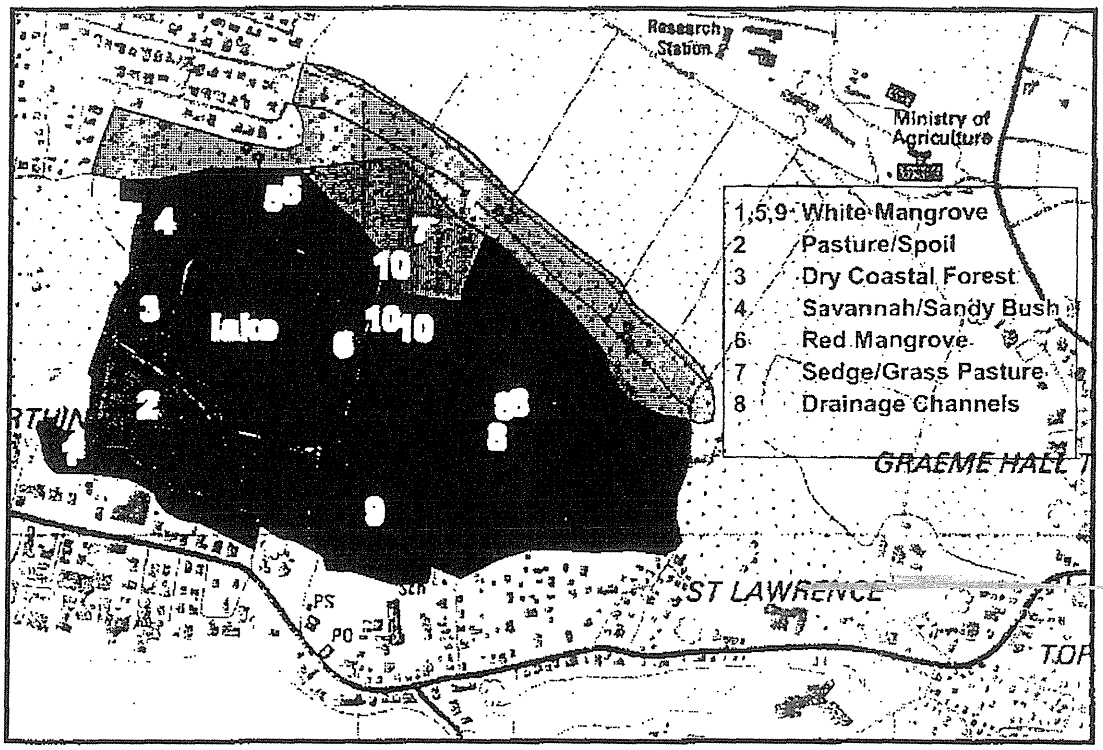
Section 5.6.9 discusses the significance and validity of the results.

5.6.1 Red Mangrove

A nearly pure stand of red mangrove (*Rhizophora mangle*) borders the lake in the West Unit, predominantly between the lake and central causeway. Four distinct size classes are present including seedlings or propagules (up to 12" tall), saplings (approximately 1" diameter and 1-11' feet in height), understory with stilt roots (12-15' tall), and mature with stilt roots (1.5" diameter +, 15-25'+ in height). Continued reproduction was occurring prior to the backwash of freshwater and sewerage pumping water initiated in November 1996. Red mangroves have been repeatedly cut back to between ground level and 5 feet in height for varying reasons since the late 1800's. Red mangrove typically occupy areas with standing, calm, brackish water. Their aggressive stilt roots can form pure or nearly pure stands like they have in Graeme Hall Swamp.

Although mangrove communities are often characterised by single species, Hardy described "Mangrove-Swamp Plants" (primarily *Rhizophora* and *Laguncularia*) on Barbados. Beard and Stoffers refer to "Mangrove Woodland" variably dominated by *Rhizophora, Laguncularia, Conocarpus,* and *Avicennia,* with other woody species in areas of reduced salinity. Similarly, Sauer described highly variable mangrove associations on the Cayman Islands, and indicated that disturbance impacts species composition in mangrove areas. Understory associates of woody mangrove species vary considerably from site to site. Hardy noted the absence of dwarf or olive mangrove (*Avicennia)* from Graeme Hall Swamp in 1917 (which had been suspected to previously have been present) and Hutt (1983) mentioned the noticeable absence of button mangrove (*Conocarpus*).

Figure 5-13. 1996 Vegetation Map of GHS.



5.6.2 White Mangrove

The scattered tracts dominated by white mangrove (*Laguncularia racemosa*) in creeks along the southern and western margins of GHS were previously noted by Hutt (1983), Riven-Ramsey (1988) and Parker and Oxenford (1994). The swampy area North of the lake is dominated by white mangrove, but with scattered exotics like seaside almond (*Terminalia catappa*) at the western end and coconut (*Cocos nucifera*) at the Northwest margin. This area, (map # 5) merges with the red mangrove community near the lake margin. The white mangrove were regularly being cut prior to 1970 but Hutt (1983) noted that by 1972 they had matured to a height of 20-25'. The area of white mangrove in the East Unit is now much reduced on its eastern border compared to mappings in 1983, 1988, and 1994. The vegetative cover in map # 9 has been allowed to continue the natural colonisation of white mangrove, and the area now contains maturing trees derived from sucker-shoot saplings from trees downed by Hurricane Allen. This area is an open canopy of white mangrove interspersed with banks covered by the sedge *Eleocharis mutata* and *Chara*-filled channels. Common planted species are interspersed where white mangrove border backyards. This area was inundated by Sewage Treatment Plant construction pumping during our field investigations, and the water overflowed banks of many canals and flooded residences to the South.

Even within the small area of the swamp, *Laguncularia* turns up as associations of almost pure stands (map # 1), mixed with exotics (map # 5), or with an understory carpet dominated by *Eleocharis mutata* (map # 9). Thus "White Mangrove Forest" only loosely applies to the diverse sites united by having *Laguncularia* as the dominant woody species. Differences from site to site may reflect varying successional stages, with apparent broad ecological tolerances by *Laguncularia* on wet brackish sites with disturbance that are only infrequently inundated (Stoffers ????). *Avicennia* is probably more sensitive to altered conditions than *Laguncularia,* and it is possible that *Laguncularia* invades as Avicennia recedes.

5.6.3 Sedge and Grass Pasture

Freshwater marshy areas North of the lake are dominated by sedges, especially *Eleocharis mutata.* Drier northern portions of these areas contain a mixed-grass pasture with scattered shrubs and trees. *Eleocharis mutata* is probably the most abundant plant in the swamp, despite being unusual elsewhere on Barbados. It is by far the dominant sedge, forming acres of a nearly mono-specific lawn on low, very wet, marly soil in large portions of the swamp. This "lawn" extends as the herbaceous understory beneath *Laguncularia* in map # 9. Areas dominated by *Eleocharis mutata* are called "Sedge Swamp" association by Gooding (1974), who places the association in areas of reduced salinity or virtually fresh water behind mangrove swamp.

This plant association appears to be the most "natural" community at Graeme Hall Swamp and, based on historical data, possibly the one of longest duration. Other members of the association (all far less abundant) are *Eleocharis geniculata* (Also encountered along streams), *Fimbristylis ovata* (many habitats), and *Fimbristylis ferruginea* (scattered throughout the swamp), *Sporobolus virginicus* (many salty habitats), and *Philoxerus vermicularis.*

5.6.4 Pasture on Spoil

The area South of the lake contains marl fill dredged from the large pool. It contained an assemblage of alkaline-tolerant weeds and grasses dominated by *Sporobolus virginicus*, which in the wetter Southwestern corner is replaced by sedges such as *Eleocharis mutata*. This area also contains sporadic distribution of weedy herbs, shrubs, and trees such as bread & cheese (*Pithecellobium unguis-cati*). Some wetter areas may ultimately be covered with *Laguncularia*, and show signs of potential mangrove colonisation.

The assortment of grasses alone is a reasonable representation of the "weed grasses of Barbados," excluding those of more fertile agricultural sites, and *Sporobolus virginicus* is abundant throughout Barbados on disturbed salty sites.

The large Southeast portion of this area was filled by a construction workpad for the Sewage Treatment Plant facilities in April 1997. The vast majority of remaining area was de-vegetated and landscaped in preparation for development on the private property portion of the West Unit of the swamp.

5.6.5 Dry Coastal Forest

This dry sandy area (map # 3), located West of the lake, is dominated by small bread & cheese (*Pithecellobium unguis-cati*) trees with a sparse understory of weedy shrubs and vines. Species present include weedy probable natives (e.g., *Acacia tortuosa, Cenchrus echinatus, Cyperus ligularis*), natives found also in inland woods (e.g., *Maclura tinctoria, Solanum racemosum, Citharexylum spinosum*), introduced weeds (e.g., *Asparagus sp., Ziziphus mauritiana, Jasminum fluminense*), and species commonly encountered on the seashore (e.g., *Sporobolus virginicus, Cocos nucifera, Cyperus ligularis)*. Although the species of *Pithecelobium, Gossypium,* and *Guiacum* may be indigenous to Barbados, their presence in the swamp probably reflects their common cultivation on the island.

Gooding (1974) recognised a variable "Coastal Forest" on Barbados transitional between sandy beach communities and interior mesophytic forest. These Coastal Forests occur on mixed clay and sand substrate, are somewhat xerophytic, and are highly variable due to their coastal location and transition between sandy shore and inland woodland. Depending on the area, frequently encountered woody genera in Coastal Forests include species of *Coccoloba, Tabebuia, Hippomane, Pisonia,* and *Caesalpinia.* This vegetative in map # 3 corresponds well to Gooding's [dry] Coastal Forest in position and transitional nature, although species composition is unnatural and indicative of substantial disturbance.

Sauer described near-coastal clearings in the Cayman Islands that may more closely describe the vegetative cover in GHS. These near-coastal clearings are repopulated with "patchy re-growth of herbs, vines, and shrubs, mostly members of the natural beach outpost vegetation but with weedy inland species, such as *Leucaena* and *Sansevieria*, mixed in."

Most of this area was cleared, ponds created and landscaped in preparation for development on the private property portion of the West Unit of the swamp.

5.6.6 "Savannah"/Sandy Bushland

This area, Northwest of the lake is very dry, and similar to vegetative cover in map # 2. It borders the "Sedge Swamp" association (map # 7), and is dominated by crab grass (*Sporobolus virginicus*) with sedges in the wetter northern end, but also contains an abundance of shrubs and small trees.

The woody cover is invaded with naturalised exotics (e.g., *Casuarina equisetifolia*, *Terminalia catappa*). The *Tabebuia heterophylla* may be a significant remnant of the Coastal Forest discussed above (map # 3). From an aesthetic standpoint, this area is attractive and has a natural feel. It may contribute to natural area of GHS if properly restored and maintained, and the invasive species are removed. Some of this area was cleared and landscaped in preparation for development on the private property portion of the West Unit of the swamp.

5.6.7 Drainage Channels & Causeways

These mostly human-created channels are filled with Stonewort (*Chara* sp.) and sedges at the margins. The raised paths or causeways between are dominated by Crab Grass (*Sporobolus virginicus*) and weedy species such as *Conyza lyrata*.

These sites are unnatural and highly disturbed. The only noteworthy vegetative species encountered on these sites was *Cyperus alopecuroides*, discovered in 1996 as new to the flora of Barbados. This species is known from only one other region on Barbados---the stream and associated pond at Three House, St. Philip. At least in Barbados, this sedge inhabits places characterised by standing or permanently running water, deep muck, and high organic enrichment.

5.6.8 Central Causeway

The central causeway basically divides the swamp. The drier portion of the causeway has weedy species typical of sandy bushlands, damp muddy flats with *Bacopa monnieri*, sedges dominating in the wetter areas, and crabgGrass *(Sporobolus virginicus)* dominating in drier raised areas. Portions of the normally dry causeway were continually flooded during the study sampling from de-watering associated with sewerage treatment plant construction.

The causeway is heavily populated by large, aggressive pasture grass *Brachiaria purpurascens* (often called *Panicum purpurascens*). This species appears to be invading the swamp from agricultural and residential areas in the the Northeast, and will be a significant component of the meadow flora, especially on slightly elevated sites.

5.6.9 Analysis of Survey and Vegetative Cover

The vegetative mapping studies conducted in 1996 and 1997 found much reduced areas of *Casuarina*, expanding areas of white mangrove, and an apparently stable freshwater sedge marsh North of the lake. The distribution of red mangrove appeared relatively consistent with previous vegetation cover maps produced from 1974 through 1994 (Gooding (1974), Hutt (1983), Riven-Ramsey (1988), and Parker and Oxenford (1994)). The filled area to the South and West of the lake showed continued changes from a weedy grassland and shrubland prior to being cleared in April 1997.

Each of the four vegetation transects established in the swamp for this study were scheduled for wet and dry season sampling. Vegetation samples were conducted on these transects from December 1996 through February 1997. Construction activities associated with the Sewage Treatment Plant on the East Unit of the swamp, and development activities on the private property within the West Unit complicated both the vegetation surveys and the validity and interpretation of the results. These activities and their effects were beyond the control of the vegetation sampling program developed for this project.

Continued alterations in water flow and quality resulting from construction at the Sewage Treatment Plant, and continuing inconsistency in water levels and salinity resulting from ad hoc operation of the sluice gate certainly influenced the vegetation of the swamp. One transect on the East Unit was inundated by the increased water levels associated with de-watering. Germination and appearance of some species may have been delayed or negated by these changes. Physical works such as the equipment staging area near the central causeway and the workpad for laying sewage pipes through the swamp may also have affected species composition sampling results.

The other major activity affecting swamp vegetation during the course of the planned vegetation samples was the extensive clearing and landscape alterations conducted during April 1997 in the West Unit of the swamp. These alterations included removal of vegetation, grading and revisions of existing drainage, and excavations of new shallow ponds. The alterations have effectively redone the vegetation of the West Unit of the swamp. These alterations may also have adversely affected vegetation communities along the drainage creek, and the areas of red and white mangroves.

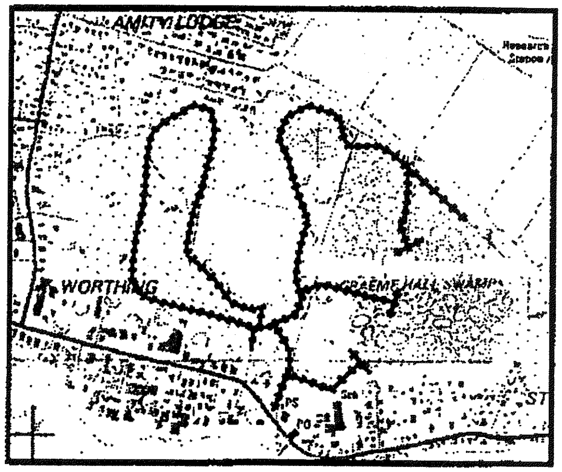
The original sample transects were designed to become permanent sampling stations for monitoring changes and making appropriate management decisions for swamp vegetation. The extensive and unexpected landscaping destroyed the two sample transects located on the private western section of the swamp, and precluded any rationale for further sampling in those areas.

These construction activities have also made it difficult to ensure that both rainy and dry season vegetation was adequately sampled. Characterisations of the swamp vegetation based on the 1996 and 1997 surveys must, therefore, be qualified by the unusual events and conditions and, in some cases, the unavailability of sample data that occurred during the sampling period. Due to these constraints, comparative analysis were restricted, and the conclusion qualified. New permanent transects will have to be established after the construction is completed to continue monitoring of vegetation change in the swamp.

Introductions of tropical species to the swamp may also have a significant effect on vegetation of the entire swamp. Even though much of the swamp is currently non-native, the mangrove and the freshwater sedge marsh communities appear to have remained relatively stable back to at least the 1700's. Aggressive aquatic species introducing into newly constructed ponds or development areas could eventually expand and compete with the existing species in the freshwater sedge marshes or in the mangrove areas.

5.7 Wildlife

Figure 5-14. Wildlife Survey Routes.



The suitability of Graeme Hall Swamp as wildlife habitat is influenced by the changes in environmental quality and surrounding land use. This is especially true for habitat, since birds are highly mobile and free to select habitat anywhere on the island or on other islands. The size of each vegetative community in Graeme Hall Swamp is generally quite small and less than the known home range or territory of many birds species occurring there. Nearly all of the wildlife in the swamp have been observed in multiple vegetative communities, and no single species (terrestrial or marine) appears to be situated in any one area.

The vast majority of bird species historically and currently using the island and the swamp are migrants. They stop on their way to and from South America and a few over-winter on the island. Their use of the swamp is limited by the condition and size of the migratory populations, the availability of appropriate cover and food, the availability of suitable stopover sites elsewhere on the island, the extent of hunting pressure in other areas of the island and the extent of human disturbance on the island and in the swamp, weather conditions, and chance. It appears that the number of species of shorebirds and waders observed in the swamp has declined in recent years due to the limitations of suitable habitat' however, the increased tree growth and woodland habitat may have increased the stopovers of wood warblers.

5.7.1 Aquatic Fauna

The status of the aquatic fauna of Graeme Hall Swamp including: insects, crustaceans, amphibians and fishes was reviewed as part of this study by the Bellaires Research Institute and is included as an appendix to this report (Appendix Section 13.2, Table 1).

The swamps aquatic insect fauna has not been documented. The crustaceans include several species of crabs and at least two species of freshwater shrimps. Although most of the crabs are not aquatic, their larvae develop in water. The freshwater shrimp presently in the swamp is *Macrobrachium faustimum*, but the swamp is also ideal habitat for the much larger *M. acanthurus* which co-occurs with *M. faustimum* in many other areas of the Caribbean.

The amphibian fauna consists of tadpoles of the toad, *Bufo americanus*. The fish fauna is a mixture of indigenous and introduced species of which 10 are believed to be resident in the swamp and 9 are primarily marine but enter the swamp for part of their life cycle.

The diversity of the swamp's current aquatic fauna is low relative to other natural Caribbean mangrove ecosystems. Developments over the last 300 years have physically altered what was originally a marine estuary by effectively eliminating direct natural connection to the sea. This.

together with physical alterations within the swamp and the pollution from the surrounding developments have reduced the swamp's faunal diversity. In spite of this, the swamp remains an area of unique natural beauty in a Barbadian context, with a unique ecosystem and a floral and faunal assemblage found nowhere else in the island.

5.7.2 Wildlife Surveys

Monthly wildlife surveys were conducted from November 1996 through April 1997 (see Appendix ??? for survey details and routes). The survey route was taken each morning for three mornings and one late afternoon survey was conducted during each month.

Birds were identified both by calls and visually observation, and the numbers of each species by major habitat type and relative abundance relative to other bird species was recorded (see Appendix ??? for the species list and observation results). A search was also conducted for reptiles and amphibians under objects and within likely micro-habitats. Fish were collected with a dip net and some were obtained during a minor fish kill.

5.7.2.1 Aquatic Invertebrates and Vertebrates

A number of fish species were captured during the field investigations, however, the fish taxonomy is extremely confused and specimens have been provided to the Florida Museum of Natural History for identification and additional study. A number of aquatic invertebrates were also collected during the field investigations, including two species of freshwater shrimp, two species of crab, three species of aquatic snails, and one species of amphipod. These specimens have been provided to the Florida State Museum for identification.

5.7.2.2 Reptiles and Amphibians

Eight species of reptiles and two species of amphibians were identified during the field investigations in the swamp. - as attached

5.7.2.3 Mammals

Five species of mammals were observed during the field investigations in the swamp, including two species of native bats and three species of exotic land mammals.

5.7.2.4 Birds

A total of 48 birds were observed, several of which were either observed as nesting, were demonstrating nesting behaviour and were in habitat that would be used by that species for nesting. Others were considered migrants, feeding and resting in the swamp.

5.7.3 Yellow Warblers

Yellow Warbler (*Dendroica petechia)* observations by a large number of investigators indicates the existence of up to 35 sub-species. These sub-species are generally separated into the following three groups:

Aestiva group: A migratory population that nests in North America and winters in the Caribbean, Central America and northern South America

Erithachorides group: A non-migratory population inhabiting both coasts of Central America, the Galapagos Islands and northern South America

Petechia group: A non-migratory population inhabiting mangrove areas on Caribbean islands. The sub-species present on Barbados is generally recognised as *Dendroica petechia petechia.*

Observations to date suggest that individual birds of the *Petechia* group generally do not intermix between islands. Additionally, other studies of Yellow Warbler on different islands have documented minor variations in several characteristics such as plumage and vocalisation.

No genetic studies have been conducted to determine the level of speciation in this group. There are also indications, however, that some island populations of yellow warblers are changing, and may become different enough over time to become separate species. If this hypothesis proves correct, protection of Yellow Warbler habitat in GHS may be an important component in protecting what may eventually become a unique species of the Yellow Warblers in Barbados.

Discussions with knowledgeable local bird enthusiasts revealed that Yellow Warblers have been confirmed to be present in every Parish on Barbados (E. Massiah, personal communication) Although no population estimates are available for Yellow warblers in these other locations, it is suspected that Graeme Hall Swamp provides the habitat for the largest individual group of yellow warblers on the island.It is notable that Yellow Warblers outside of Graeme Hall have been documented in habitats other than mangrove swamp.

The only written estimate of Yellow warbler abundance in Graeme Hall is 6-8 pairs reported by Maurice Hutt in 1983, based on his observations during the period from the 1950's through the early 1980's.

5.7.3.1 Survey Results and Population Estimates

A survey of the Barbados race of the Yellow Warbler, based on observations of the habits and habitats of the birds, was conducted during the week of 31 March 1997 (estimated to be at the beginning of the nesting season) to establish a population estimate of Yellow Warblers in Graeme Hall Swamp. These observations were also designed to subsequently develop recommendations for Yellow Warblers management in the swamp.

Based on visual observations and the location and abundance of territorial calls and courtship singing within each habitat type (Table ????), a conservative estimate is that the swamp provides habitat for approximately 20-40 pairs of Yellow Warblers. This estimate is consistent with the number of Yellow Warblers observed during all general bird surveys.

The locations of the visual and auditory observations indicate that Yellow Warbler prefer the dense mangrove forest habitat in the swamp. The density of the trees appears more important to Yellow Warblers than the species of tree. Open areas of white mangrove and shrubby uplands appear to be used for foraging, but these areas appear to be less desirable and they may be used by comparatively "young" or disadvantaged birds.

There is limited scientific information available on the Barbados Yellow Warbler. The population in the swamp appears to be primarily dependent upon adequate dense mangrove stands and limited disruptive activities during critical stages of its life cycle. Management recommendations for Barbados Yellow Warbler in the swamp must, therefore, be especially conservative to protect this unique Barbados bird species.

6. Comparisons To A Natural Mangrove Ecosystem

6.1 Introduction

The internationally-recognised significance of natural mangrove ecosystems is reflected in the growing scientific literature on mangrove community characteristics, function, and status. The United Nations, The Conservation Foundation, the World Wildlife Fund, the Caribbean Conservation Association, and a variety of national conservation organisations and individual governments have funded studies on the status and management of this fundamental vegetative community of tropical and subtropical sheltered coastlines. These studies provide a body of comparative data from which recommendations can be made for rehabilitation and management for Graeme Hall Swamp.

6.2 Mangrove System Constraints

Mangroves are found in the tropics and sub-tropics world-wide. Theis distribution is influenced by five main factors Odum (1982):

Climate — annual average temperature must exceed 66 °F (19 °C) with only rare and brief episodes of freezing temperature.

Salinity — salt water is not an absolute requirement for mangroves, but their tolerance of higher salinity allows mangrove to out-compete other more salt-sensitive species that might have an advantage in freshwater areas. On the other hand, high substrate salinity above 60-65 ppt limits red mangrove (*Rhizophora mangle).* White mangrove (*Laguncularia racemosa*) and olive mangrove (*Avicennia nitida*) can grow in salinity greater than 80 to 90 ppt (Cintron et. al. 1978).

Water fluctuations — tidal action and freshwater runoff both contribute to mangrove development by distributing propagules, flushing accumulated hydrogen sulphide and salts, and transporting nourishment with nutrients from terrestrial run-off. Topography plays a significant role in the extent of water fluctuation within a tidal basin.

Substrate — mangrove flourish where deposition of terrestrial run-off provides nutrients to substrates that are nutrient poor with waterlogged anaerobic fine sediments that exclude most competitors.

Wave action — mangroves require areas of low wave energy conducive to allowing establishment of propagules and developing fine anaerobic sediments. Heavy wave action will exclude mangroves.

It is the unusual root structures and physiological adaptations that allow mangrove to thrive in anaerobic soils and out-compete other species in saline environments. These special adaptations also make them very sensitive to stress, particularly anything that kills or clogs aerial roots, or lenticels. Prolonged flooding, pollutants (oils, suspended sediments), excessive wave action (opening of reef or breakwater, boating), excessive input of freshwater, lowered pH, increased salinity from reduced rainfall, or increased evaporation, can adversely affect mangroves or allow competitors to flourish. Early research characterised mangrove as "land builders"; thereby fuelling beliefs that regular cutting and thinning of mangroves was needed to maintain open water (Davis 1940). Recent research suggests mangrove are "land stabilisers", and factors such as sedimentation and hydrological processes are much more likely to determine shoreline (Thom, 1975). Understanding these complex processes is key to managing Graeme Hall Swamp for long-term sustainability.

6.3 Comparative Mangrove Environments

A number of well-known mangrove areas have been studied in recent years, including Fort Vieux, St. Lucia suggested by Hutt (1983); four sites in Florida - Indian River Lagoon, Florida (Lewis et. al. 1985, Peene 1991), Rookery Bay (Clark 1974), Tampa Bay (Lewis et. al. 1985), North River Estuary (Odum 1991), and some historic systems in the Caribbean (Stoffers 1956).

Rookery Bay in Florida represents a significant natural ecosystem with many component habitats, and it lies within the influence of the major population centres of Southwestern Florida. The surrounding land remains nearly undeveloped; though external pressures are, in some ways, similar to those experienced by Graeme Hall Swamp. Rookery Bay is a well managed fully functioning system, qne iw one of the largest (15,000 acres) mangrove areas left in the world today.

Rookery Bay has areas of undisturbed mangrove estuaries and second growth mangrove woodlands (ranging from 30 to 100 years in age) surrounding shallow bays with dry upland areas inland. The historical vegetation pattern of Rookery Bay has continued to change due to both human actions and natural geological processes Clark (1974). The surrounding shoreline is less than 12 feet above mean sea level, and has a slope of less than 1 foot per mile. The similarities between Graeme Hall Swamp and Rookery Bay are sufficient to provide useful management comparisons. In addition, research on mangrove recovery in Rookery Bay following a series of devastating hurricanes may provide insights into recovery following man-made changes to mangrove systems.

6.4 Hydrology

The most dramatic difference between GHS and Rookery Bay hydrology is the magnitude of water exchange between the estuary and the ocean. Rookery Bay has multiple interconnecting channels that allow free passage of clean ocean water through tide and wind action. In addition, nutrient rich upland runoff has free exchange with the ocean waters that flush accumulations of hydrogen sulfide and salts from sediment poor waters, and transport propagules throughout the system. These mechanisms, termed tidal or fluctuating water subsidies (Odum 1971), are primary determinants of the extent, height and biomass of mangrove communities.

The only direct connection between Graeme Hall Swamp and the ocean occurs through the drainage channel running along the central causeway. This channel passes under the coastal highway, built on sand bar deposits during the early 18^{th} century. Flow through this channel is restricted by the operation of the sluice gate, and in recent years the operation and effectiveness of the sluice gate to allow water interchange with the swamp has been sporadic.

It is clear that mangrove's tolerance of higher salinity allows them to out-compete other more salt-sensitive species that might have an advantage in freshwater areas. In Graeme Hall Swamp, like in

These samples should provide a natural system base for comparison with the Graeme Hall System. Because 1996 samples at Graeme Hall Swamp were taken during the de-watering program for the Sewage Treatment Plant, comparison of these results to Rookery Bay must be approached with caution. Historical water quality data from Graeme Hall Swamp provides addition collaboration, where appropriate, to develop a comparative characterisation of Graeme Hall Swamp with the relatively natural conditions at Rookery bay.

6.5.1 Salinity

Salinity measurements within Rookery Bay ranged from as low as 0.1 ppt up to 34.6 ppt, with a mean salinity of 15.7 ppt. This wide range of salinity is typical of an natural mangrove estuary. Salinity at Graeme Hall Swamp ranged from 7 to 20 ppt are clearly within the range of salinity measurements at Rookery Bay. The average lake salinity at Graeme Hall Swamp of 11-12 ppt, which is slightly less than the average of 15.7 ppt found in Rookery Bay, may reflect the lack of ocean-source water samples from Graeme Hall Swamp that were constantly available in the Rookery Bay system.

Salinity levels within the mangrove areas near the lake at Graeme Hall Swamp are very consistent with natural salinity levels at Rookery Bay and with reported salinity levels favourable to mangrove development. Outside of the lake, particularly East of the causeway during dry periods, the generally lower salinity and the proximity to the freshwater sources may account for the different vegetation distribution. The samples collected at Graeme Hall Swamp in 1987 provide a clearer comparison with Rookery Bay, because the lake samples are very comparable to the Rookery Bay salinity and the East Unit samples are significantly lower than those at the lake, reflecting the continuing influence of the fresh water supply.

6.5.2 Dissolved Oxygen

Dissolved oxygen within the Rookery Bay/Ten Thousand Island system averaged 6.0 mg/ L (range 2.8 to 12 mg/L. Dissolved oxygen in Graeme Hall Swamp samples in 1996 were very comparable with Rookery Bay. Again, however, the swamp data displayed effects of the Sewage Treatment Plant construction de-watering activities during fall and winter 1996. The measurements were taken during the end of the wet season, when overall water exchange within the swamp was relatively high.

Samples were not collected in Graeme Hall Swamp during the dry season when overall water exchange is reduced, and low water conditions could create stagnant water. Limited data available from the April 1987 sampling indicates that dissolved oxygen conditions within the lake were not low even during what was supposed was a dry hot period.

These limited data indicate that dissolved oxygen levels at Graeme Hall Swamp, even during the dry season, generally to not appear to be reduced to levels constituting serious water quality concerns.

6.5.3 Nutrients

Levels of Total Phosphorus, Ortho Phosphorus, Total Nitrogen, and Nitrate/Nitrite samples collected at Graeme Hall Swamp during December 1996 were consistently higher than comparable measurements for Rookery Bay system. In some samples, such as near the Egret Rookery, concentrations of phosphorus and nitrogen were significantly higher than at Rookery Bay. These 1996 sample results at Graeme Hall Swamp are corroborated by the water quality samples collected in 1987 during the dry season. The 1987 samples also had consistently high Total Phosphorus and Total Nitrogen concentrations; with one measurement of 10.2 mg/L Total Phosphorus near the Egret Rookery. Total Nitrogen samples at Graeme Hall Swamp were also higher than concentrations recorded at Rookery Bay, with the highest measurement of 10 mg/L near the Rookery.

Elevated nutrient concentrations at Graeme Hall Swamp can be the result of:

- Reduced flushing in the system due to lack of tidal exchange
- Increased loading of nutrients from surrounding urban areas
- Increased internal loading of nutrients from the Egret Rookery being distributing throughout the system.

Periodic general and targeted monitoring of nutrient levels at Graeme Hall Swamp will be required to determine the source and effects of the nutrient levels in the system, and to develop appropriate management strategies to deal with nutrient loading and flushing. These monitoring programs will become particularly important if developments on the West Unit include aviaries and expanded programs to encourage additional migrant and local bird traffic to the Graeme Hall Swamp wetlands.

6.6 Vegetative

The vegetation species survey conducted for this study (Section 3.3) provided the basis for comparing existing vegetation in the swamp with other disturbed Caribbean mangrove habitats, and with other relatively healthy and sustainable mangrove ecosystems. This vegetation survey incorporated literature research and on-site plant surveys during November 1996-June 1997. The 1996-97 surveys were compared to vegetation present at Graeme Hall Swamp in 1983, and to vegetation present at Rookery Bay (Appendix Section 12.5) which encompasses habitats similar to what Graeme Hall Swamp conditions prior to the 1700's. Comparative species in Appendix Section 12.5) also include all wetland and upland vegetation sampled at Rookery Bay.

Half of the Rookery Bay surveys included transects dominated by olive (black) mangrove (*Avicennia nitida)* and half by red mangrove (*Rhizophora mangle)*. None of the transects were dominated by white mangrove (*Laguncularia racemosa)*, and white mangrove was the least frequent species in all sample plots at Rookery Bay. In comparison, white mangrove dominates at Graeme Hall Swamp because of changes in water regime and historical human intervention. White mangrove at Rookery Bay attained a greater dbh (diameter breast high) than red mangrove, and researchers speculated that red mangrove is slower growing (Wadsworth 1955 and Craighead 1971).

About one-half of the 129 plant species recorded for Rookery Bay are also present on Barbados, and about one-quarter of the Rookery Bay plants have also been reported from Graeme Hall Swamp. The 34 species common to Rookery Bay and Graeme Hall Swamp included trees, shrubs, herbaceous plants, and grasses. The limited diversity of species at Graeme Hall Swamp may represent the habitat degradation and species isolation that has occurred at the swamp since construction of the road and sluice gate, the dredging and filling of the West Unit, and the private developments that have occurred all along the edge of the swamp.

Descriptive comparisons of mangrove vegetation in habitats similar to Graeme Hall Swamp on other islands such as Aruba, Bonaire, Curacao, and St. Maarten are include in the Appendix Section 12.5. These comparisons provide some insights into what the Graeme Hall Swamp vegetation may have been prior to human disruption.

6.7 Wildlife

Graeme Hall Swamp prior to English settlement probably had typical Caribbean wildlife species commonly found on the beach, back dune areas, and red mangrove and white mangrove lagoon areas. The current nesting records and biodiversity of the resident and migratory bird populations reported at Graeme Hall Swamp is still similar to that reported for other Caribbean mangrove swamps (Appendix Table 4.4). This comparability is in spite of the swamps relatively small size, its location on a relatively small island, and its long history of agricultural and human intrusions.

The greatest divergence between Graeme Hall Swamp and other mangrove swamps reviewed is in the fish and marine invertebrate faunas, primarily due to differences in water quality and exchange. The nursery functions attributed to most mangrove systems has been greatly reduced in Graeme Hall Swamp because of sluice gate operations. Species present elsewhere and noticeably absent from Graeme Hall Swamp may have occurred historically. Comparisons with Rookery Bay indicate that Graeme Hall Swamp has some species typical of similar less human-impacted mangrove swamp and associated upland habits, but shows evidence of great disturbance and exotic species influx.

The number of reptile and amphibian species in Graeme Hall Swamp are very comparable to Rookery Bay. Few amphibians are tolerant of high salt concentrations. The two anurans found in Barbados have been found in good numbers in the upland areas of Graeme Hall Swamp. Similarly, frogs and toads such as the Green Treefrog, *Hyla cineria*, Narrow-mouthed frog, *Gastrophryne carolinensis;* and the southeastern leopard frog, *Rana sphenocephla* have some tolerance for salt and are found in Rookery bay. All reptile species expected in the habitats of Graeme Hall Swamp were found; along with one recent and one previously introduced species.

The only terrestrial mammal probably native to Graeme Hall Swamp was the Barbados racoon, which appears to be extirpated. There are at least three introduced species of land mammals and at least two species of bats recorded from Graeme Hall Swamp while there are four mammal species total listed for Rookery Bay.

In summary, non-marine wildlife in Graeme Hall Swamp is highly comparable to Rookery Bay and other mangrove systems on other islands. In fact, species diversity may be higher than most. However, the overall biodiversity is low when potential marine species are included.

6.8 Conclusions

Graeme Hall Swamp has been the recipient of over 300 years of human intrusions and manipulations. In spite of this, it still endures and provides a biophysical base for an impressive diversity of flora and fauna, some of which are unique to Barbados. Its continuing challenge for maintaining these biophysical systems is its location within one of the most highly urbanised areas of the island, the growing tourism developments within the entire South Coast, its limited size, and the lack of a proper buffer zone between the swamp and encroaching developments.

In contains the hydrologic attributes necessary to maintain a coastal wetland mangrove ecosystem with adequate freshwater from springs and streams, and with adequate saline water from underground sources. This salinity nurtures the abilities of the mangrove forests to compete with other freshwater species.

The measured nutrient levels in the swamp appear to be relatively high compared to other nature mangrove systems. This may be due to a combination of unusually high nutrient loadings particularly from the egret colony, the lack of proper flushing mechanisms, or a combination thereof. These nutrient levels will require careful monitoring, particularly if facilities and management programs on the West Unit increase the local bird populations.

The existing vegetation in the swamp is low relative to other natural mangrove areas such as Rookery Bay in Florida. This reduced species diversity is not unexpected, however, given its long term use for agriculture and the associated habitat alterations. Its location may also have contributed to species isolation and reduced species diversity. The swamp still maintains the biophysical capabilities to expand the floral diversity under proper management.

The existing wildlife diversity of the swamp is low, but is generally what would be expected in a tropical mangrove environment. The diversity of freshwater and brackish water invertebrates and vertebrates is significantly lower than would be expected in a natural mangrove system. This condition is primarily the result of the construction and operation of the sluice gate at the exit of the swamp to St. Lawrence Bay. Resolution of this impediment to adequate mixing of the swamp and the bay organisms is a necessary precursor to increasing invertebrate and vertebrate diversity in the waters of Graeme Hall Swamp.

Coastal wetlands have historically been a magnet for migrating birds passing by Barbados. Graeme Hall Swamp had a long history of luring these migrants, primarily shorebirds, to the swamp for shooting clubs. The key to increasing these bird visitations is to provide safe habitat with adequate food and rest areas. Restoration of shallow freshwater and brackish water "trays" as shorebird habitat will measurably increase the numbers and diversity of birds species in the swamp.

Overall, the biophysical characteristics still exist, or can be rehabilitated, to provide a base from which to develop a sustainable flora and fauna within Graeme Hall Swamp that mimics the extensive systems of coastal wetlands that existed in Barbados prior to European settlement. This requires immediate actions both within and adjacent to the swamp. The following Section describes a series of biophysical recommendations that address the overall sustainability of the swamp in total. The following Section reviews the development objectives and options available for the swamp, and makes recommendations based on the biophysical realities and the country's policy directives on environmental protection and tourism development. The final Section of the report addresses the programmes necessary to implementation the recommended course of action.