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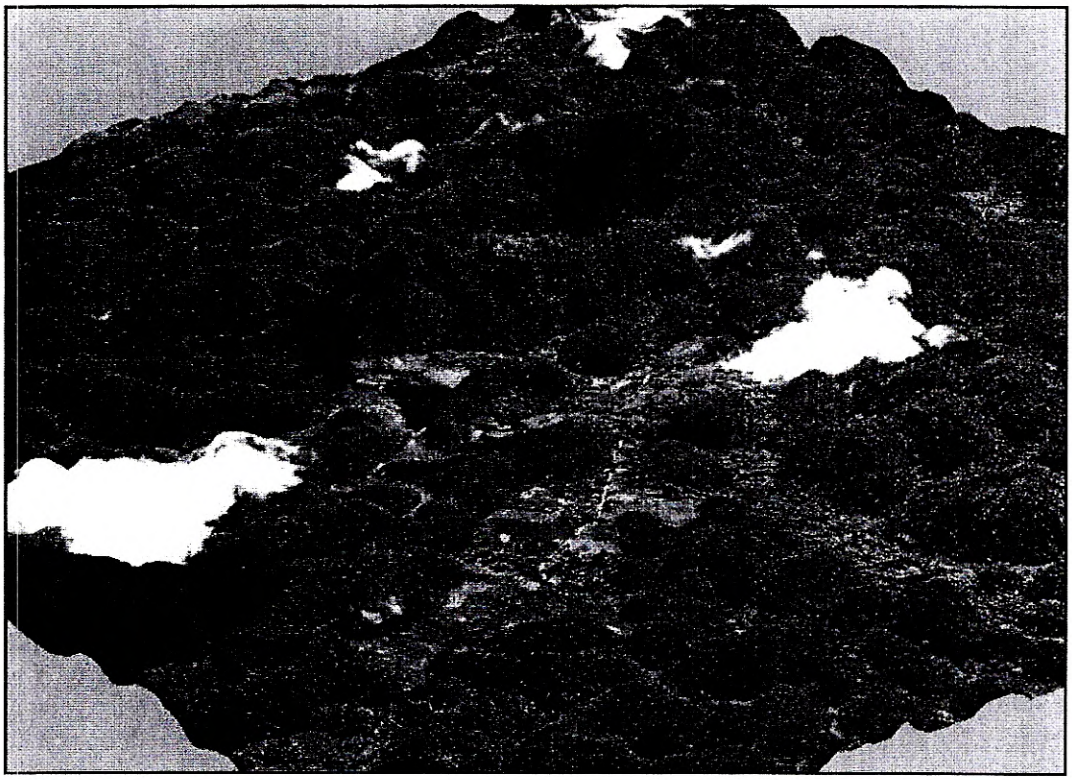
COCKPIT COUNTRY HYDROLOGICAL ASSESSMENT

A Desk Study of the Hydrological and Hydrogeological Regime Governing Flow in the Cockpit Country of Jamaica



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1.0 INTRODUCTION

1.1Background

The Cockpit Country is the type locality for 'cockpit karst' a particular form of karst topography developed from eroded limestone plateaux. It consists essentially of steep sided conical hills, separated by lobed depressions (in form resembling an overturned egg tray), in filled with bauxitic clays and characterized by the general absence of surface streams. This rugged landform hosts a largely undetermined diversity of flora and fauna that is to be brought under active environmental management. Toward this end the Government of Jamaica (GoJ) has designated the Cockpit Country a national park. The Nature Conservancy (TNC) through its international 'Parks in Peril' programme seeks to lend support to the establishment and management of the Cockpit Country National Park.

TNC as part of its initiative to define the natural resources of the Cockpit Country, commissioned the Water Resources Authority (WRA) to prepare a hydrological assessment of the Cockpit Country. The report was completed in December 2004.

1.2 Objectives and Scope

To generate and provide hydrological, hydrogeological, water availability, and water use information for the drainage basins within the Cockpit Country (as defined by the project ring road) which is in support of a subsequent water valuation study.

The Terms of Reference issued by the TNC required the Water Resources Authority to implement the following: -

- A characterization of the drainage basins encompassing, traversing, or recharging the Cockpit Country (including Black River, Martha Brae, Great River, and Dry Harbour Mountain Hydrologic Basins) in terms of:
  - i. Total area of each basin within the Cockpit Country.
  - ii. Identification of Hydrostratigraphic units.
  - iii. Detailed description of aquifers (type, permeability etc.)
  - iv. Hydrological Balance – recharge, storage and discharge volumes for areas within and outside the Cockpit Country.
  - v. Hydrological regime – surface and subsurface flow amounts and pathways and temporal trends
  - vi. Water Quality
  - vii. Risks to Water Resources
  - viii. Identification and mapping of existing water usage
  - ix. Identification of strategies to minimize risk to Water Resources.
  - x. Identification of data gaps and recommendations for future research.

1.3 Approach and Methodology

Implementation of the assignment involved execution of the following activities: -

- Literature review of published and unpublished reports with a view to the identification of information of relevance to the project objective;
- Preparation of maps in GIS format
- Field investigation on water quality and discharge rates within the Cockpit Country
- Compilation of data and completion of final report.

1.4 Acknowledgements

The Water Resources Authority (WRA) is grateful for the cooperation and assistance provided by the organizations listed below: -

National Water Commission
Environmental Technical and Analytical Sercives Ltd.
The Nature Conservancy – Jamaica Programme
Hydrology Consultants Limited

2.0 BOUNDARIES OF THE COCKPIT COUNTRY

The boundary of the Cockpit Country remains ambiguous. Several boundaries, however, have been delimited on the basis of different criteria (see Figure 2.1). These include: geomorphology, hydrogeology, biodiversity, and history. The Cockpit Country boundary was first assigned in the eighteenth century according to a patrolled road system that surrounded the region inhabited by runaway slaves called the Maroons. However, this delimitation of the Cockpit Country, although pragmatic, is unscientific.

2.1 Biological Criteria and Boundary

The Cockpit Country boundary has been defined based on bio-diversity criteria. The Cockpit Country is a rugged, inaccessible inland area of Jamaica. The very physical nature of the area has allowed a high biodiversity of flora and fauna to develop and thrive. Additionally, the ruggedness of the terrain has left the region relatively undisturbed. On this basis, forest cover may be used to demarcate the region. Large areas of undisturbed wet limestone forest, with large numbers of endemic flora, characterize much of the Cockpit Country. Chenoweth and Day (2001) maintained that vegetation reflects the physical heterogeneity of the region and hence could be used as the basis for delimiting the region.

In view of the environmental management objectives for the Cockpit Country, the Government of Jamaica has designated a portion of the Cockpit Country as a forest reserve. This is a measure for preserving the large numbers of endemic flora and fauna present in the region.

2.2 Geomorphology Criteria and Boundary

The geomorphological criteria used to define a boundary are essentially based on the distribution of karst landforms. In particular, the occurrence of cockpit karst within the Cockpit Country.

Sawkins (1869) identified all portions of the parish of Trelawny south of Windsor as being part of the Cockpit Country. His descriptions clearly identified cockpit karst landscapes: "... a rough, uncultivated tract of country covered by fragmentary limestone, with pointed hills on narrow ridges, with deep precipitous hollows like inverted cones..." (Sawkins, 1869, p. 220).

Urquhart (1958, p. 39) in his description of the Cockpit Country related the following: an "undulating upland surface," with glades (elongated, discontinuous depressions) and cockpits (deep circular or star-shaped depressions). These features, according to Urquhart (1958), make up the Cockpit Country proper. The depressions are surrounded by a "more or less continuous ridge of hills" with rounded tops. The boundaries could be inferred by areas of less intense relief which surround the region.

Sweeting (1958) attempted a redefinition of the entire Cockpit Country from geomorphological criteria. She identified the region as "bounded by the Duanvale Fault Zone in the north, separated from the (degraded karst of the) Dry Harbour Mountains in the east by the conspicuously faulted area trending NNE-SSW along the Alps road. On the southeast, the Cockpit Country extends around the western end of the Central Inlier. Its southwestern boundary is marked by the interior valley of Raheen, while its limits in the west are picked out by the series of inliers of the Yellow Limestone which stretch from Aberdeen and Maggotty in the south to Maroon Town in the north" (Sweeting, 1958, p. 4).

2.3 Hydrological Criteria and Boundary

The homogeneity of hydrological conditions across the Cockpit Country may be used for aligning a boundary for the area. The absence of surface streams within the Cockpit Country and the discharge of groundwater from the limestone aquifer may be used to demarcate a hydrogeological boundary.

The hydrologic character of the rocks in the area may be sufficient to define a hydrogeological boundary. The north of the Cockpit Country is bounded by the Duanvale Fault system. North of this escarpment, relatively flat-floored alluviated basins exist. The alluviums overlie the chalky Montpelier limestones. Drainage to the north of the Cockpit Country usually has its source in springs emerging from the Cockpit Country for e.g. underground rivers that issue at the northern edge of the Cockpit Country constitute the headwaters of the Martha Brae River. The southern boundary is defined by the Oxford and Nassau valleys, with very gentle relief and isolated limestone towers. The valleys are in filled with alluviums that overly the Yellow Limestone and Troy formation of the White Limestone Group.

The southeastern and western boundaries are defined by the lithological change in rocks, from the permeable limestones of the Cockpit Country to the volcaniclastic rocks belonging to the Central, Maldon and Sunderland Inliers. The outcrops of the impure Yellow Limestone also help to define the western boundary of the Cockpit Country. Both the impure limestone and the volcaniclastic rocks have very low permeability (ability of rock to transfer water) and are responsible for a distinctly different topography present along the fringes of the Cockpit Country. Urquhart (1958, p. 12) called the region occupied by the stream-dissected landscape to the southeast of the Cockpit Country, the Black Grounds. The region of "valleys and low hills" (presumably referring, at least in part, to the doline karst topography found in this region) to the west of the Cockpit Country was called the Western Upwarping (Urquhart, 1958, p. 29); the numerous exposures of impure limestone and volcaniclastic rock in this region are due to the significant folding activity that occurred after the Miocene tectonic event which exposed the limestone plateau.

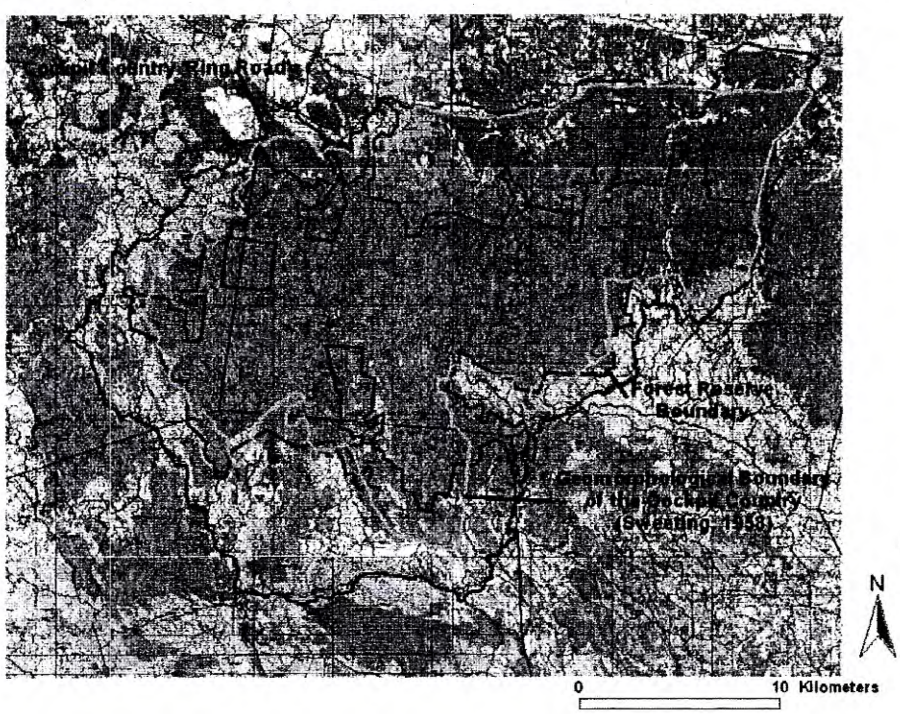


Figure 2.1 Boundaries of the Cockpit Country (prepared by: Parris Lyew-Ayee Jr.)

3.0 HYDROLOGICAL SUB-DIVISIONS

3.1 Hydrostratigraphy

The geology of Jamaica, i.e. the various rock formations and their interrelationships, play an important role in determining the occurrence, type and subsequent availability of water resources. In the study area each rock formation, based on its prevailing hydrologic character, is grouped into one of two hydrostratigraphic types: aquifer or aquiclude. The regional hydrostratigraphic units are defined based on criteria developed by the Water Resources Authority (WRA). The following hydrostratigraphic units have been identified: Basal Aquiclude, Limestone Aquifer, Limestone Aquiclude, and Alluvium Aquiclude.

The designation of a hydrostratigraphic unit as an aquifer is based on the known or expected capacity of the unit to store and transmit (under the influence of a pressure gradient) significant quantities of water. An aquiclude, on the other hand, is any subsurface material (rock/sediment) that does not yield useful quantities of water. While groundwater is the dominant water resource potential of aquifers, surface water is the main potential in areas of aquiclude outcrops. Porosity and permeability are the fundamental properties of rocks on which the study of groundwater is based. These properties affect the type and rate of flow within an aquifer and determine the vulnerability of the aquifer to pollution and its potential for use as a water source. The table below summarizes the properties of each hydrostratigraphic unit.

UNIT	GEOLOGY	AQUIFER PROPERTIES	RESOURCE TYPE	POLLUTION RISK
Alluvium Aquiclude	Limestone valley fills and sediments	Low permeability	Surface water	Low
Limestone Aquifer	White Limestone Group except Montpelier Fm	Permeable	Groundwater	High
Limestone Aquiclude	Montpelier Formation	Semi-permeable	Surface and groundwater	Medium
Basal Aquiclude	Cretaceous rocks and Yellow Limestone	Impermeable	Surface water	Low

Table 3.1 Summary of Aquifer Properties

The hydrologic map of the Cockpit Country illustrates the geographic distribution of the hydrostratigraphic units in the Cockpit Country. From this map, the area of each hydrostratigraphic unit that outcrops within the Cockpit Country is summarized in table 3.2.

Hydrostratigraphic Unit	Area (Square Kilometres)	Percentage of Cockpit Country
Alluvial Aquiclude	32.65	5.36
Basal Aquiclude	68.934	11.33
Limestone Aquiclude	0.050	0.02
Limestone Aquifer	506.731	83.29
TOTAL	**608.362**	**100%**

Table 3.2 Summary of area of each Hydrostratigraphic Unit within the Cockpit Country

The hydrologic properties of each hydrostratigraphic unit are explained below.

- ***Basal Aquiclude*** – The rocks characterized regionally as the Basal Aquiclude are essentially those that form the lowest stratigraphic sequence of Jamaica. These are the oldest rocks and they range from Cretaceous to Mid-Eocene (100 mya to 45 mya) in age. Rocks of the basal complex are for the main part comprised of volcanics and volcaniclastics and to a lesser extent the Yellow Limestone Group. These rocks constitute the base level for karst processes in the Cockpit Country.

  Table 3.3 summarizes the stratigraphy of the Basal Aquiclude.

  Volcanics that occur as part of this basement complex have undergone mild metamorphism. Subsequently, these rocks have been characterized by very low permeabilities and have very little capacity to transmit and store groundwater. Based on these properties, the rocks of the basal complex have been classified as an aquiclude. Outcrops are characterized by dense networks of surface streams, having high peak flows in the rainy season, and conversely low flows in the dry season. Diminished flows in the dry season reflect the absence of groundwater support as base flow.

  The Basal Aquiclude contains no active production wells but supports low yielding seasonal and perennial springs.

  The Yellow Limestone Group consists of impure limestone formations, within which karstification has not occurred to a significant extent. In the absence of chemical dissolution, the occurrence of well-developed secondary porosity is clearly inhibited. The capacity of the Yellow Limestone Group to store and transmit any considerable quantities of groundwater is also very limited. The Yellow Limestone is also classified as an aquiclude. The weathered Yellow Limestone produces thick clays. These clays do not form aquifers locally or regionally; instead surface water runoff in these areas is the dominant water resource type.

  Within the Cockpit country the Basal Aquiclude covers approximately 68.934 square kilometres. This is 11.33% of the study area.

Geology	Name		Age
Esn	Stettin Member	YELLOW LIMESTONE GROUP	**MID-EOCENE**
Eat	Albert Town Member		
Egh	Guy's Hill Member		
Ec	Cavaliers Conglomerate		
Ef	Font Hill Formation		
Ks	Summerfield Formation	BASEMENT COMPLEX.	**CRETACEOUS**
Kt	Guinea Corn Formation		
Ksr	Slippery Rock Formation		
Kbh	Bullhead/ Main Ridge Volcanics		
Kvs	Veniella Shales		
Kv	Vaughansfield Limestone	MAINLY VOLCANIC AND VOLCANI-CLASTIC ROCKS	**CAMPANIAN – MAESTRICHTIAN**
Ksc	Shaw Castle Limestone		
Km	Maldon Limestone		
Kch	Carlton Limestone		
Kpl	Praebarettia Limestone		
Ksh	Shepherds Hall Tuffaceous Beds		
Ksl	Stapleton Limestone		
Knhs	Newman's Hall- Sunderland Shales		
Kjh	John's Hall Conglomerate		

Table 3.3 Stratigraphy of the Basal Aquiclude

- ***Limestone Aquifer*** – The Limestone Aquifer rests unconformably on the Yellow Limestone. The Limestone Aquifer occurs very extensively throughout the Cockpit Country as various subdivisions of the highly karstified White Limestone Group but is comprised mainly of the Troy/Claremont Formation, the oldest formation of the White Limestone Group. The Montpelier Member, however, of the White Limestone Group is a deep water facies that has hydraulic properties characterized as an aquiclude. The age of this formation ranges from Mid-Eocene to Oligocene (45 mya to 30 mya).

Geology	Name		Age
		WHITE LIMESTONE GROUP	**MID EOCENE TO OLIGOCENE**
Mn	Newport Formation		
Owb	Walderston-Brown's Town		
Egb	Gibraltar-Bonnygate Formation		
Est	Sommerset Formation		
Es	Swanswick Formation		
Etc	Troy/ Claremont Formation		

Table 3.4 Stratigraphy of the Limestone Aquifer

The White Limestone Group in Jamaica seldom exhibits less than 98% purity. In addition to its pure carbonate content, the limestone has been deformed by brittle fracture, thus making the unit extremely susceptible to karstification. Regional aquifers display a complex multitude of joints/fractures (secondary porosity), as well as solution-enlarged conduits.

The high permeability of these limestones and the associated high infiltration capacity does not support extensive surface water systems. Instead, most of the rainfall over these areas is immediately channeled into the subsurface, thus establishing well-developed drainage systems.

Transmissivity of the Limestone Aquifer is variable, as the size and number of conduits will determine its local productivity. Transmissivity (yield per unit volume of aquifer) of the aquifer will be very high within the conduits and then decreases almost drastically to very low values in sections of the aquifer that do not have well developed channels. Data on transmissivity calculated at well pump tests and compiled from various sections of the island illustrate the variations that can occur within the Limestone aquifer. The range of values observed island wide within the Limestone Aquifer are presented in table 3.5.

Well name	Hydrologic Basin	Location		Transmissivity Range (GPD/ft)*	Specific Capacity** (GPM/ft)
		Easting	Northing		
Clark's Town Exp III	Martha Brae	192732	196088	29,000-40,000	26
Clark's Town Exp III	Martha Brae	192732	196088	21,000-48,000	22
Duanvale Exp IV	Martha Brae	186560	194536	37,000	29
Deeside Exp V	Martha Brae	172311	192920	20,000	17
Deeside Exp VII	Martha Brae	171244	199351	***	550
Friendship Corehole	Martha Brae	176334	193529	110	
Mountainside Exp I	Black River	171958	147063	465,000-480,000	234
Beacon Exp II	Black River	171653	138377	240,000	195
Watchwell Exp IV	Black River	171180	141760	880,000	21
Brucefield Exp VI	Black River	166395	147536	86	
Barton Isle Exp VIII	Black River	175068	164132	32,000-48,000	19
Elim Corehole	Black River	178603	161099	300	
Bay Filly Corehole	Black River	171531	144747	5,000	
Elim Wharf	Black River	176637	163019	3	

Table 3.5 Island wide variations in transmissivity in Limestone Aquifer

* Units computed as Gallons per day per foot (GPD/ft).

** The Specific Capacity is the yield per unit of drawdown in a well. This value is an indicator of the productivity of the aquifer in the vicinity of the well. In areas where transmissivity data is not available specific capacity may be used to illustrate the properties of the aquifer. Units are gallons per minute per foot.

*** Transmissivity too large to be computed. Yield was very high with very little effect on level of water in the well.

Groundwater has the potential to flow rapidly through the limestone aquifers because the void spaces are large and have a high degree of interconnection. The flow through the interconnections is referred to as compartmentalized flow. This makes the aquifer extremely vulnerable to pollution at any point on the surface. The tracing experiments, such as those carried out as part of studies by the UNDP/ FAO have shown flow rates in known conduits/channels to be very rapid.

Traverse	Distance	Time of transit	Flow rate (metres/hour)
Raheen- Bogue (St. Elizabeth)	4,500 metres	23 hours	195
Raheen- Elim River (St. Elizabeth)	3,200 metres	21 hours	152
Mouth River – Fontabelle Springs	11,600metres	10-14 days	34.5- 48.3
Fontabelle Sink – Potosi Spring	6400 metres	8 hours	800

Table 3.6 Flow time in Underground Rivers

In the Cockpit Country the Limestone Aquifer covers 506.731 square kilometres or 83.29% of the study area.

- ***Limestone Aquiclude*** – The Montpelier Formation, although a member of the White Limestone Group, has been designated a limestone aquiclude based on its hydraulic properties. The Limestone Aquiclude forms a down-faulted block to the north of the Cockpit Country, functioning as a subsurface barrier, preventing groundwater flow to the north. The Montpelier Formation is typified by chalky limestones. The formation is Miocene in age (20 mya) and overlies the White Limestone.
  Table 3.7 outlines the stratigraphy of the Limestone Aquiclude.

Geology	Name		Age
Mm	Montpelier Formation	WHITE LIMESTONE GROUP	**MIOCENE**

Table 3.7 The Stratigraphy of the Limestone Aquiclude

The Limestone Aquiclude is not considered to have undergone sufficient karstification to generate any significant levels of permeability. Faults that traverse the Limestone Aquiclude function as preferential groundwater flow paths (i.e. zones of relatively high permeability) only where the fault is linked to significant limestone aquifer storage ponded upstream of the limestone aquiclude subsurface barrier. This allows for wells to be developed in the Montpelier Formation and structural conditions may be suited to the occurrence of springs. The thickness of the unit has been estimated as 1,000 metres, although its thickness within the study area may be less.

- ***Alluvium Aquifer /Alluvium Aquiclude*** – This formation consists of unconsolidated sediments that are formed by the weathering of surface exposed rocks. These sediments have been deposited in association with surface water channels or within interior valleys formed on the limestone. These sediments are all regarded as recent in age (1.8 mya to present).

Table 3.8 outlines the stratigraphy of these units.

Geology	Name	Age
Qa	Alluvium	Recent

Table 3.8 The Stratigraphy of the Alluvium Aquifer/ Aquiclude

The hydrologic properties of the alluvium are varied and the major local property of the sediments has been used to classify the various deposits. For the most part the sediments that are associated with limestone interior valleys are clay rich, that is, those that have been derived from limestones. These deposits are generally poor transmitters of groundwater and have been classified as an aquiclude. The thickness of such deposits has been estimated at less than 30 metres [WRA 1990]. The Alluvial Aquiclude covers 32.65 square kilometres or 5.36% of the study area.

3.2 Hydrogeological Structure

Within the Cockpit Country two hydrostratigraphic units are of hydrologic significance – the Limestone Aquifer ad the Basement Aquiclude. The Limestone Aquifer is highly permeable and is characterized by high infiltration to the subsurface, a corresponding absence of surface drainage and rapid subsurface drainage via a conduit system. The Limestone Aquifer rests directly on the Basement Aquiclude and is a maximum 30 metres thick in the North of the Cockpit Country. In the Cockpit Country the Troy/Claremont Formation of the White Limestone Group forms the principal aquifer.

In sharp contrast, the Basement Aqiclude is a low permeability sequence of geological formations which do not contain significant groundwater resources, that is, it is largely impermeable. Where exposed at the surface it favours the development of surface water resources. The Cockpit Country coincides with the Central Inlier. The Central Inlier constitutes this low permeability sequence of formations and has several implications for surface drainage. From the ridge drainage occurs to the north and south coasts toward the Caribbean Sea.

The Cockpit Country is traversed by numerous faults (of post-White Limestone age) trending in a NNW-SSE direction (Zans 1953). The trends of the lines of sinkholes or cockpits are often aligned in this direction. The Cockpit Country is bounded by the Duanvale Fault Zone in the north, and is separated from the Dry Harbour Mountains in the east by the conspicuous faulted area trending NNE-SSW along the Alps road (Sweeting, 1955). It is along these trend lines that surface and groundwater will flow, hence such relief trends are of immense hydrological importance. On the southeast, the Cockpit Country extends around the western end of the Central Inlier. Its southwestern boundary is marked by the interior valley of Raheen, while its limits in the west are defined by a series of inliers of Yellow Limestone that stretches from Aberdeen and Maggotty in the south to Maroon Town in the north (Sweeting, 1955).

3.3 Hydrological Basins

The boundaries of the hydrologic subdivisions within the Cockpit Country are topographical water divides. These surface water divides are assumed to coincide with the groundwater divide. This introduces a measure of uncertainty involved in defining the alignment of basin boundaries within the Cockpit Country. Groundwater tracing may be used to align hydrologic boundaries that represent a compromise between surface and groundwater divides. Several studies have been undertaken to derive flow direction and velocities for e.g. Smith [1967], the UNDP/FAO [1971], the National Water Commission [1980] etc.

4.0 SURFACE WATER HYDROLOGY

4.1 Rainfall Distribution

There are twelve rainfall stations that have been selected as representative of rainfall distributed across the Cockpit Country. (Please see Appendix for map on rainfall distribution).

4.2 Infiltration Capacities

Variable recharge and subsurface heterogeneity accentuates the hydrologic complexity of the Limestone Aquifer as water enters it by infiltration through soils, pores, fractures in exposed outcrops, solution enlarged fractures and collapse zones (sinks). Rainfall recharge into karstic limestone aquifers has been approximated from base flow analyses. Studies have shown that groundwater recharge of the Upper Morass and Essex Valley together varies between 17.4 and 29% (average 23.6%) of the rainfall. Other studies have derived indices between 28 and 31% (Tolenaar).

The importance of the Cockpit Country as a recharge area for several hydrologic basins may be attributed to its high annual rainfall amounts concentrated over an area of predominantly karstified/recrystallized White Limestone. Infiltration into the subsurface within the Cockpit Country occurs via a sinkhole, located at the lowest point of the depression (which is an entry into a cave system). There is no connected surface flow from one depression to the other. As a result the Cockpit Country is characterized by an absence of surface streams, because of this closed surface drainage system.

4.3 Surface Streams

The occurrence of surface water in the Cockpit Country is not widespread. The surface water resources of the area include: rivers, resurgences, and ponds. Just a little north of the centre of the Cockpit Country is the island's major watershed divide. The Black River and Y.S. River flow to the south, the Great River flows to the northwest (a few km west of the "Ring-Road" boundary), the Martha Brae River flows to the north, and the Hectors River to the east.

<u>Martha Brae River Basin</u>

Underground rivers that issue at the northern edge of the Cockpit country constitute the headwaters of the Martha Brae River. The Martha Brae River rises at Windsor at an elevation of about 76 m. Mean monthly flow is approximately 3 m^3/sec. The Roaring River, a major tributary of the Martha Brae River issues at an elevation of about 99 m in the vicinity of Deeside. It has a mean monthly flow of 2.42 m^3/sec. During the dry season, the perennial surface flows that issue from the Cockpit Country, often disappear underground through sinkholes in the riverbed. Flow re-emerges further north; with the Potosi springs contributing to base flow.

To the southeast of the Martha Brae River Basin, the Mouth River drains a portion of the central Cretaceous Inlier. It flows for a relatively short distance to the northwest and then sinks on the highly permeable White Limestone. Dye tracing carried out by Boon and others in 1966 showed a correlation between the Mouth River and the resurgence known as the Fontabelle Springs at the northern boundary of the Cockpit Country. The time of travel (Mouth River to Fontabelle Spring) was recorded as 10 – 14 days. Surface flow at Fontabelle is very short (approximately 100 metres). Dye tracing has shown that water from the Fontabelle Spring after sinking rises about 6.5 kilometres north as the Potosi Springs, within the bed of the Martha Brae. A small portion of this flow also rises at Bunkers Hill. The travel time from Fontabelle to Potosi is reported as eight (8) hours. Mean monthly flow of the Mouth River at Rock Spring is 0.9 m^3/sec.

Black River Basin

The Hectors River also known as the Cave River drains an area of Basement Aquiclude in the east Cockpit Country before disappearing into a series of sinkholes at Troy. Mean monthly flow for the Hectors River at Troy is 0.72 m^3/sec. Dye tracing has proven that the water from Hectors River rises as a part of the flow of the One Eye River. Other small rivers are known to flow and sink in the vicinity of the One Eye River; these include the Golding River and the Marley River. There are a number of glades in which water is present such as the Bluefields and Breeze Hole. It is believed that all these sources: Marley River, Golding River, Breeze Point, and Bluefields, all combine to form the One Eye River. The One Eye River flows on the surface before sinking at Wallingford Cave near Balaclava, St Elizabeth. Monthly flow for the One Eye River near Balaclava is 1.76 m^3/sec.

The One Eye River rises again at the Mexico Cave and flows west across the Nassau Valley. Within the valley a portion of the water sinks and rises again in the Upper Morass as the Elim River. The other portion of the river flows to be joined west of Raheen by the Blue River. The Blue River originates as a resurgence at the south-eastern edge of the Cockpit Country; from its junction with the One Eye, the river becomes known as the Black River. In the vicinity of Maggoty, the Black River is joined by the Maggoty River, which issues from underground rivers in the Cockpit Country. The Black River then drains the Upper Morass area. During its course it is joined by several resurgences. These represent groundwater discharge from the eastern portion of the Santa Cruz Mountains as well as discharge from the Nassau Valley/Cockpit Country area.

The Y.S. River is one of the main tributaries of the Black River and joins the Black River in the Lower Morass. The Y.S. River originates as two spring sources at the foot of the Cockpit Country near Ipswich in St. Elizabeth. Above the point of origin of the Y.S. River, the Water Sink, Niagara River, Maiden Valley River, Barracks River and Jones River all rise and flow for short distances before sinking again into the limestone. Dyed lycopodium spores were used to determine flow directions, and based on this tracing it was found that rivers are interlinked in a complex flow system.

Great River Basin

The Tangle River in the Great River basin, studied by D.I. Smith using dyed lycopodium spores in 1967 was proven to contribute to water flows in the Martha Brae River Basin. The river begins in the Mocho area of St. James, slightly west of the Cockpit Country. It drains an area of Yellow Limestone before sinking and rising several times, often associated with the occurrence of cave complexes. This river emerges in the vicinity of Deeside, Trelawny, where it becomes known as the Roaring River. Along this flow system other rivers and springs join the flow of the Tangle River.

4.3.1 Springs

Springs are concentrated along the base of the Cockpit Country. Springs are the sites of groundwater discharge from the Limestone Aquifer at a point in contact with the less permeable volcanics/volcaniclastics and Yellow Limestone that comprise basement rocks. This is illustrated in the Hydrologic Map of the Cockpit Country. Major springs are located at Deeside, Dromilly, Windsor, Benlomonds and Fontabelle. The flows from these springs vary considerably between wet and dry seasons. The springs at Dromilly and Windsor cease flowing during drought periods, while the other two have comparably low flow.

Some of the major springs in the Cockpit Country have been documented by the Food and Agriculture Organisation (1971) - Appraisal Report of the Martha Brae Valley, Trelawny, Jamaica. These include:

- Deeside Spring: The water issues at about an 88 m elevation from a cavernous fissure and forms the head of the Roaring River. There are two separate rises with a difference in elevation of about 6 m. The flow fluctuates greatly, dropping in the drought period to a few cubic metres per second, while the flow in the wet season usually exceeds 0.8 m^3/sec (Zans, 1951). The actual source of water issued at Deeside is the Tangle River in the area of Maroon Town from where the water after sinking flows underground to Spring Vale Valley. Here it flows at the surface for about a mile and then disappears in another sink to later reappear as the Deeside Spring.
- Dromilly Spring: This spring, also called Guineappa Spring, rises at about 82 m elevation. The flow is normally only a few cubic metres per second and ceases flow during dry periods (Zans, 1951).
- Windsor Spring: The water issues from three springs located at slightly different elevations, the average elevation being about 97 m. Flow varies considerably. The mean flow during the wet season is about 11.33 m^3/sec and during the dry season about 0.71 m^3/day.
- Fontabelle Spring: The Fontabelle Spring issues at the eastern end of the Fontabelle Valley at an elevation of about 91 m. The flow during wet season ranges between 1.5 m^3/sec to 1.7 m^3/sec, and during the dry season as little as 0.03 to 0.17 m^3/sec. The Fontabelle spring water partly consists of water from the Mouth River that sinks about 11 km south-east in the Black Ground Area.

Several springs were measured in the study area to more closely respresent discharge volumes in the Cockpit Country. The yield from springs has been listed in the appendices and are typically dry season flows. Water samples were also collected at spring sources and have been subsequently analyzed. Results have been considered critically representative of the ambient water in the Cockpit Country.

4.3.2 Ponds

Two ponds have been identified in the Cockpit Country. These are the Dromilly and Kinloss ponds, both of which are less than 2 acres in size. The ponds are situated in topographical depressions in areas with clayey soil. As the permeability of clays is extremely low and rainfall relatively high, the ponds usually keep water all year. Ponds in karstic areas are generally not considered to be in hydraulic continuity with the water table. However, water is relatively nearer the surface along the northern edge of the Cockpit Country, where these ponds are located, and also at its southern edge. For both ponds it is therefore safe to assume that water maintained in storage is reliant on rainfall.

5.0 GROUNDWATER HYDROLOGY

5.1 Subsurface Water Occurrence and Movement in the Cockpit Country

Subsurface water is confined to the Limestone Aquifer in the Cockpit Country. The Limestone Aquifer occupies approximately 506.731 km^2 or 83% of the Cockpit Country. Although the aquifer dimensions (length and width) for the Limestone Aquifer have been undetermined within the Cockpit Country, exploratory drilling near Deeside (northern Cockpit Country) confirmed less than 30 m thickness of limestone beneath the ground surface.

The flow of underground rivers in massive limestones, such as in the White Limestone within the Cockpit Country, is controlled predominantly by joints, fissures and faults. The crystalline, well-jointed formations of the White Limestone Group allow for freer circulation of groundwater than the denser, more chalky beds of the Montpelier Formation. In the Montpelier Chalky beds to the north of the Cockpit Country, water flow is impeded by the lack of well-developed fissures.

Underground drainage in the Cockpit Country is relatively simple in nature. The fairly gentle northerly dip and uncomplicated geological structure of the limestone allows for predictable flow paths. Overall, subterranean channels though deep, flow north for considerable distances in the Martha Brae River basin and do not cross and re-cross underground. The Duanvale Fault Zone, at the Cockpit Country's northern boundary, interrupts this northerly flow and redirects this flow to the east. Many of the larger resurgences/springs occur near the actual faults of the Duanvale Fault Zone. Offshore discharge of freshwater from the Martha Brae River basin has not been documented. In the Black River basin groundwater flows to the south toward the coast.

Caves occur extensively within the study area and are typical of mature karst settings (See Hydrologic Map of the Cockpit Country). The occurrence of such cave systems suggests a close relationship between their formation and the circulation of relatively large bodies of groundwater in fairly confined flow over large distances.

5.2 Subsurface Water Storage

Well-connected pathways or high ground-water velocity pathways are maintained between recharge and discharge areas in karstic regions. Rainfall recharge appears to percolate vertically down through the Limestone Aquifer to the surface of the Basement Aquiclude, where it flows horizontally as subsurface streams. The limestone of the Cockpit Country is underlain by basal aquiclude at a shallow depth. Given the relatively thin limestone under the bottom of the dolines, there is not believed to be any regional water table and/or significant perennial groundwater storage within the Cockpit Country.

However, when groundwater becomes ponded behind geologic barriers within the Limestone Aquifer, storage occurs. In the north of the Cockpit Country, the presence of the Limestone Aquiclude (i.e. the chalky Montpelier Formation) serves to pond water in the juxtaposed Limestone Aquifer. To the south a groundwater reservoir is created in the Upper Morass area of the Black River basin.

6.0 WATER RESOURCES BALANCE

A quantitative determination of the water resources in the area is critical for planning its optimum use and development. Water balance methodology is now well developed and is based on the principle of conservation of mass. For any three-dimensional section of the Earth, the total input equals the total output and if they are not equal, then the difference is accounted for by the change in storage within the section. Thus, a proper water balance involves the measurement of both storage and fluxes or rates of flow. The water balance often expressed as a simple equation (storage equation) is:

INPUT = OUTPUT + CHANGE IN STORAGE

In the long-term change in storage is zero. Therefore, the water balance equation will be represented as:

INPUT = OUTPUT

The input component of the equation is based on a rainfall mean of stations within and on the perimeter of the Cockpit Country that may be used to characterize the rainfall regime. The Jamaica Meteorological Service has published 30-year means for rain gauges at the following locations: -
Trelawny – Cockpit Country, Kinloss, Ulster Spring, Warsop, Windsor
St. Elizabeth – Oxford, Appleton, Y.S., Raheen Estate

By employing the use of 0.28 as the index for infiltration into the Limestone Aquifer (506,731,000 m^2) and a rainfall mean of 1676.9 mm/yr, the water resources input to the Cockpit Country is **237.9 MCM/yr** (million cubic metres). Long-term change in storage is nil **input = output**.

7.0 WATER QUALITY

Land use decisions often impact on the water resources within a given area. The Cockpit Country's complex system of surface and subterranean drainage are highly vulnerable to pollution and sedimentation which have the effect of changing water quality and modifying flow regimes. Flow regimes may change when surface run-off is accentuated and the infiltration capacity of the limestone becomes reduced.

7.1 Methodology

The approach adopted for assessing water quality involves a number of components.

7.1.1 Comparison With National Ambient Water Quality Standard

Initially a comparison of the quality of water from the eleven springs is made with the National Ambient Water Quality Standard. *This standard defines the typical concentrations of selected parameters in relatively unpolluted fresh water (ground and surface) of Jamaica; water which is considered safe and generally suitable for all the primary anthropogenic uses and supportive of natural* aquatic *ecosystems.* Source: Draft National Ambient Water Quality Standard, 1998.

As such it is determined whether water sampled at each spring meets the Ambient Standard or not. If all parameters compared meet the Ambient Standard then the quality of the water is considered High, however if one or more parameters do not meet the Ambient Standard, the water is considered to be showing either Early Signs of Deterioration or Poor Quality. A table is included which indicates which parameters fell short and shows the actual concentrations.

7.1.2 Assessment Of Suitability For Specific Uses

An assessment of the suitability of the water for a range of uses namely drinking water sources, irrigation, industry and recreation (primary contact) is also conducted. The use specific standards are selected and the comparison made to determine whether each standard is met or not. The tables presented indicate which parameters were exceeded and the absolute readings, which show the extent to which specific parameters were exceeded.

Colour Designation (Quality Classification) Based on Use Suitability and Comparison with the Ambient Water Quality Standard.

The color designation is based on an assessment of suitability of water for four (4) beneficial uses: drinking, recreation, industry and irrigation, and the determination of whether the quality is pristine/excellent based on compliance with the Jamaican National Ambient (Freshwater) Water Quality Standard. In total, five (5) water quality standards are applied and used to assign the quality status: Blue (High Quality), (Early Deterioration) and Red (Poor Quality). This approach is taken from the Jamaica National Water Quality Atlas, 2002.

Determination of Water Type and Source Rock

A graphical plot of the proportion of major ions and cations using Stiff Diagrams (a water chemistry characterization tool) is made to determine water type of the springs and to deduce their source rock.

7.1.3 Assessment Of Pollution Indicators

The pollution indicators are used to identify possible source(s) of pollution. Those applied include the following: -

Nitrates – High nitrates in natural water is usually attributed to *drainage from nearby barnyards, or septic tanks and cesspools. Farm animals produce considerable amounts of nitrogenous organic waste that concentrates where large numbers of animals are confined* [Hem 1992].
The over use of nitrogen fertilizers and their use on lands with high levels of erosion may also contribute to elevated levels of nitrate in natural waters. Nitrate as a source of pollution to limestone aquifers in Jamaica is more often correlated to the disposal of sewage in absorption pits.
Concentrations over 45mg/L may present human health problems.

Phosphate – High phosphate concentrations in natural water may be related to phosphate mining and processing, as well as the use of phosphate fertilizers. *Soil erosion may add considerable amounts of suspended phosphate to streams.* Source: Hem 1992.

Chloride – Elevated chloride concentrations may indicate influence of seawater, for areas near the coastline. This may also be caused by the impact of brine or industrial and domestic wastewater.

Sodium – Elevated sodium may result from the reuse of irrigation water or over-pumping of groundwater in coastal regions. Sodium may also be elevated in waters affected by waste from the alumina processing industry.

Faecal Coliform – Elevated levels of faecal coliform points to the influence of faecal waste from warm blooded animals and indicate the likely presence of pathogens (disease causing organisms).

Biochemical Oxygen Demand (BOD) – is not a pollutant itself, but is a measure of organic pollution. A BOD load can pose a threat to the aquatic environment by depressing the oxygen concentrations to levels that affect the survival of aquatic fauna. High BOD also limits the use of waters for public consumption and irrigation.

The water quality evaluation involved the application of the following guidelines/standards: -

[1] National Ambient Water Quality Standards, Jamaica 1995
[2] WHO Drinking Water Guidelines - Acceptable Limits 2004 (except Turbidity. USEPA Guideline for turbidity)
[3] I-JAM Interim Water Quality Standards, Ministry of Health
[4] Guidelines For Interpretation of Water Quality For Irrigation Ayers, R.S. and D.W. Wescot. 1976
[5] NRCA Interim Irrigation Standards
[6] Industrial-Process Water Quality Requirements and Industrial Boiler Feed Water Quality Requirements, Water Pollution Control Federation 1989 in L. Mays 1996
[7] Turbidity Conversion See: http://www.photometer.com/en/abc/abc_054.htm
[8] DRAFT National Recreational Water Quality Standard, Jamaica 2000
[9] National Water Quality Atlas 2002, Water Resources Authority

7.2 The Limitations of The Assessment

A major constraint is placed on the reliability of the conclusions of this water quality evaluation, due to the limited data available for the evaluation. All conclusions are based on only one (1) set of samples taken on December 11, 2004. Although this evaluation provides some indication of the status of water quality at these eleven (11) springs, it should not be construed as a robust evaluation and as such, important decisions must be based on analysis of additional water quality data taken, at a minimum, during the wet and dry seasons of the year. Such additional data on the water quality by its chemical and physical parameters are historical, spanning the period 1971 to 2004.

The Water Quality Sampling Programme

Eleven (11) springs were included in the sampling programme, namely

Aberdeen
Bailey's
Niagara
Sherman
Ulster
Dawson's
Deeside
Dromilly
Fontabelle
Benlomonds
Hectors

(See Map Showing Water Quality Sample Locations)
The parameters tested were: -

- Biological Oxygen Demand
- Chemical Oxygen Demand
- pH
- Conductivity
- Phosphate
- Total Coliform
- Faecal Coliform
- Nitrate
- Total Dissolved Solids
- Calcium
- Turbidity
- Chloride
- Magnesium
- Iron
- Aluminium
- Sodium
- Hardness
- Bicarbonate

One set of samples was collected on December 11, 2004 for all eleven (11) springs and analysed by the laboratory Environmental Technical Analytical Services Ltd (ETAS)

Comparison with National Ambient Water Quality Standard (Freshwater)

Six (6) of the eleven (11) springs met the Ambient Water Quality Standard and as such these nine are considered to be of high quality. Aberdeen, Bailey, Niagara, Sherman and Ulster did not meet the Ambient Water Quality Standard and are showing early signs of deterioration as defined in the Methodology – Colour Designation.

Parameters Exceeding Ambient Water Quality Standard				
	Na mg/l	TDS mg/l	BOD mg/l	Ca mg/l
Ambient Standard	**12**	**300**	**1.7**	**101**
Aberdeen	17.2	347.76		
Bailey's			1.95	111
Niagara		309.93		
Sherman			4.6	
Ulster		328.59		

Table 7.1 Springs showing early signs of deterioration

2.6.3 Assessment Of Suitability for Specific Uses

Suitability for Domestic (Drinking) Use

Physical and Chemical

Ten of the eleven (10/11) springs met the WHO and USEPA drinking water guidelines based on the chemical and physical parameters tested for a source to be used for domestic purposes. Fontabelle's turbidity level (62 FTU) exceeded the guideline (5 FTU). This value should be re-checked as it could possibly be a lab error. See Appendix.

Microbiological Characteristics

All springs exceeded the WHO drinking water guideline based on bacteriological content. The total (TC) and faecal (FC) coliform levels at the springs indicate that the water is contaminated by faecal waste. (See Table 2.11)

According to the I-JAM Criteria, the Benlomonds (460 MPN/mL), Hector's (1100 MPN/mL), Sherman (460 MPN/mL), and Ulster (240 MPN/mL) springs are classified as Class II (Raw Water Classification) as the Total Coliform count falls within 50-5000 MPN/100 mL. The required treatment is Conventional i.e. Coagulation, Filtration and Disinfection. (See Table 2.11 and Appendix).

All other springs are classified as Class I (Raw Water Classification) as the Total Coliform count falls within 0-50 MPN/100 mL. Disinfection is the only required treatment to achieve potability.

Table 7.2 Comparison with Drinking Water Standards

	Standard		
	Drinking (D)[2,3]		
	Chemical	**Bacteriological**	**CLASS based on Level of Treatment Required**
Spring Location	Met (✓)/ Not Met (X)	Met (✓)/ Not Met (X)	I = Primary:0-50 MPN/mL TC II = Conventional: 50-5000 MPN/mL TC
Aberdeen	✓	X	I
Bailey's	✓	X	I
Benlomonds	✓	X	II (460 MPN/mL)
Dawson's	✓	X	1
Deeside	✓	X	1
Dromilly	✓	X	1
Fontabelle	✓	X	1
Hector's	✓	X	II (1100 MPN/mL)
Niagara	✓	X	I
Sherman	✓	X	II (460 MPN/mL)
Ulster	✓	X	II (240 MPN/mL)

2 WHO Drinking Water Guidelines - Acceptable Limits 2004 (except Turbidity. USEPA Guideline for turbidity)

3 I-JAM Interim Water Quality Standards, Ministry of Health

Suitability for Irrigation

Bacteriological

Ten of the eleven (10/11) springs meet the required standard for a source to be used for irrigation purposes and as such are suitable for irrigation. (See Table 3). Hector's (93 MPN/mL) and Ulster (23 MPN/mL) springs exceed the faecal coliform (12 MPN/mL) standard and hence are unsuitable for irrigation. Feacal coliform is associated with human/animal waste and indicates contamination of these sources from sewage sources. The presence of faecal waste suggests the presence of pathogenic (disease causing) bacteria and hence limits the use of these springs for irrigation.

Physio-chemistry

All eleven springs are suitable for irrigation based on physio-chemistry. All springs are unlikely to develop increased salinity problems, as they did not exceed the salinity threshold (<0.75 Ew)[1]. They are also unlikely to result in sodium build-up problems, as all springs did not exceed the sodium absorption ratio threshold (SAR<6)[2]. Permeability problems of the soil or detrimental effects to crops are NOT expected if these sources are used for irrigating crops. See Appendix.

1 Electrical Conductivity as measure of water salinity: Total Dissolved Solids/640

2 Sodium Absorption Ratio: Sodium/ (square root (Calcium + Magnesium)/2

Suitability for Industrial Use

All springs were unsuitable as raw water sources for industrial use and would require treatment for this purpose. The Recommended Industrial Boiler-Feed Water Quality Criteria (for Intermediate Pressure 150-700 psig) was used for this Assessment. Six (6) springs met one of the eight (1/8) parameters tested, while five (5) springs met two of the eight (2/8) parameters tested (See Appendix).

The parameters in compliance were iron and chemical oxygen demand. Elevated levels of parameters such as calcium, magnesium, hardness, pH, aluminium and bicarbonates which were all out of compliance result in corrosion, release of carbon dioxide and scale build up in boilers. These parameters also affect the beverage and textile industries as well as cooling towers but the requirements may vary.

Suitability for Recreational Water Use

All eleven (11) springs met the requisite standard, FC -200 MPN/ mL and pH 6-9, for primary contact recreation (e.g. swimming, bathing) and as such are suitable for recreation. Hector's (93 MPN/mL) and Benlomonds (43 MPN/mL) springs had elevated faecal coliform levels.

7.3 Summary and Conclusions

7.3.1 Water Quality Status (Based on Water Quality Atlas Classification System)

Using the National Water Quality Atlas Classification, five of the eleven springs (5/11) show excellent or high water quality, as they are assigned the colour blue, indicating their suitability for all three beneficial uses; drinking, recreation and irrigation and further their pristine nature, since the Ambient Water Quality Standard is also met.

Six of the eleven springs (6/11) are assigned the colour yellow which represents a state of early deterioration in quality. The Early Deterioration designation identifies water, which is neither heavily polluted nor pristine, but shows elevated concentrations. As such, three (3) scenarios may result in a yellow designation. Water is designated yellow when: -

Scenario 1 - **Recreation Standard is not met**
Scenario 2 - **Ambient Water Quality is not met or**
Scenario 3 - **Both these standards are not met**

See Table 2.12 Water Quality Status of springs

Benlomonds, Dawson, Deeside, Dromilly and Fontabelle springs are considered to be excellent/high quality water sources as they meet all the applied standards; Ambient, Recreational, Drinking, Irrigation and Industry.

Hector's and Bailey's springs are considered to be in a state of early deterioration. Both springs did not meet the Ambient and Recreational Standards. Aberdeen, Hectors, Niagara, Sherman and Ulster springs did not met the Ambient Standard and hence are also considered to be in a state of early deterioration.

Table 7.3 Water Quality Status of Springs (Based on National Water Quality Atlas Classification System)

Sample Location	Ambient 	Recreation 	Drinking (with requisite treatment) 	Irrigation 	Water Quality Class
Aberdeen	x	✓	✓	✓	
Bailey's	x	x	✓	✓	
Benlomonds	✓	✓	✓	✓	
Dawson	✓	✓	✓	✓	
Deeside	✓	✓	✓	✓	
Dromilly	✓	✓	✓	✓	
Fontabelle	✓	✓	✓	✓	
Hectors	✓	x	✓	✓	
Niagara	x	✓	✓	✓	
Sherman	x	✓	✓	✓	
Ulster	x	✓	✓	✓	

✓ Standard Met   x Standard <u>Not</u> Met

Poor Quality (Exceeds Drinking & or Irrigation Standard)

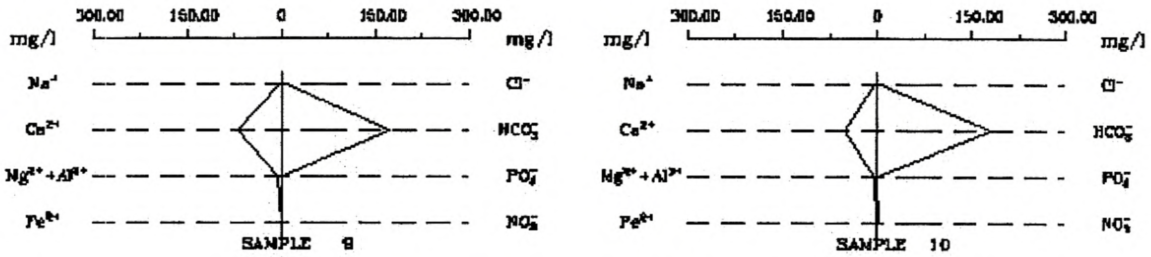
Early Deterioration (Exceeds Ambient Standard & or Recreational Standard

Excellent/High Quality (Meets Ambient and Recreational Standards)

7.4 Water Type and Rock Source Determination

All eleven (11) springs when evaluated indicate a **calcium bicarbonate** type water originating from aquifers composed of limestone rock rich in calcite where carbonate weathering is dominant. This is consistent with the geology of the area, as it is predominantly limestone. See Figure 2.1 Stiff Diagram Plots – Niagara and Sherman Springs.

Figure 7.1 Stiff Diagram Plots – Niagara and Sherman Springs



Sample 9 = Niagara Spring
Sample 10 = Sherman Spring

7.5 Pollution Indicators

Nitrate
Nitrates for all eleven springs ranged between <0.76 – 3.96 mg/l. The highest nitrate level was at Dawson spring. Nitrate levels at all springs fall within the standard range (Ambient), indicating no direct impacts from nitrogen fertilizers or leaching from sewage systems in the area. For all nitrate data see Table 2.13 Assessment of Pollution Indicators.

Phosphate
Phosphates for all eleven springs ranged between <0.02 – 0.42 mg/l. The highest phosphate level of 0.42mg/l was at Niagara spring. Water at these springs shows no contamination from fertilizers rich in phosphates. For all phosphate data see Table 2.13 Assessment of Pollution Indicators.

Chloride
Chlorides ranged between 5-15 mg/l. The highest chloride level of 15mg/L was at Fontabelle Spring. These chloride levels suggest the absence of impacts from saline/connate water. For all chloride data see Table 2.13 Assessment of Pollution Indicators.

Sodium
Sodium ranged between 2.47 – 17.2 mg/l. The highest sodium level of 17.2mg/L was at Aberdeen spring. The Ambient Water Quality Standard for sodium was exceeded at Aberdeen. Generally these readings indicate the absence of impacts related to alumina processing or the marine environment.
For all sodium data see Table 2.13 Assessment of Pollution Indicators.

Faecal Coliform
Faecal coliform (FC) levels ranged between 3 - 93 MPN/mL. The highest FC level of 93MPN/100mL was observed at Hectors spring. FC levels at Benlomonds and Ulster springs were 43MPN/100mL and 23MPN/100mL respectively. Since levels at all springs are well below 200MPN/100mL, the standard for

primary contact recreation, the water at these springs can be considered bacteriologically acceptable. For all FC data see Table 2.13 Assessment of Pollution Indicators.

Biochemical Oxygen Demand (BOD)
BOD levels ranged between 0.4 – 4.6 mg/l. An elevated BOD level of 4.6mg/L was observed at Sherman Spring. High BOD levels indicate the presence of organic waste possibly from a wastewater source. The data therefore suggests the impact of organic waste at Sherman Spring. The other ten springs do not appear to be affected by organic waste. For all BOD data see Table 2.13 Assessment of Pollution Indicators.

Table 7.4 Assessment Of Pollution Indicators

	Pollution Indicators					
	Nitrate mg/l	**Phosphate mg/l**	**Chloride mg/l**	**Sodium mg/l**	**Faecal Coliform MPN/mL**	**BOD mg/l**
STANDARD	7.5[1]	0.8[1]	20[1]	12[1]	200[2]	1.7[1]
Sample Location						
Aberdeen	<0.76	0.19	5	17.2	4	1.60
Bailey's	0.88	0.23	5	2.90	4	0.95
Benlomonds	1.76	<0.02	5	1.52	43	0.40
Dawson	3.96	0.37	10	10.7	3	1.15
Deeside	2.20	<0.02	5	3.65	9	0.75
Dromilly	1.76	0.09	5	2.47	4	1.30
Fontabelle	2.64	0.02	15	4.58	<3	0.95
Hectors	2.2.	0.02	7.57	5.98	93	1.55
Niagara	1.32	0.42	7.57	3.11	7	1.25
Sherman	3.08	<0.02	7.523	3.15	7	4.60
Ulster	3.52	<0.02	15	9.79	23	1.25

Values compared to:

[1] Upper Limit of Ambient Water Quality Standard

[2] National Recreational Standard

7.6 Potential Water Quality Risks

(1) Settlements, essentially concentrated along the periphery of the Cockpit Country place a number of risks to the regional water quality. High levels of fecal coliform as well as nitrates in water samples are often representative of contamination by human waste. Such high levels are a cause for concern, as many diseases can be spread through fecal transmission. The widespread occurrence of pit latrines and absorption pits in the project area has contributed to the proliferation of excess coliforms in the water. Inspections of public water facilities, the results of routine water quality tests, and Health Department statistics have revealed unsatisfactory levels of coliform in the water from 1996.

(2) Although farming is the dominant economic activity, concentrated along the fringes of the Cockpit Country, it has not degraded the water quality to a significant extent. This is thought to be due to the natural farming activities carried out and the very limited use of agrochemicals. However, the increased and improper use of agrochemicals may pollute water resources, and sedimentation and turbidity of streams will result if clearing of land proceeds indiscriminately. At present, clearing of forests for agriculture has been observed but is minimal. Small-scale agricultural practices (shifting cultivation) particularly, yam cultivation is a threat to the forests but is not reflected in the water quality. Farmers use saplings harvested from the forest as "yam sticks" to provide support for the plant as it grows (The Nature Conservancy).

(3) Major bauxite reserves are known to occur within the Cockpit Country. The widespread occurrence of bauxite reserves is tied to the prevailing geologic conditions and karst topography. Bauxite is found extensively as blanket deposits atop the hard, pure formations of the White Limestone, which occupies approximately 83% of the Cockpit Country. Karst depressions may be seen as natural receptacles for Miocene volcanic ash, which was leached to form bauxite (Comer, 1972; Lyew Ayee, 1986). Bauxite mining, a major extractive industry, has the potential to contribute to the degradation of the water quality of the Cockpit Country and severely affect the availability of water resources within the respective hydrologic basins. A lower quality and quantity of bauxite, however, is associated with the Troy Limestone of the Cockpit Country than those found on the Moneague limestones. In areas of degraded karst (such as the Dry Harbour Mountains) there is greater access to the potential mining sources as opposed to the more rugged cockpit karst topography found in the Project Area. The smaller depressions that characterize the Cockpit Country result in smaller deposits. Due to the smaller bauxite filled depressions (ore bodies) in the Cockpit Country, as well as the generally lower quality of bauxite and the difficulty of accessing the region, the Cockpit Country has not been a priority mining area for the different companies (Lyew-Ayee, 2004).

The Jamaican government has designated specified areas within the Cockpit Country as Special Exclusive Prospecting Licence areas – Sherwood, Content, and Barbecue Bottom. This allows for exploratory drilling and tests of bauxite quality and quantity. No mining operations are currently being conducted. Still there are major reserves in the study area and these may be mined in the future. A risk analysis has also been included to highlight the environmental impacts in the study area with a particular focus on regional water quality if mining operations were to be initiated.

Subsequent to implementing mining operations in the Cockpit Country might be the construction of an Alumina Refinery. This becomes a further threat to the water resources of the Cockpit Country. Alumina processing generates more effluent that could contaminate the groundwater resources if not treated or disposed of safely to the environment.

7.6.1 Risk Analysis – Bauxite mining in the Cockpit Country

The potential water quality risks associated with bauxite mining are:

- Turbidity from erosion of cleared and excavated land, and the use of unsealed roads and tracks
- Hydrocarbon contamination through fuel spills from vehicles and machinery

- Pathogen contamination due to increased human activity in the area indicated by high coliform levels

If mining operations (workshops, crusher, refineries, offices etc.) are to be constructed within the area, this compounds the potential risks to the water quality. The associated risks include:

- Improper use and disposal of chemicals may result in hazardous leaks or spills with contamination of water resources
- Leaky industrial waste ponds, known as mud lakes, which are created as recipients of caustic waste from the bauxite to alumina processing may be a potential source of contamination as indicated by the increased sodium (Na), pH/alkalinity concentration in groundwater
- Fuel spills from vehicles and heavy machinery and storage tanks
- Risk of pathogen contamination from the leakage of sewage and wastewater systems
- Increased turbidity due to clearing of land and the use of vehicles on unsealed roads and tracks

With the removal of bauxite deposits there also exists the possibility of increased surface run-off, as infiltration becomes significantly impeded. This will result in an altered flow regime and over time drainage will become modified as recharge becomes reduced and overland flow becomes more dominant. The removal of bauxite-rich soil, overlying areas of limestone aquifer, reduces the filtering potential of the soils. Recharge water that contains potential contaminants would correspondingly increase the risk of contamination to the groundwater.

(4) The introduction of bauxite mining into the Cockpit Country may open up avenues for the development of other industries. As a population grows so does its demand for building materials such as aggregate. The response to such a demand has been marked by limestone quarrying in some of our nation's more environmentally sensitive areas. The quarrying of the highly karstic limestone is an area of concern as a result of the potential environmental damage that could be done. Water quality can be impacted in a variety of ways through quarrying activities. The most common concern is turbidity pollution, when fine particulate material can be transported quickly throughout the Karst system. Increases in runoff and sedimentation can also deteriorate groundwater quality and quantity.

In cases where quarried stone acts as a protective layer over an aquifer, removing that rock allows surface water to infuse groundwater, carrying contaminants along with it. Blasting can open and close passages, altering the groundwater flow regime, which also can expose the water to contaminants including fine particulate material. Dewatering quarries can result in the lowering of water tables, which can cause the collapse of sinkholes.

(5) The industrialization of the area may spark new housing developments. At present human settlements are concentrated along the fringes of the Cockpit Country. Communities include Jackson Town, Maroon Town, Clarks Town, Albert Town and Maggotty. Risks to water quality that may arise from new developments include pathogenic contamination from leaky septic systems (indicated by an increase in nitrates as well as faecal or total coliform levels), increased surface run-off on newly paved surfaces and an associated increase in turbidity or total suspended solids, unregulated dumping of domestic waste, and hydrocarbon contamination from vehicles.

(6) Industrial wastes from sugar processing or rum distilleries also represent important sources of organic and inorganic pollutants of a serious nature. In certain areas adjacent to sugar factories/distilleries, the practice of dumping dunder into gullies and sinkholes is known to affect groundwater. Distillery wastewater is characterized by large amounts of organic matter, low pH, and large amounts of nutrients (nitrate, phosphate and potassium). The risk of contamination to both surface and groundwater include:

i. *Deoxygenation* – because of high BOD and COD caused by decomposition of vast amounts of organic matter present. Where anaerobic conditions prevail due to extreme deoxygenation, foul odours may come about.
ii. *Acidification* – because of its low pH, and

iii. *Eutrophication* – due to high level of nutrients

Long Pond Distillers Ltd. (LPD) owns and operates a distillery at Clarks Town (northern Cockpit Country), just adjacent to the Long Pond Sugar Factory and Long Pond Estate. Although the Estate is resting on clayey alluviums (several metres thick), pollution may reach the waters of the underlying karstified limestone aquifer. Wastewater may travel down into the aquifer through fissures and cavities in the limestone. The well at Clarks Town (Parnassus) was contaminated by dunder and was subsequently abandoned in 1993 by the National Water Commission.

(7) Eco-tourism does not pose a major threat to the water quality of the Cockpit Country. However, due consideration must be given to the carrying capacity of the Cockpit Country. Ecotourism increases human access to the area. There are associated risks that include dumping into waterways or removing materials from the forest. Tracks implemented for nature walks may accentuate surface run-off as well as increase the sediment load of rivers.

7.7 Water Quality of the Niagara River

Water quality analyses on the Niagara River, spanning the period August 1975 to August 1986, are available for comparison with the spring samples collected in December 2004. All 73 complete physical/chemical water quality analyses, except those of August 1986 were obtained from the files of the National Water Commission (NWC) Water Quality Laboratory in Montego Bay (Hydrology Consultants Limited, 1986). The data on the physio-chemical analyses is listed in the Appendices. The following was observed:

- ✓ A general trend for Iron content – there was an increase in iron content with increasing turbidity.
- ✓ Headwaters of the Niagara River are characterized by rain-induced turbidity. Sharp increases in turbidity were observed to occur within hours of the start of rainfall over the Catchment.

The results of some 60 bacteriological analyses on the Niagara River were obtained from the files of NWC Water Quality Laboratory located in Montego Bay. These spanned the period February 1978 to June 1986 and included 38 samples of untreated river discharge and 22 of treated water collected from the distribution system (hydrology Consultants Limited, 1986). These data are listed in the Appendices. The following were to be noted from the analysis:

- ✓ The persistence of a large number of feacal coliform detected in the untreated water samples. This gives clear evidence of the contamination by household effluent from the communities located within the Catchment of the Niagara River. The concentrations detected a range from a high of 110,000 to a low of 38 MPN/100ml.
- ✓ The non-detection of the treated supply was surprising given the high coliform content, high turbidity of the untreated source, the inadequate treatment available (notably the absence of settlement/filtration), and the visual estimation of turbidity used to decide when the turbidity was low enough to permit "adequate treatment".

7.8 Suitability for Domestic Supply

The suitability of the untreated river discharge of the Niagara River as a source of domestic water supply was evaluated with respect to the World Health Organization (WHO) – Guidelines for Drinking water Quality (1984). A comparison of the WHO recommended standards for physical and chemical quality and that of the Niagara River is listed in the Appendices.

The comparison shows a river water quality adequate for domestic supply provided that it is filtered to reduced turbidity to acceptable levels.

Other water quality studies conducted within the Cockpit Country indicate a general calcium bicarbonate type of water. With respect to salts and chloride ion content, all sources of water within the study area have been considered satisfactory. However, nitrate content, has been detected at somewhat elevated levels in most studies. The UNDP/FAO report of 1971 noted that in most of the wells the nitrate content is below 10 ppm but in about five percent of the wells, the nitrate content is 25 ppm or more. Nitrate concentrations in water become a risk to human health above 20 ppm.

8.0 WATER RESOURCES MANAGEMENT ISSUES

8.1 Definition of Basin Boundaries

The boundaries of the hydrologic subdivisions within the Cockpit Country are topographical water divides. These surface water divides are assumed to coincide with the groundwater divide. This introduces a measure of uncertainty involved in defining the alignment of basin boundaries within the Cockpit Country. This is issue is very critical in the water resources management of the Cockpit Country. Assigning hydrologic boundaries that represent a compromise between topographic and groundwater flow is essential and basic to the quantitative assessment of the several hydrologic basins that have their boundaries within the Cockpit Country.

Underground tracings may be usefully employed in the definition of hydrologic basin boundaries in the karstic limestone areas of the limestone areas of the Cockpit Country.

8.2 Protection of Water Quality

The most strategic and comprehensive way to protect regional water resources is to embark on the process of watershed conservation/management. Watershed protection is an initiative to safeguard water resources. It involves controlling wastewater discharge and stormwater runoff pollution as well as mitigating development's disruption of the natural drainage processes within the watersheds. Because watersheds are so important in protecting water resources a number of considerations arise for efficient watershed management.

Strategies to reduce impervious cover so that storm water runoff does not cause sedimentation of streams and accelerate flow over the surface must be in place. Watershed based land-use planning may be essential to ensure that land-use decisions are compliant with the standards of a sustainable environment. Other conservation measures include: protecting floodplains, watersheds and areas with steep slopes, limiting clearing/erosion to accommodate various land uses, treating the quality and quantity of storm water, and ultimately maintaining the watershed management infrastructure. The following strategies highlight ways of watershed conservation based on potential and actual land-use applications within the Cockpit Country.

Farming – The potential risks associated with farming are essentially contamination by agrochemicals and sedimentation as a result of bad farming practices. Strategies to minimize risk include avoidance of the use of chemicals such as pesticides or restricting their use to once per year. Secondly farming should proceed in such a way as to minimize soil erosion. Farmers must be instructed on the potential hazards of farming on hill slopes.

Bauxite mining – If bauxite mining is authorized there should be an enforcement of environmental (including water quality protection) conditions where appropriate. A comprehensive review of clearing plans based on field inspection must be done, and a subsequent modification of proposals that may affect water quality. Programmes must be put in place for sediment control, prevention of erosion and monitoring. Proposals can be made to mine in a mosaic to minimize the time that mining occurs in any area. Areas identified as high risk to water quality should be cleared, mined and rehabilitated in the shortest possible time.

Strategies aimed at reducing operational risks caused by mining are:

- Meticulous design of waste ponds (or 'mud lakes') by engineers so as to minimize the possibility of leaks or seepage of industrial effluent into underlying karstified rock.
- Alternatively, wastewaters from the bauxite-to-alumina processing may be treated to National Drinking Water Standards, and subsequently released to the environment. All discharges must meet the required standards.

- Septic systems engineered for onsite amenities and workshops should be suitably designed to prevent effluent from entering the catchment.
- Hydrocarbon contamination from the use of machinery can be minimized if waste oils are collected and recycled. The construction of sealed roads should minimize pollution by hydrocarbons.

Limestone quarrying – This activity has the potential to degrade both the regional water quality, reduce recharge as well as alter the hydrological regime. Quarrying for limestone and marl is potentially quite damaging in these highly karstic and sensitive environmental areas. If possible the area should not be declared a quarry zone and quarrying should not be allowed in this area.

Distillery wastewater – The application of distillery wastewater as a fertilizer to sugar cane fields may strategically minimize risk to both ground and surface water resources, rather than direct dumping of wastewater into sinks or gullies. Large amounts of organic matter and substantial nutrients that cause such drastic environmental impacts also make the wastewater well suited as a fertilizer. Phosphate, potassium and some nitrogen from the distillery wastewater are favourable for growth. An additional nitrogen source is required to make the wastewater a complete fertilizer for the sugar cane.

The benefits of this application are two fold. While providing nutrients for sugar cane, the plant removes the organic matter and nutrients from the wastewater. If there is no leaching to the underlying limestone aquifer or runoff form fields this application is an effective measure of handling effluent from the distillery. To ensure minimal risk to water resources continuous monitoring at specific sites around the estate may be required. An experimental project was conducted at the Appleton Estate to examine the effects of applying wastewater as a complete liquid fertilizer. Most parameters were in compliance at all sites and there were no distinct environmental problems.

Another method of treatment would involve constructing well-designed ponds to receive wastes and these would subsequently be treated and safely released to the environment.

New housing complexes – The major risks associated with new housing developments to water quality and quantity include unregulated dumping of domestic waste and leakage from septic systems; increased runoff from roofs and paved areas and a possible increased risk of flooding. Sinkholes are often sites of dumping and may be indiscriminately used as natural repositories. The enforcement of environmental regulations should restrict dumping in certain areas. Properly engineered septic systems should be implemented to minimize the risk of contamination to the water resources.

8.3 Hydrological Data Network and Programme

The establishment of a hydrological data network for the Cockpit Country is critical to water management. Rainfall, surface water, subsurface water, water quality, water production etc., are components of the hydrological network. An associated programme of data collection should be in place and routine monitoring so that quantitative hydrological assessments of the Cockpit Country can be done.

9.0 WATER RESOURCES DEVELOPMENT & USE

9.1 Water Demand

The water demand of the Cockpit Country is a product of total population (of Mile Gully) and a per capita unit demand of 0.23 m^3 (50 igpd). An allowance of 30% in system losses has been applied to the demand. The domestic water demand of the Cockpit Country is therefore 33,288.3 m^3/day. Potential industrial demands for bauxite mining/alumina processing may require an additional demand of 15,000 3 m^3/day.

9.2 Water Availability

The freshwater limestone aquifers are the primary source of potable water within the project area. The limestone of the Cockpit Country, however, is underlain by Basal Aquiclude at a shallow depth. Given the relatively thin limestone under the bottom of the dolines, there is not believed to be any regional water table and/or significant perennial groundwater storage within the Cockpit Country. Groundwater is essentially available for development to the north and south of the Cockpit Country that have been defined as down-faulted areas. In the karst aquifers of the Cockpit Country subsurface water flows in a conduit system and the capacity for storage of significant quantities of water is very small. Seasonal fluctuation of 10 to 15 m is generally associated with limestone aquifer formed primarily of the totally recrystallized Troy Formation largely because of its lower permeability and storativity, whereas the rubbly reef limestones of the Newport Formation with its higher permeability and storativity often exhibit annual fluctuations of only 1.5 m (HydroConsult, 2005). In general there is a perennial absence of both surface and groundwater resources. In order to meet the current demands of the resident population rainwater harvesting may be used to fulfill some of this demand.

9.3 Water Supply System and Water Use

There has been no large-scale exploitation of groundwater resources in the Cockpit Country. Extensive developments are hindered due to a number of topographic and hydrologic considerations. Groundwater exists in those down-faulted areas to the north and south of the Cockpit Country. Numerous wells have been developed in these areas to serve a variety of purposes but are mainly for public supply. Besides the National Water Commission's production wells, groundwater exploration has been conducted in the area to determine the potential for increased development of water resources.

The extremely high secondary permeability of the White Limestone and the upland areas within the Cockpit Country makes groundwater production impractical due to the low hydraulic gradient to the sea and the corresponding greater depth to the water table (Appraisal Report of the Martha Brae Valley). Sweeting (1955) also acknowledges that such developments would be relatively expensive, in relation to population size, as the terrain is difficult. However, parts of the Cockpit Country where water is recognized to exist relatively close to the surface, wells have been developed. Public supply wells are to be found at: Duansvale, Clarkes Town and Wakefield.

Water supply for the most part comes from the Martha Brae River and serves areas in the northern part of Trelawny as well as some coastal parts of St. James (outside of the Cockpit Country). Approximately 6.65 MCM/yr is supplied from the Martha Brae River as part of the National Water Commission's public supply system. Springs that have been entombed for public supply are mainly found in the southern Cockpit Country and are considered inadequate low yielding sources, especially during dry periods.

10.0 WATER RESOURCES DATA GAPS

The following is a summary of the key data gaps and recommendations identified during the hydrological assessment of the Cockpit Country. Not all data gaps identified have been listed as feasible recommendations for future research. Data gaps and recommendations include:

- The hydrological regime as it refers to flow amounts and pathways needs to be resolved. Tracer substances may be introduced to elucidate groundwater flow directions and determine flow times within the karstic aquifer system. However, owing to the dynamic nature of karst systems flow regimes may constantly evolve and prove problematic in long-term characterization of flow paths.
- There is a paucity of data as it relates to depth to water in the Cockpit Country. It may be useful to drill exploratory wells in the project area to assist with monitoring the resource.
- Spring discharge should be monitored regularly and hence reflect annual seasonal variability in discharge volumes. This should be correlated to the rainfall.
- A major constraint is placed on the reliability of the conclusions of the water quality evaluation, by reason of the limited data available for the evaluation. The conclusions are based on only one (1) current set of samples taken on December 11, 2004. Although this evaluation provides some indication of the status of water quality at these eleven (11) springs, it should not be construed as a robust evaluation and as such, important decisions must be based on analysis of additional water quality data taken, at a minimum, during the wet and dry seasons of the year. The rest is historical data taken from FAO/UNDP reports and Hydrology Consultants limited.
- Watershed management systems must be put in place to ensure minimum risk to water resources that arise from current land use and potential land use applications.

APPENDICES