"Rain Water Harvesting – Case Studies from the Barbados Experience"

Andrew P. Hutchinson, CEng, MICE, PEng.
Senior Principal, Caribbean
Stantec Consulting Caribbean Ltd,
Black Rock, St. Michael, Barbados
andrew.hutchinson@stantec.com

Abstract:

Barbados was classified as a "water scarce" country by the UN Water Commission (1990's) with a renewable water resource allocation of 210 m^3/ person / year, well below the UN standard of 1,000 m^3 / person / year. By comparison, other allocations computed were, St Lucia 5,500 m^3/ person / year and Antigua 2,800 m^3/ person / year.

With the average annual rainfall varying between 1,016 mm (40") and 1,524mm (60"), the paper examines the potential for utilising rain water harvesting in Barbados primarily for non potable uses, as a means of reducing the demands on the potable water supply system.

In Barbados, the current potable supply of 57.9M m^3/yr (15G US gals per year) represents some 13% of the total precipitation for a 40" rainfall year or 8.6% of the total precipitation for a 60" rainfall year. The paper identifies water conservation methods that can optimise the use of current renewable resources, as well as the benefits of using "rain water harvesting" to capture a small percentage of the precipitation that is now lost to runoff; this captured rain water can supplement the national non potable water demand and reduce the demand on the potable supply.

The role of the regulatory planning agency and the subsequent impact of the implementation of a national "rain water harvesting" policy since 1996 is also examined, together with the need for additional creative fiscal policies that would serve to support and encourage the aggressive use of "rain water harvesting" on a wider national scale.

The paper also presents a number of case studies that demonstrate the positive impact of a number of sustainable "rain water harvesting" projects that have been successfully implemented in Barbados. These include the Millennium Heights Residential Development (2000), The Lion Castle Polo Estate (2003), the Mount Gay Distilleries Rum Ageing & Blending Facility (2005), the Farmers Dam & Water Impoundment (2006) and the Kensington Oval Redevelopment (2007).

The author demonstrates how 150 years of rainfall data for Barbados was utilised to prepare a hydrologic water balance model for the analysis and prediction of yields from "rain water harvesting" at particular project locations. The potential for the utilisation of the model for the future development of several unused watersheds is also discussed.

1.0 INTRODUCTION

Barbados, an island of 430 km^2 located at 13^o 10' N and 59^o 30' W is the most easterly of the Caribbean islands; with a population of approximately 277,000 it is one of the most densely populated countries in the world.

The topography of the island is characterised by two distinctive physiographic regions. To the leeward, there is a series of gently sloping, step like coral terraces rising from the south and west coasts to a height of 340 meters at Mount Hillaby. On the windward side, the land falls steeply from Mount Hillaby to the eastern coastline.

Approximately 86% of the island is covered with a 100m thick permeable karsts limestone formation giving an undulating land surface with deep gullies and sinkholes.

The other 14% comprises steeply eroded mud, shale and clays of the Oceanics Group located in the "Scotland District" on the eastern or windward side of the island.

The climate of Barbados is maritime and tropical with a sub-humid to humid rainfall regime that approaches a semi-arid character in the drier parts of the island. The island's annual average rainfall is 1524 mm/yr (60"/yr), based on over 150 years of records. However, the variation in total rainfall across the island from month to month and year to year presents a challenge for agricultural activities. In general, the dry or lower rainfall season runs from January to May and the wet or higher rainfall season from June to December. The inception of the seasons can vary each year with transitional months between seasons. Approximately 75% of the annual rainfall occurs in the wet season with heavy localized short duration and high intensity showers.

Humidity does not vary significantly through the year, averaging 71% for the dry season and 76% for the wet season. Diurnal or seasonal temperatures vary little with wet the season ranging from 23^{o}-$31^{o}C$ and the dry season ranging from 21^{o}– $29^{o}C$.

As technocrats across the Caribbean and the world grapple with the possible impacts of climate change, the subject of water and its importance to sustainable development quickly comes to the fore. The debate is very relevant to Caribbean island states that are dependent on ground and/or surface water resources.

In the case of Barbados, its label as a "water scarce" country has already lead to the utilisation of rain water harvesting techniques to meet the demand for non potable water, necessary to sustain expansion within the industrial and tourism sectors.

2.0 BARBADOS AND WATER SCARCITY

2.1 Global Water Perspective

On a global scale, 97% of the available water is sea water and 3% is fresh water; of the available water 2% is held as fresh water in polar ice caps leaving only 1% as fresh water for use by the population of the earth.

Water scarcity affects one third of the world's population (WHO 2009). In simple terms it is the imbalance between availability and demand for potable water. In the last century, water demand has increased at more than twice the rate of population growth. Although there is no global water scarcity, a number of regions continue to experience regular water shortages.

A **"water stressed"** region is generally defined as having an available renewable water resource in the range of 1,000 to 1,700 m^3/p/yr; approximately 2.0 billion people currently live in water stressed regions.

A **"water scarce"** region is generally defined as having and available renewable water resource of less than 1,000 m^3/p/yr; currently there are approximately 1.2 billion people living in water scarce regions.

By 2025 it is estimated that 1.8 billion people will be living in regions with physical “water scarcity” and two thirds of the world population could be under “water stress” conditions (FAO, 2009).

At present Barbados is labelled as “water scarce” with a rating of 210m^3/p/yr, well below the benchmark of 1,000m^3/p/yr. By comparison, St. Lucia has a rating of 5,500m^3/p/yr, Antigua a rating of 2,500m^3/p/yr, Trinidad 4,200m^3/p/y and Jamaica 3,300m^3/p/yr.

2.2 Local Water Resources

At present, the Barbados Water Authority (BWA) supply approximately 159,000m^3/d (42M US gpd) from ground water sources to about 98% of the population through a well developed distribution system. In addition, approximately 36,400m^3/d (9.6M US gpd) is abstracted from some 120 private wells, mainly for farming. It is reported that approximately 98% of the islands known ground water resources are currently being utilised. In 2001 the BWA commissioned a reverse osmosis (brackish water) desalination plant with an output capacity of 30,000m^3/d (7.9M US gpd) to supplement the water supply.

It is therefore clear that there are challenges ahead in meeting any growth in demand.

However, it appears that little attention is focused on improving the utilization of the available natural resource; the annual precipitation that falls on the Barbados land mass. A comparison of the annual gross volume of precipitation with the BWA annual volume delivered to consumers is revealing.

The BWA currently deliver 57.9M m^3/yr (15.2G US gpy); the effective utilization is computed as a percentage of the total annual precipitation;

- In a 1,016 mm (40”) rainfall year; total volume of precipitation is 435M m^3/yr (115G US gpy); BWA utilization rate is 13.3%.

- In a 1,270mm (50”) rainfall year, total volume of precipitation is 549M m^3/yr (145G US gpy); BWA utilization rate is 10.5%.

- In a 1,524 mm (60”) rainfall year; total volume of precipitation is 655M m^3/yr (173G US gpy); BWA utilization rate is 8.8%.

It is recognised that there are losses due to evapo-transpiration and evaporation; indeed best estimates suggest that only approximately 20% of rainfall actually reach the aquifer as a result of the high incidence of runoff through gullies.

Notwithstanding the above considerations, there is still a strong case to be made for the use of rain water harvesting on a national scale to augment the available water resource. This effort has to be driven by a BWA policy initiative supported by public information and education programme. If by the collective implementation of “domestic” and "commercial" rain water harvesting the utilization rate can be increased by 5% to 10% then a significant gain would have been made.

In addition, there are significant untapped watersheds on the East coast of Barbados that can be used for rainwater harvesting, with treatment, to supply potable water to East coast communities now suffering regular outages.

2.3 Conservation Measures

A number of conservation initiatives are required to maximise the use of available water in the years ahead. These are summarised here for consideration;

- Reduction of the "Unaccounted for Water" from the current level of 55% to 35%; this would realise a saving of 30,300 m^3/d (8.0M US gpd);
- Update operations – flow control systems at pump stations;
- Establish National Pressure Zones – with use of an island wide hydraulic model;
- Reduction of water toilet cistern leakage due to faulty flapper valves; this is estimated to result in a saving of 18,900m^3/d (5.0M US gpd); this requires a regulatory framework that restricts the use of unauthorised toilet cisterns;
- Implement a water tariff structure that rewards conservation;
- Promote and reward "rain water harvesting" – encourage rain water use in toilet flushing, landscape irrigation, swimming pools, clothes washing etc.

3.0 REGULATORY INITATIVES TO SUPPORT RAIN WATER HARVESTING

In Barbados, the Town & Country Development Planning Office (TCDPO) controls all physical development on the island through the issue of permits for all development, including the construction of any building. In 1996 the introduced a regulation that mandated all buildings erected after that date to provide a rain water storage tank to capture water for secondary or non potable uses.

The regulation specified the storage requirements for each type of structure. Residential structures with 139 to 279 m^2 (1,500 to 3,000 ft^2) of roof area require a 13,600L (3,000 Imp. gal) tank; a residence greater than 279 m^2 (3,000 ft^2) of roof area requires a tank of 27,300L (6,000 Imp. gal). All commercial and industrial buildings require a tank with a volume computed on the basis of 193 L/m^2 (4.0 Imp. gal/ft^2) of roof area.

This regulation was effectively implemented by the TCDPO as applications for a building permit to erect a structure were not accepted or processed if the rain water tank was not included on the drawings submitted. This regulation was also enforced by the inspection of all water tanks prior to the issue of a compliance certificate from the TCDPO, on completion of the construction.

This regulatory measure had a dynamic effect on residential, commercial and industrial property developers; developers were forced to construct rain water tanks and engage in the practice of rain water harvesting. Although this regulation initially met with some resistance; it has challenged developers and home owners, having invested in the tank, to find creative ways to utilise and maximise the rain water stored.

Generally, this regulation had a positive effect on the storage and use of rain water for secondary uses; thus reducing the demand on the potable water system. However, there is a need for supportive environmental guidelines and regulations to proactively encourage the construction and operation of rain water storage tanks on a wider scale across communities. In the absence of these regulations some undesirable practices have developed; some persons have developed negative opinions on the use of rain water for non-potable uses such as irrigation, toilet flushing, washing clothes and general exterior cleaning.

4.0 RAIN WATER HARVESTING

4.1 **Need for rain water harvesting**

The capture and storage of rain water for use, with or without treatment, has been around for centuries. However, some countries (like Barbados) fortunate to have reliable ground water supplies became dependent on this source to the extent that rain water harvesting was not practiced. In other Caribbean communities, particularly the Grenadines islands, rain water harvesting is taken more seriously as it is the main source of water for individual properties, public sector offices and institutions.

As a "water scarce" country, Barbados must revisit the use of rain water harvesting to produce water for non potable uses, as a means of reducing the stress on the public water supply. The wide acceptance and practice of rain water harvesting will require a substantial public information and education programme, and fiscal incentives to encourage the home owner and commercial sector to embrace the concept.

It is reasoned that Barbados must engage in an aggressive rain water harvesting programme so as to increase the effective utilization of the total volume of precipitation deposited on the island; a valuable natural resource that is currently under utilized.

4.2 Rainfall Data

The real challenge to the implementation of a sustainable rain water harvesting solution is the determination of the amount of storage required during the wet season so as to meet the demand for water during the annual low rainfall period (dry season) of approximately five months. It is therefore necessary to have reliable rainfall data over a period of at least 25 to 30 years to support a prediction model.

Thanks to a network of approximately 50 rain gauges located on sugar cane farms, Barbados has some 150 years of rainfall data based on twice daily readings by dedicated farmers at 6.00am and 6.00pm. This data was analysed to provide average monthly precipitation levels; used in predictive models that perform a monthly water balance for various rainfall scenarios.

4.3 Water Balance Analytical Model

The author has developed a computer model for conducting a monthly water balance on any project. The interactive model takes into consideration the requirements for water use, water storage, losses through evaporation and evapo-transpiration, and the water runoff potential from defined watersheds, analysed for each month of a year using a given rainfall scenario.

The model uses monthly rainfall scenarios for a 1,43mm (45") year, 1270mm (50") year and a 1534mm (60") year to measure the sensitivity of the storage to the selected rainfall regime. After setting up the model with the various specific parameters, the storage volume can be selected and tested using each rainfall scenario to determine its sustainability over an entire year; whether the storage is sustainable during the low rainfall season.

This model has been used with success on the five case studies presented in this paper and implemented between 2000 and 2007.

5.0 RAIN WATER HARVESTING CASE STUDIES FROM BARBADOS

5.1 Background

The 1996 TCDPO regulation that mandated the installation of rain water tanks was the catalyst that engaged developers in the concept of rain water harvesting. Recognising that a rain water tank was mandatory, most developers chose to find creative ways to maximise their investment in a tank or pond, particularly for commercial and industrial projects.

In other instances, the TCDPO permit for development prohibited the use of the potable public water supply for the irrigation of golf courses and polo fields; not an unreasonable approach in the context of a "water scarce" Barbados. However, this action triggered the search for creative solutions, including rain water harvesting, to support the irrigation needs of large scale projects that were considered important to the continuous development of the Barbados tourism product being offered.

If necessity was the mother of invention then creativity was its father. The author was challenged to find creative water harvesting solutions that responded to the water demand for these large projects.

Subsequently, the author used interactive computer models to design and implement a number of commercial rain water harvesting projects that successfully responded to the irrigation needs of the case studies highlighted in this section. The projects highlighted here are good examples of the engineer's role in harnessing the materials and forces of nature for the benefit of mankind.

5.2 Millennium Heights Complex, Welches, St. Thomas (completed 2000)

This 16.2 ha (40 acres) residential gated community was completed in 2000. It consisted of two phases; Phase 1 has 78 two and three bedroom condominiums and villas; Phase 2 provided 20 duplex units, 16 two and three bedroom condominiums, and 64 free hold residential lots that are partially built out at this time.

The TCDPO permit for development required the provision of rain water storage. However, the design was developed around an existing sink hole on the property so as to utilise this for storage of rain water runoff from car parking and landscape areas, and some roofs. The sink hole was re-graded and lined with an HDPE liner to create a 6,000 m^2 (1.5 acre) pond with a capacity of approximately 18,939 m^3 (5.0M US gal). The storage capacity was in excess of the TCDPO requirement.


Photo 1: Millennium Heights Pond


Photo 2: Units around pond

Subsequently, the pond provided the duplex residential units around the pond with a water front vista that enhanced property values and improved the ambience of the area. Today the pond is a sustainable ecosystem with fish and water lilies that provide added value to the adjacent residential community; all the result of a rain water harvesting project.

5.3 Lion Castle Polo Estate, St. Thomas (completed 2003)

This 26 ha (64 acres) residential sub-division was constructed around a 4.8 ha (12 acres) polo field of international class. The TCDPO permit for development prohibited the use of the potable public supply for irrigation of the polo field; this presented a real challenge as polo was played during January to May, the traditional dry months.

Rain water harvesting offered the only solution. Subsequently, hydrological analysis confirmed that the 16 ha (40 acres) available watershed could sustain the irrigation needs of the polo filed, but 22,727 m^3 (6.0M US gal) of storage was required. An existing sink hole down grade of the sub-division was re-graded and lined to provide the necessary storage. The watershed comprised of the polo field, sub-division roads, home sites and an adjacent paddock used by the polo ponies.

Photo 3: Lion Castle Pond

Photo 4: Lion Castle Polo Field

This was an example of the use of commercial rain water harvesting to sustain the re-development of former sugar cane lands into a polo estate with a substantial value added to the economy.

5.4 Mount Gay Rum Ageing & Blending Facility, St. Lucy (completed 2005)

Since 1704, Mount Gay Distilleries has produced rum at the site of the St Lucy distillery. To sustain the demand for the brand, a TCDPO permit was obtained for the construction of three bonds for ageing approximately 35,000 barrels of rum and a blending facility on 4.8 ha (12 acres) of land adjacent to the distillery.

Photo 5: Mount Gay Bond & Pond

Photo 6: Mount Gay Pond

This facility required rain water storage for compliance with the conditions attached to the TCDPO permit for construction. An existing sink hole on the site was developed with the aid of an HDPE liner to provide 11,363 m^3 (3.0M US gal) of storage; this exceeded the permit requirements. The watershed for the pond consisted of the car parking and other hard standing areas, and the roofs of the four buildings.

The pond supplies water for irrigation and also acts as a reservoir for the pressurised on line fire fighting ring main system. This project was another good example of the effective utilisation of rain water harvesting for economic benefit; thanks to the TCDPO regulatory framework that mandated rain water storage.

5.5 Farmers Dam & Water Impoundment, St Andrew (completed May 2006)

The TCDPO permit for the construction of the 194 ha (480 acres) Apes Hill Golf Resort prohibited the use of potable water from the public supply for irrigation. The need to identify a sustainable source of non potable water for irrigation of the golf course became a necessity, if the project was to proceed. The author was commissioned to investigate the options for supply of irrigation water. Options investigated include wastewater reuse, a sea water desalination plant and rain water harvesting.

After hydrologic studies and analysis of several watersheds on the East coast of Barbados, a 99.6 ha (246 acres) watershed at Farmers Plantation was identified as the preferred site for the construction of an impoundment to capture stormwater runoff. Subsequent geotechnical investigations and design lead to the construction of a 220m (723ft) long earthen dam across the valley that flooded and area of 6.1 ha (15 acres) with a storage capacity of approximately 223,484 m^3 (59M US gal).

Photo 7: Farmers Impoundment

Photo 8: Overflow structure

The dam had a crest elevation of +250m above mean sea level; the impoundment had a top water level of +248m and an invert of +243m. A 5m x 5m overflow structure with a 2.4m x 2.4m (8ft x 8ft) discharge culvert was provided to cater for a 1:100 year storm event. A pump station was provided to deliver 3,787 m^3 (1.0M US gal) per day via a 250mm (10”) PVC pipe to the Apes Hill Golf Resort irrigation lake approximately 2.1km (1.3 miles) to the north west of the site. The project cost was BD$10.0M (2004).
This project demonstrated the effective use of rain water harvesting to provide a non potable source of water that afforded the re-development of former sugar cane farmland for an alternative economic use, compatible with the further enhancement of the Barbados tourism product.

After completion in May 2006, the impoundment was filled by December 2006 and has since continued to fulfil the irrigation needs of the golf course that was completed in December 2009.

5.6 Kensington Oval Redevelopment (completed December 2006)

Since 1895 the Kensington Oval has been used as a cricket stadium. The staging of the Cricket World Cup (CWC 2007) in April 2007 necessitated the reconstruction of the oval to meet the international standards required for the world cup; the final of the world cup was scheduled for the Kensington Oval before the eyes of the world.

Apart from reconstructing most of the stands, the cricket field was shifted and completely reconstructed to achieve the layout, grades and quality of turf required. Prior to the reconstruction, the Kensington Oval site had a history of poor drainage conditions and frequent flooding; it was located in a low lying area only +2.4m (+8ft) above mean sea level on the outskirts of the city.

After analysis of the sub-grade soil conditions a hydrologic model was developed for the design of an integrated drainage / irrigation solution for the 3.12 ha (7.5 acres) watershed. The design solution was based on the use of HDPE parabolic “storm chambers” to facilitate the storage and infiltration of stormwater into the sub-grade. Runoff from the field and all roofs was collected and discharged into the storm chambers.

The system was sized to accommodate a 1:25 year storm event, however an auxiliary relief system was provided to discharge excess runoff to the public storm drain, in the event of a storm event with a longer return period.

Photo 9: Kensington Oval

Photo 10: Storm Chambers

A total of 230 storm chambers were laid in a 418m (1,370 ft) long by 3.0m (10ft) wide by 1.5m (5ft) deep trench around the perimeter of the field; this acted as a “French Drain” for the effective infiltration of runoff into the sandy sub-grade to recharge ground water; a fresh / brackish water lens at sea level.

The irrigation needs of the site were met with the provision of an on site irrigation ground water well excavated into the sandy sub-grade; this well pumped brackish water at a uniform rate to a buffer storage tank that feeds the irrigation system. In addition, the facility also provided a rain water storage tank that captures runoff from the roof of the “Worrell, Weeks and Walcott” stand for transfer to the irrigation buffer storage tank.

Rain water harvesting provided an integrated solution for the drainage of the complex and recharge of the aquifer that was then used for the irrigation of the playing area.

6.0 CONCLUSIONS

The characterisation of Barbados as a "water scarce" country has made the regulatory agencies (TCDPO), since 1996, very sensitive of the need to reserve the scarce water resources largely for potable use.

The mandatory requirement to provide rain water storage tanks for secondary uses has therefore sensitised home owners and developers that Barbados is "water scarce" and that the use of rain water for non potable uses must be encouraged so as to reduce the demands on the potable public supply system.

To every action there is a reaction; therefore the TCDPO conditions that prohibit the use of potable water for irrigation on certain developments has, to a large extent, triggered the search for creative "rain water harvesting" solutions to meet the non potable water needs for a number of projects.

This paper has demonstrated that it is indeed possible to construct effective and sustainable rain water harvesting projects in "water scarce" Barbados. It also highlights the potential for the use of rain water harvesting to supplement the potable water demands of the island, particularly on the East coast of the island where there are several significant watersheds that remain untapped.

Finally, it is clear that the Government of Barbados through the Barbados Water Authority needs to provide leadership with public information and education programmes, and policy initiatives to encourage the use of rain water harvesting on a national scale. Such an initiative would allow greater utilization of rain water; a valuable natural resource.