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# Rainwater Harvesting, Vernacular Architecture and the Culture of Water Resource Management in Bermuda

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**Abstract**

Bermuda is a subtropical island archipelago located in the North Atlantic Ocean at approximately 1070 km east off the coast North Carolina. The mainland comprises the seven largest islands and has an area of 53.2 $km^2$ and approximately 64, 237 residents,[9] making it one of the highest population densities in the world.

Bermuda has no rivers, streams, lakes or freshwater ponds. Consequently, for over 350 years, rainwater harvesting has been practiced in Bermuda and continues to be the primary source of drinking water and the key feature of the Island's vernacular building architecture. Born out of necessity and ingenuity, in Bermuda

collecting rainwater is not only a way of life but is also mandated by law, with each household being responsible for their water supply**.**

Droughts, changes in demographics, environmental contamination, and a loss of the cultural history of water are just some of the factors that have been placing the sustainability of Bermuda's already fragile water management infrastructure under continuous threat over the years.

In January 2017, following the positive response by local residents to a series of public forums on sustainable water management held at the Bermuda College, a multidisciplinary consortium was established with the aim of gaining a holistic and comprehensive view current status of Bermuda´s rainwater harvesting model. The primary goal of this initiative was to identify the challenges facing the present and future of this cornerstone of the Island´s intangible cultural heritage, as well as outline key focus areas for further research and development.

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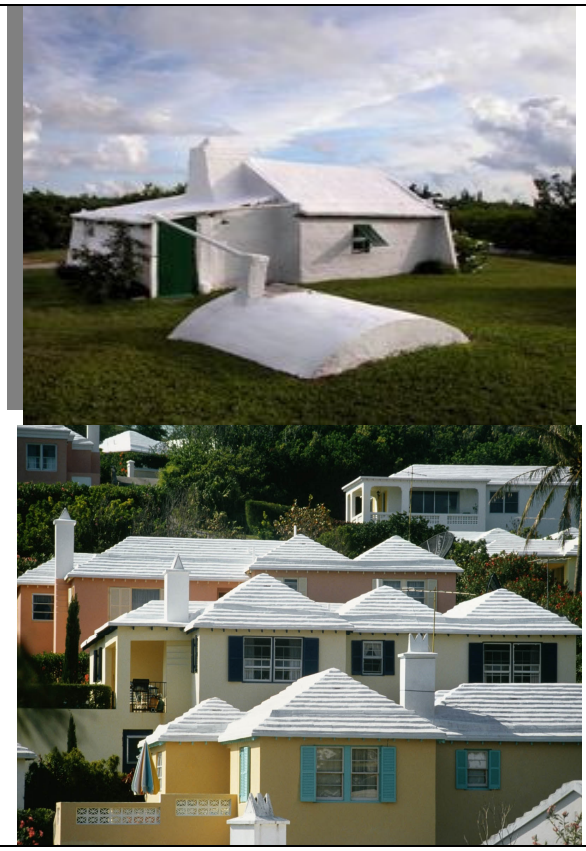
| **Image or graphic** |  |
| **Location** | The Bermuda Isles (Bermuda), North Atlantic |

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| **Duration** | 3 months |
| **Time Frame** | Start date: 02/2017 End date: 03/2017 |
| **Consortium** | • Koom Consulting (private water engineering and project management consulting entity),<br>• Bermuda College Science Department<br>• Department of Health of the Bermuda Government,<br>• Middleway Media (independent environmental research entity and documentary film maker),<br>• Greenrock (Environmentalist NGO) |
| **Resources** | Human Resources:<br><br>College students and professors, civil servants, independent researchers, independent environmental and water engineering consultants, local environmental NGO´s, vernacular know-how and expertise. |
| **People Affected** | The subject of rainwater harvesting in Bermuda affects, whether directly or indirectly, the entire national population of approximately 64, 000 residents. |
| **Urban Sectors** | Water resource management, intangible heritage, building and architecture, public health, environmental contamination, population density |
| **Resilience Dimension** | • Adaptation to resource limitations with appropriate technologies<br>• Adaptation of vernacular appropriate technologies to population growth and environmental pollution,<br>• Community education and empowerment<br>• Multidisciplinary approaches to resource management<br>• Mitigation of public health risks<br>• Adaptation of local legislation to meet new environmental and socio-demographic challenges |
| **Strengths** | • The multidisciplinary nature of the consortium created for this initiative.<br>• The diverse and enriching contributions of each one of the collaborating authors and researchers of this article.<br>• The wide range of information sources and reference materials compiled on the subject matter.<br>• The variety of perspectives offered on the subject matter. |
| **Weaknesses** | • Limited time available for team building, task planning and coordination among all contributing authors of the consortium<br>• Limited time for locating, contacting and interviewing local researchers, environmentalists, masons, architects and other key stakeholders. |

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| **Article objectives and impact** | • Generate a greater appreciation of Bermuda's vernacular architecture and rain water harvesting model.<br>• Highlight Bermuda´s rainwater harvesting model as being the cornerstone of its integral water management infrastructure.<br>• Raise awareness on the importance of community education and empowerment in the effort to achieve sustainable water management in Bermuda.<br>• Highlight the importance of holistic, multidisciplinary approaches toward sustainable water management.<br>• Highlight the need for further research and development in the subject of rainwater harvesting and water resource management in Bermuda. |
| **Stakeholders List** | • The national population of approximately 64,000 residents.<br>• All ministries and Departments of the Bermuda Government<br>• The Bermuda College and other public and private educational institutions<br>• Local environmental and research NGOs, associations and foundations<br>• Architects, masons, engineers, water and environmental consultants, independent researchers and related professions<br>• The water trucking industry<br>• Public and private groundwater treatment and desalination facilities<br>• Hoteliers and other guest accommodations<br>• Home, business and other property owners.<br>• Health and medical workers |
| **Challenge / Project Description** | In January 2017, as part of their annual science week, a series of public forums on sustainable water management were held. Although the forums were not focused specifically on Bermuda, the themes addressed resonated greatly with local residents, given the direct applicability of the subject matter to the current situation of water management on the Island. This fact was made very evident, not only through the keen interest shown by those who attended the forums or viewed them in the local media, but also by the countless questions and concerns voiced by residents about the possible links between their water supply and their health and well-being.<br><br>In response to this enthusiastic feedback, and in very short notice, a consortium comprising teachers and students of the Bermuda College Science Department, Koom Consulting, The Bermuda Health Department, Middleway Media and Greenrock, was assembled to compile essential primary and secondary data to gain a comprehensive and multidisciplinary understanding of the current situation of rainwater harvesting and water management in Bermuda.<br><br>The main goals established for this initiative were the following: |

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| | • Generate a greater appreciation of Bermuda's vernacular architecture and rain water harvesting model.<br><br>• Highlight Bermuda´s rainwater harvesting model as being the cornerstone of its integral water management infrastructure.<br><br>• Raise awareness on the importance of community education and empowerment in the effort to achieve sustainable water management in Bermuda.<br><br>• Highlight the importance of holistic, multidisciplinary approaches toward sustainable water management and evaluate possible strategies for addressing some of the key issues that are currently placing this infrastructure under threat.<br><br>• Identify key focus area requiring further research and development in the subject of rainwater harvesting and water resource management in Bermuda. |
| **Lessons Learned** | • The potential for human health risks associated with water quality could be significantly mitigated through increased public awareness of tank water as raw water and the widespread adoption of appropriate disinfection procedures by Bermuda residents.<br><br>• Most research on the Bermuda´s water catchment system has been observed to come from non-Bermudians.[18]<br><br>• Striking differences in education and awareness concerning rainwater harvesting can be observed, not only between residents, foreign workers and tourists, but also intergenerational aspects.[1]<br><br>• Water has become less of a social and environmental concern, and more of an economic commodity.[1]<br><br>• A greater emphasis on capacity building is essential for empowering residents to manage their independent water supply units more effectively and sustainably.[24]<br><br>• There appears to be a significant imbalance between the wealth of information available on good water management practices in Bermuda, and the percentage of the local population are aware of and/or apply such practices.[24] |

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| **Upscaling and Replication** | The following items were identified as requiring further research and / or development:<br><br>• Public awareness and understanding of the concept of tank water as "raw" water [27]<br><br>• The effects that microbial contamination and / or sediment quality of water could potentially have on human health.[18]<br><br>• Sustainable methods of water quality control assurance.[27]<br><br>• Strategic management of water resources as an integrated part of the solution toward water sustainability. [18]<br><br>• Tank water chlorination and the potential for the formation of chlorinated disinfectant by-products (DBPs).[24]<br><br>• The use of licensed private well water sources for non-potable purposes as a means of supplementing stretched harvested rainwater supplies.[18]<br><br>• The status of "water catchment hills" in Bermuda and the potential role they could play in the future.[18]<br><br>• Comparative studies on the environment / carbon footprint of rainwater harvesting, piped water systems, water trucking and bottled water.[24]<br><br>• Climate change and the potential effects on long term efficiency of rainwater harvesting.[24] |
| **Web page** | http://www.middlewaymedia.com/portfolio/trusting-rain/ |

## 1.1. A Brief History of Rainwater Harvesting in Bermuda

The houses constructed by the first settlers in Bermuda were initially very similar to those of their native England. However, construction quickly adapted to the indigenous materials of Bermuda cedar (*Juniperus bermudiana*) and limestone.

Bermuda cedar was in short supply as early as 1620, and stone buildings were encouraged, using cedar for framing and trim.[26] The native limestone, which can be cut with a saw and which hardens on exposure to the atmosphere, was cut into blocks for walls. Roofs, supported on cedar framing, were formed of overlapping limestone slates, 30.5 cm x 45.7 cm x approximately 3.8 cm. Limestone, burned in kilns, also provided the mortar used to assemble both walls and roofs. This form of construction is essentially the same as the vernacular architecture of today, with the exception that concrete block walls have replaced limestone in recent decades.

A unique feature of Bermuda roofs has been their role in water supply. Given its geology, Bermuda has no rivers, streams, lakes or freshwater ponds for obtaining freshwater. Thus, for basic survival, the first settlers were obliged to meet their drinking water needs by way of rainwater harvesting. Until the 1930s, rainwater provided the only source of potable water. Water was collected on roofs, where wedge-shaped limestone "glides" were laid to form sloping gutters on the roof surface, diverting rain water into vertical leaders and subsequently into storage tanks.

Early storage tanks were rum puncheons or cisterns made of cedar. Others were formed by excavation into rock and made tight with mortar. Prior to the 20th century, when roof water systems with adequate storage first began to be systematically encouraged, tanks were located at the outside rear of dwellings, partly or entirely above ground. Water was removed from tanks by bucket or hand pump and carried indoors. In some later systems, hand pumps transferred water to elevated indoor storage tanks.[26] Eventually, the tanks were moved underground and became part of the foundation. Current systems include storage tanks under buildings with electric pumps and pneumatic tanks.

Historically there were also large catchment areas on hillsides, created by removing thin hillside soil and sealing the rock surface with mortar, that collected water, providing significant quantities of water as recently as the 1980s.[26] However, according to local experts, these have not been maintained. Many are disappearing after having been left in disrepair.[1]

From the small original cottages to the office blocks of today, for over 350 years roof-top rainwater harvesting has been practiced in Bermuda and continues to be the Island's primary source of drinking water. Today, roof-top rainwater harvesting is mandated by law for all buildings in Bermuda and is the primary source of water for domestic supply, with approximately 85% of Bermuda residents currently using their tank water for drinking on a regular basis.[5]

Bermuda's legislation and building codes specify the requirements for the construction and maintenance of water catchments and water storage tanks. All buildings are required to have rainwater catchments and tank(s) to supply and store rainwater for people occupying or using the building.[8] Buildings must have at least 80% of the roof area sufficiently guttered to catch rainwater, or must have a ground catchment with a corresponding area, and have a water storage tank with a capacity of at least 100 gallons (US) for every 10 square feet of catchment area. Waivers for these requirements can be granted by the Minister, if they are not feasible, or if the building can be supplied with potable water from a main piped supply. Tanks are required to be cleared of sludge and properly cleaned at least every 6 years.[15] There is the provision for issuing fine(s) for offences against these regulations.

## 1.2. Rainwater Harvesting in Bermuda and the Challenges of Water Supply

Rainwater harvesting is particularly suitable to locations where the average rainfall exceeds 400mm/year and other sources of water are scarce and/ or of poor quality.[20] Bermuda's annual average rainfall (1949-1992) was 55.5" (1410mm).[11] More recent data for annual rainfall shows a low of 40.57" (1030 mm) in 2009[10] and a high of 68.24" (1733 mm) in 2015.[9] While precipitation is fairly evenly distributed through the year, it is somewhat less reliable in April and May, Bermuda's driest months on average.

Although the primary source of water for domestic use is rainwater collected by roof catchments, this system does not meet the demand for high occupancy buildings such as large hotels and multi-storey office buildings.

In 1932 development of the largest of the groundwater lenses began, providing up to 3.5 million L/day of brackish water for nonportable uses (primarily flushing) through a distribution system serving the central part of the island. Part of this water fed a desalination plant that provided potable water to several major tourist facilities. In the 1960s, desalination plants had been installed by several major hotels, industry, and government,[26] and In 1979 the rational development of groundwater resources began, involving the development of new wells and the de-

livery of potable water to large areas of Bermuda. This water is abstracted from wells and treated by reverse osmosis and microfiltration, with reverse osmosis of seawater being introduced in 1996.[11]

Most recently, in 2008 the 500,000 gallons per day Tynes Bay Seawater Reverse Osmosis (RO) was constructed, with the aim of meeting the needs of the Island well into the future. However, in 2010, only 10% of the population had connections to this piped water supply.[10] Other important sources of supplementary water are private wells for flushing and other non-potable uses, and treated groundwater, delivered by water truckers.[11]

The Bermuda Public Health Act 1949 specifies that it is illegal to use well water for drinking or food or drink preparation or manufacture, unless licensed by the Minister. Well water can only be used to supply toilets, washing machines, or outdoor hose bibs used for irrigation. In addition, any water treatment systems such as reverse osmosis or chlorination units must be licensed by the Environmental Health authority and the Department of Health.[13]

In extreme cases of water scarcity, local authorities have had to resort to the importation of fresh water from North America. This occurred, for example, during a 5-year period between 1938-1968 in order to supplement the deficiencies in local resources.[26] More recently, in 1990 and 2005 abnormal drought conditions led to the use of water tankers to import fresh water from North America as a contingency plan for meeting local demands.[3]

The use of residential roof areas to create catchments is maximized in Bermuda, and yet the quantities of harvested rainwater are insufficient to meet collective residential water demand. Currently, an average of 35.5 $m^2$ of residential roof catchment area is available per person compared to the required amount of 40 $m^2$, based on average annual rainfall. Nearly two-thirds of houses in Bermuda do not have a piped supplementary supply or a private well. At the ''typical'' house with four occupants, the average supply of harvested rainwater is 428 L/ day which is barely enough rainwater to meet the demand of a family of three (at 137 L/day per capita). It is recommended that this deficit be offset by supply of non-potable raw well water for toilet flushing. This would foster self-sufficiency and reduce the demand for ''produced'' supplementary water which has been treated to a potable standard (at considerable expense by processes requiring high energy consumption).[23]

## 1.3. Rainwater Harvesting in Bermuda and the Challenges of Water Quality

Although rainwater is one of the purest sources of water, once it contacts the catchment surface, the risk of contamination significantly increases. Microorgan-

isms, sediments and contaminants can be washed into the tank, (e.g. bird droppings, vegetation). Therefore, Bermuda's rainwater catchment systems require regular maintenance. The treatment techniques used in Bermuda tank water systems to minimize pollution include the following: screening by strains on gutters to prevent leaves and other debris entering the tank; sedimentation, which is the settling of particulate matter within the tank; filtering to remove sediment before or at the tap; and disinfection by boiling, chlorination or ultraviolet light. Tanks should be cleaned as often as necessary to prevent sediment accumulation and, by law, at least every 6 years. Refilling of tanks that are low in water and high in sediment should be avoided, as contaminants in the sludge could be re-introduced into the water.[12]

The roof is cleaned by power washing or wire brush to remove old paint and fungal growth, then washed with a 50/50 solution of unscented bleach and water, before painting with an approved roof paint.

The "first flush" system or roof washing is a technique, using a pipe system, whereby when it first starts to rain, the first flush of water washes most of the debris from the catchment to waste, then allows the cleaner water into the tank". However, this system has not been widely adopted in Bermuda.

Public Health Officers are empowered under The Public Health Act 1949 to act to remedy a situation where water in a tank appears to be polluted or in danger of pollution, and may by order require that a tank be temporarily closed, emptied and cleaned, or chlorinated or otherwise disinfected.[19] The Department of Health strongly recommends that residents disinfect tank water used for drinking and food preparation, and offers guidance as well as a water testing service.[12]

Recent research carried out on Bermuda rainwater tanks found the chemical quality of the water to be good, with a very low incidence of health-based primary drinking water standards being exceeded. The studies of microbial contamination of household tanks in Bermuda, however, have indicated very high rates of contamination (88% and 66% of total coliforms and *E. Coli* respectively).[6] More recently, researchers have identified wildlife sources (e.g. pigeons, lizards, feral chickens) of *Salmonella* Mississippi, which has been found in Bermuda's tank waters.[4]
Certain segments of the population may be particularly vulnerable to such microbial populations, namely young children whose immune systems are still developing as well as people with fragile or compromised immune systems.[22] The Health Department recommends that tank water be considered as "raw water" requiring treatment by disinfection before using for drinking or food preparation. Disinfection can be by techniques such as chlorination, boiling, ultraviolet light/filtration systems, or a combination of these. Testing of untreated tank water is not recommended, because of its variable bacterial quality, as well as it being very unlikely to meet the recommended bacterial values for drinking water. Testing of water,

once it has been treated by disinfection, is recommended to ensure the disinfection is adequate.[12]

There are currently no standards or guidelines in effect in Bermuda, with which to assess the quality of water cisterns with regard to sediment quality.[21] However, recent studies on the effects of contaminated water tank sediments on local amphibian species have raised considerable awareness on the need for further research in this area, namely on the potential effects of such contaminated sediments on human health.[2]

A study carried out in 2004 revealed that whilst most residents carried out roof maintenance (washing and painting) every 1-3 years as recommended, most did not respect the health department guidelines when it came to disinfecting tanks with chlorine and the cleaning of tanks.[6]

## 1.4. Conclusions

Given the widely-decentralised nature of Bermuda´s water supply infrastructure, community level education is not only a vital tool for creating awareness but, more importantly it is essential for empowering residents to manage their independent water supply units more effectively and sustainably. Of equal importance is the application of clear indicators by which the success of such initiatives could be gauged.

Although there seems to be a wealth of informative material on Bermuda's rainwater harvesting model available to the public, a significant percentage of the population seems to be either totally oblivious to it or simply take it for granted. Furthermore, there are rarely signs in hotels or educational materials on Bermuda's rainwater harvesting system designed to advise the Island´s visitors to conserve.[1] These and other factors have contributed to the loss of the cultural heritage of water conservation, leading to the idea of water being less of a social and environmental concern, and more of an economic commodity.[1]

Whilst there is room for progress with respect to the enforcement of water management legislation, the assurance of water quality through effective capacity building and water monitoring and control programs must be a core focal point. Ultimately, given the broad, multi-disciplinary and national scope of rainwater harvesting and water management in Bermuda, the sustainability and resilience of this intangible cultural heritage could only be achieved by way of an holistic and long-term strategic approach to water resource management.

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