PERSPECTIVES PAPER

Global Water Partnership
Caribbean

STATUS, NEED AND ROLE OF FRESHWATER STORAGE IN THE CARIBBEAN

This Perspectives Paper was prepared by Anika Cole and Dr. Adrian Cashman.
It is intended to galvanise discussion within the GWP-C network and the larger water and development community.

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ABOUT GLOBAL WATER PARTNERSHIP-CARIBBEAN

The vision of the Global Water Partnership-Caribbean (GWP-C) is for a water secure Caribbean. Our mission is to support Caribbean countries in the sustainable management of their water resources at the community, national and regional level.

GWP-C is 1 of 13 Regional Water Partnerships of the Global Water Partnership (GWP).
It was established in 2004 to foster the application of Integrated Water Resources Management (IWRM) in the Caribbean region. IWRM is the coordinated development and management of water, land, and related resources, in order to maximise economic and social welfare without compromising the sustainability of ecosystems and the environment.

Any organisation with an interest in water sustainability in the region, can become a GWP-C Partner. GWP-C currently has over 100 partners in more than 20 Caribbean countries. These include water management agencies, water user associations, private water management agencies, government institutions, academic and research institutions, private sector companies, non-governmental organisations, community-based organisations, civil society organisations, youth organisations, regional agencies, consultancy firms, among others.

This Perspectives Paper was prepared by the GWP-C Technical Committee members:

- Anika Cole
- Dr. Adrian Cashman

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INTRODUCTION

Freshwater storage is a key, underappreciated, area of interest that is vital for ensuring the provision and continuity of supply to users of water whether they be farmers, industrialists, hoteliers or utilities charged with the provision of water services. Water storage is both a resource and a service and as such, forms an essential part of a country's water infrastructure. Efficient storage and management of water helps every country in achieving their national goals, as well as Sustainable Development Goal (SDG) 6 (Clean Water and Sanitation). Yet it is often taken for granted. The purpose of this paper is to give a broad overview of the status and need for freshwater storage in the Caribbean (See Figure 1), highlight current trends and initiatives, and contribute to ongoing discussions on salient issues related to water and regional development.

Figure 1. Map of the Caribbean Region

WHY WATER STORAGE?

Water is an ephemeral resource whose availability varies in time and place.

Water availability ultimately depends on rainfall. Rainfall has different characteristics; it varies in intensity and duration and frequency, it changes with the seasons and varies from year to year - there can also be a superabundance, a prolonged absence or anything in between. Most productive activities require a degree of certainty with respect to the availability of water, that it is there when it is needed, where it is needed and in the quantity that it is needed. Very often there is a disconnect between when, where and how much rainfall replenishes water resources and of those resources how much can be available for use. Taken together, this can mean that water is not available when you want it and where you need it.

One of the roles that a water system performs is to bridge that disconnect to even out the variations. Within water systems this is the function that water storage performs, its purpose is to even out the fluctuations and provide a buffer between the resource and the consumer. How much of a buffer it should be depends on the characteristics of the resource and the characteristics of the use and requirements of the user(s).

Storage therefore has multiple purposes and plays an important role in ensuring water availability providing multiple benefits such as: balancing variability in precipitation, ensuring availability to meet demands and mitigating vulnerability to floods and drought. Each of these brings with them their own challenges such as, natural endowments that can be compromised by human activities, built storage which is subject to sedimentation, water demand changes which is determined by consumption patterns, increased climate variability which changes precipitation patterns and affects floods and droughts.

While water storage is becoming increasingly important, it has to be thought of as part of a system and not treated as an end in itself.

Water storage shifts resource availability across time and space. Looking at the Caribbean on a macro level, the region is relatively well endowed with water resources, receiving 1.4 percent of the world's precipitation and generating 1.8 percent of its water resources (FAO, 2003).

Table 1. Snapshot of Water Resources in the Caribbean.
Adapted from Global Water Partnership, 2014.

	MAIN SOURCE OF WATER SUPPLY			
	GROUNDWATER	SURFACE WATER	DESALINATION	RAINWATER HARVESTING
Flat, low lying	Bahamas		Cayman	
Extensive lowlands		Cuba		
Flat, coralline	Barbados Barbuda		Antigua, Barbados (25%)	
Mountainous, Volcanic	St. Kitts	Dominica Grenada St. Lucia St. Vincent	Grenadines	Grenadines
Fairly mountainous with narrow coastal plains	Jamaica Guyana	Haiti Trinidad and Tobago		

N.B. All countries practice rainwater harvesting to varying degrees. Desalination is also practiced to some extent in Barbados and Bahamas. Guyana has significant surface water resources, but utility supply is predominantly from groundwater via wells.

At a granular level, the region varies geographically, hydrologically, demographically, and in institutional and operational capacities. The geographical variation is reflected in Table 1, where average rainfall can vary between 1000 to over 7000 mm per year whilst populations vary from a few hundred in the Grenadines to several millions in countries like Jamaica and Haiti. These factors dictate that water resources are not always available in the required quantities at the right time. While some countries have significant water resources (e.g. Guyana), others are failing to keep up with supplying adequate freshwater as they face climate extremes from droughts to floods.

The disparities between population distribution and water resource locality are also evident as urban sprawl continues at an increasing rate in areas with over exploited resources (e.g. the Kingston Metropolitan Area, Jamaica). Some rural communities have developed in an ad hoc manner on marginal, hilly lands relying on small community-based surface water sources that generally have reduced output with drought or dry season conditions. Such variability can affect water quality and these sources may not consistently meet public health standards, though this is not always well monitored and documented. Governments are finding themselves challenged and are reactive in their approach to constraining these peculiarities.

Sectors across the Caribbean including agricultural, industrial, municipal and tourism are heavily dependent on a consistent supply of water and must rely on storage to meet their needs. Tourism, service and manufacturing sectors have risen in prominence over the decades in the Caribbean. While large scale agriculture may be declining, subsistence rain-fed farming is still widely practiced and forms an important aspect of food security in the Caribbean. Drought conditions that have become more frequent and pronounced stand to threaten the water security of these sectors. For most Caribbean islands, rainfall seasonality means a relatively dry period from December to March (Taylor et al., 2012).

The timing of socio-economic activities is often misaligned with the availability of resources. The peak tourist season when demand is at its highest have traditionally coincided with the dry season for many countries. On the other hand, the timing of the rainy season is important for planting cycles in the agricultural sector. In Jamaica, for instance, the timing of the May rains could determine the success of a farmer's crop. The additional stressors on an already diminishing resource in low flow/dry season, impacts a natural system challenging its capacity to meet demands whilst maintaining essential ecosystem services. Interest in understanding flows for maintaining ecosystem services is growing though much more work is needed to understand environmental flows (Hirji and Davis, 2009; Roberts et al., 2017). Storage is essential for coping with intra- and inter-annual temporal variability of water resources (Gaupp et al., 2015) and to cope with occasional shocks (e.g. severe floods or droughts). Natural systems are adapted to normal seasonal fluctuations but if thresholds are exceeded then they lose functionality.

Often, in the past, the water needs of ecosystems have been poorly understood and seldom considered. Storage secures a reliable provision of water supply to meet demands when and where it is needed and in times of reduced capacity. Storage performs a variety of functions; it allows for the capture of resources for future needs and provides a buffer for emergency or during the aftermath of natural disasters. Storage in natural water bodies contributes to ecosystem goods and services, such as the regulation of water quality and sustenance of aquatic life.

WHAT ARE THE DIFFERENT TYPES OF STORAGE?

Water storage exists in many different forms.

Freshwater storage is an important part of the hydrological cycle and can be both natural and artificial/man-made. Natural systems of water storage co-exist with an increasing number of constructed water storage structures, both small and large, which are built to satisfy human needs (Lindstrom et. al, 2012). Natural storage includes soil moisture, groundwater in aquifers, lakes, rivers and other naturally occurring water bodies. Artificial storage refers to interventions and infrastructure that facilitate the capture and storage of water for immediate or future use and at different locations.

The typology of constructed water retention structures varies from small tanks at the household level, community-based structures, impoundments, dams and reservoirs/tanks within a system or at point of use/consumption. Storage can take place 'at source' or at a different location to the source through varying modalities throughout a watershed or transferred across watersheds, as depicted in the water storage continuum in Figure 2. Storage can be undertaken by a variety of actors, for different purposes including private and public sectors.

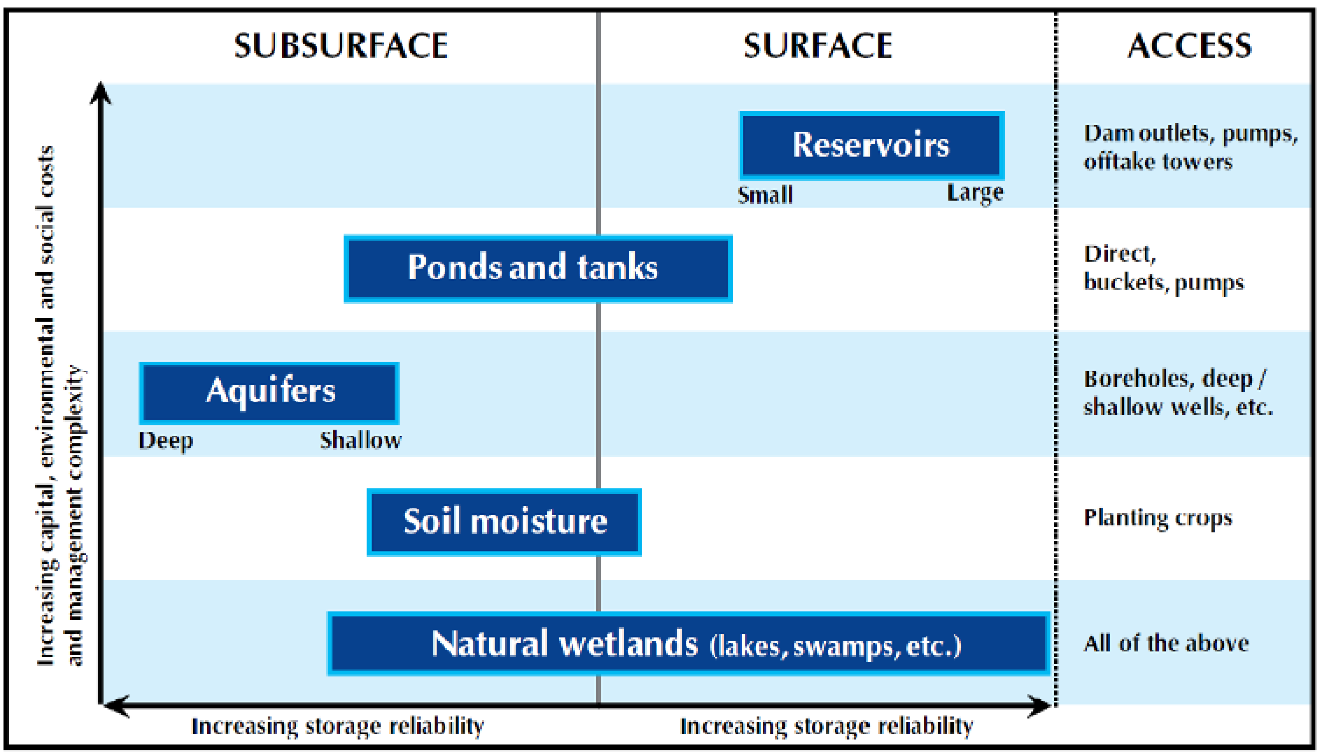

Figure 2. Water Storage Continuum – From McCartney (2013)

NATURAL STORAGE

Surface water resources (e.g. rivers, lakes, wetlands) can provide storage and are of importance in small island developing states.

From islands with no permanent flowing streams to those with navigable inland waters, the insular Caribbean contains a great range of conditions regarding the access to freshwater resources. Because of the variation in topography and size, the ability of islands to retain freshwater also varies widely (Scalley, 2012). Natural bodies of water are important aspects of the storage continuum that are utilized for varying purposes throughout the Region. In fact, many islands directly transfer water from these natural water bodies to customers with little to no intermediary man-made storage infrastructure.

Although they provide storage, the exploitable resources within these natural water bodies are oftentimes not widely characterized or quantified. The assessment of water resources in the Caribbean is often based more on assumptions and extrapolations from climatological data than on hydrometric data measured over long periods (FAO, 2003). Water resources monitoring is at varying stages of maturity throughout the Caribbean.

Figure 3: Lake Antoine, Grenada - used to irrigate banana plantation

Few countries including countries such as Jamaica and Trinidad and Tobago have captured consistent and long-range datasets. Thus, the understanding of the behaviour of the natural water systems and how their dynamic storage varies is not well understood nor their role in maintaining ecosystem services. Yet countries that rely mainly on surface water sources are susceptible to climatic variations as these resources are largely rainwater fed.

Groundwater is important in the Caribbean.

Globally there is more water stored in aquifers than in any other form of storage, it is therefore an important storage medium. In the Caribbean too, groundwater aquifers constitute an important form of storage of water (Fetter 2001; Jones and Banner 2003, Jones et al. 2000). Some countries rely heavily on groundwater for their source of water supply e.g. Jamaica, Barbados and Guyana, whilst in others it contributes to maintenance of base flows in rivers and streams.

Traditionally, groundwater was accessed through hand dug wells for both domestic and agricultural purposes and is still used where access to other sources such as rivers is either restricted or inaccessible. At present, tapping groundwater resources is mostly through drilling wells with accompanying pumping machinery. Groundwater wells require high capital costs to construct and maintain. Wells are also expensive to operate as pumping water from depths into the distribution system is energy intensive. Generally, water utilities in countries such as Guyana and Jamaica that rely heavily on groundwater resources are coincidentally the largest customers of the energy utility sector.

Groundwater reserves are also under threat due to sea level rise (salinization due to seawater intrusion), over abstraction with resultant lowering of the water table, and urban spread into natural recharge zones impeding recharge rates. Lack of proper sanitation systems have also resulted in impacts to water quality and has resulted in the closure of some groundwater resources for potable supply e.g. the Kingston Metropolitan Area, Jamaica. Given these circumstances, water resources development with respect to new drilling of wells has slowed but has not diminished the importance of aquifer storage. More emphasis now is being placed on rehabilitation and maintenance of existing well infrastructure. With increasing variability and apparent decreases in surface water resources, countries such as St. Lucia and Guyana have recognized the need for quantifying their groundwater resources and are moving towards exploration and studies to better understand their behaviour.

Water in soils is a form of storage.

The volume of water stored in soils in the Caribbean is not widely quantified and is much less significant as other water resources but can influence a catchment's rainfall-runoff response. The way water moves in a watershed relies on the topography of the land, soil type, geology etc. as excess water can be stored in a watershed – in low-lying areas or below ground – slowly being released over time during drier periods to rivers and streams. It therefore stands to reason that land use changes in a catchment can influence antecedent soil moisture conditions and a watershed's hydrological response to a specific precipitation event. Much of the Caribbean is characterized by small hilly islands with small natural catchment basins or watersheds and rapid-rainfall runoff responses. Adding to this is the soil salinization on extensive hectares of irrigable lands on the coastal plains of Caribbean islands such as Jamaica and Trinidad. Salinization is the increase of salt concentration in soil and can be caused by dissolved salts in the water supply used for irrigation, sometimes from sources impacted by saline intrusion due to over abstraction of groundwater wells.

MANMADE STORAGE

Constructed storage is important as a water management strategy.

Historically people have settled in areas with easy access to water, as such settlements have developed around natural water bodies i.e. springs, rivers, lakes etc. This has changed over time where settlements, farming and trade have spread into areas that are not always close to water resources – the dilemma of water not being where it is needed to support human activities. To overcome this, societies have developed a range of solutions of which the development of water storage and distribution systems are significant examples. As population needs extend, humans have constructed a broad variety of water retention structures at a variety of scales to capture this vital resource. The proven options for enhancing potable water availability in islands is through: roof top collection; desalination plants; treatment and recycling of wastewater, run of the river schemes, dams, impoundments with each of these options fitting into particular demands and have a unique price point. Larger water storage systems i.e. reservoirs and dams have been largely underdeveloped in the insular Caribbean. Population centres are often not perceived to be large enough to warrant the high capital costs associated with constructing and maintaining dam infrastructure.

There are very few freshwater reservoirs/dams in the Caribbean as many of the islands are shaped by rugged and steep topography which offers limited opportunities to construct large storage infrastructure. Dams, impoundments and their associated reservoirs, provide the ability to store water for later use, provide hydropower and provide some level of protection from extreme precipitation events (FAO Aquastat). Large reservoirs do exist for example in Cuba, Hispaniola, Jamaica, Puerto Rico, and moderately sized ones in other islands such as St. Lucia and Dominica (Geoghegan 2002) (See Table 2). These surface water storages can be unpredictable and unreliable in the dry season.

Figure 4: Water pond for cattle on Carriacou, Grenada

Some islands have outgrown the peak output capacity of their run-of-the-river schemes and would benefit from increased storage retention. There are, however, perennial problems associated with financing construction, operation and maintenance of dam infrastructure. Added to this are challenges with high levels of siltation due to the removal of land cover in the upper watershed above reservoirs. The outcome of which is a loss of storage capacity. The loss of capacity is felt the greatest during drought conditions when water inflows into the storage facilities can be reduced by up to 90%.

Figure 5. Potwork Damn, Antigua

Figure 6. Mona Reservoir, Jamaica

Table 2. Profile of Water Supply Reservoirs and Dams in the Caribbean

COUNTRY	NAME	Surface Area (hectares)	Storage Capacity (Millions of m^3)	SOURCE	USAGE
Antigua	Potwork Dam (Figure 5)	2.43	4.142	Rainfed	Water utility
Jamaica	Mona Reservoir (Figure 6)		3.675	Hope and Yallahs Rivers	Water utility
	Rio Cobre Damhead			Impoundment on Rio Cobre River	Irrigation and water utility
	Hermitage Reservoir		1.789	Wagwater River impoundment	Water utility
St. Lucia	John Compton (formerly Roseau Dam)		2.6	Roseau River impoundment	Water utility
Trinidad and Tobago	Navet Reservoir	324	19.1	Dam of Navet River and tributaries	Water utility
	Hollis Reservoir		4.75	Dam on the Quare River	
	Caroni-Arena Reservoir	680	46.6	Small weir on the Tumpuna River and an earthfill dam across the Arena River; water pulled from river during wet season for reservoir storage and pumped back to Arena river during dry season when river levels are low	
	Hillsborough Reservoir		1.02	Impounding reservoir	

Hydropower and pumped storage.
In the insular English-speaking Caribbean only Dominica, Jamaica and St Vincent have operational hydroelectric power generation schemes. Belize (54MW), Cuba (66MW), Dominica Republic (616MW), Guadeloupe (11MW), Haiti (61MW) and Puerto Rico (100MW) all have hydropower schemes.
In Jamaica there are 8 schemes with a total installed capacity of 23MW, of the 8 the largest is Maggoty Falls in St Elizabeth parish which was upgraded to 7.2 MW and commissioned in 2014. The remainder are on the White River (2), Roaring River, Rio Bueno (2), Rams Horn and Constant Spring. In Dominica there are three cascading run-of-the-river power plants on the Roseau River with an installed capacity of 7MW, whilst on St Vincent there are five hydropower at three locations with an installed capacity of 5.6MW.

In the past, hydropower in Dominica and St Vincent contributed a significant part of the electrical capacity. However, hydropower has since declined in importance with respect to generation and now contributes between 25% to 35% of the total in Dominica and 16% in St Vincent. The amount generated depends on the flows in the rivers on which the plants are located. All of the hydropower plants are run-of-the-river schemes and typically consist of a weir across the river which allows water to be diverted to an intake structure taking water via a pipeline to a power generation station and returning the water to the river. Most of these plants are in the upper parts of the catchment to be able to create enough static heat for power generation.

A problem experienced by all the schemes is that the amount of electricity that can be generated depends on the flow in the rivers. Flow that varies between seasons and across years. The result is that power generation can vary by as much as 50% between the wet and the dry season. This situation could be alleviated by creating storage by building an impoundment structure to capture and store more water and even out the seasonal and inter-annual fluctuations. However, creating dams on rivers is a complex and costly undertaking and given the challenges involved for the potential additional generating capacity when weighed against the cost of other alternatives, it is unlikely that there will be significant development of further hydropower in the Eastern Caribbean. Indeed, with the potential effect of climate change on river flows, it may be that hydropower will continue to decline in importance.

Belize is an exception, partly due to economies of scale when it comes to building dams and hydropower schemes and partly due to politics. Belize wanted to free itself of being dependent on imported power from Mexico and set about diversifying and domesticating its power generation, such that now hydropower contributes 50% of its power needs and only 30% is imported. Belize has constructed a number of dams for hydropower, principally a cascade of 3 dams on the Macal River, two run-of-the-river schemes: one on Booth's River in the north and HydroMaya in the south of the country, and is actively looking at further hydropower impoundment potential in the central part of the country. It can do so because a combination of terrain and rainfall favours the development of dams with large impoundments. This suggests that the development of storage dams for hydropower generation in the Caribbean is likely to be limited to those countries which have significant river flows and the potential to develop sufficient storage to make them viable. And, as in the case of dam construction in Belize, developers will face stiff opposition from environmental groups.

Figure 7a. Chalilo Dam, Belize

Figure 7b. Chalilo Dam, Belize

How much storage is needed in water distribution networks?

In the same way that the cyclical fluctuations in supply from surface water resources often require some form of balancing storage to even out the highs and lows, so too do water distribution networks.

Water distribution networks are designed to meet the water consumption needs of a range of different customers and consumers. These needs vary depending on the type of consumer and their water use characteristics. Fluctuations occur at different timescales from hourly to annual and from year to year.

Storage in distribution networks is provided to enable the system to meet the periods of peak consumption, to provide for fire-fighting needs and, ideally, to provide contingency storage for when supply interruptions occur. How much storage depends on the number of customers, their consumption needs and for how long the storage should be able to meet those needs. In this respect, information on interruptions would provide valuable input into quantification of required storage volumes.

A typical standard is to provide storage equivalent to 24 hours of average demand, noting that anything over a day's storage is going to be expensive to provide. It has been noted that whilst there is an intention to have the equivalent of 24 hours' storage, often increases in demand have served to reduce that standard. A possible measure is to increase connectivity between different sources and storage reservoirs to allow water to be transferred in the event of say equipment failure or pipeline bursts.

This though is not always possible. An increasing concern is how to address the impact of extreme events such as hurricanes on water distribution systems. Hurricanes such as Maria which hit Dominica in 2017, damaged water intake structures and washed away trunk mains connecting the intakes with in-distribution system storage reservoirs. The minimum recovery time to get water systems functioning is around 14 days, during which time water supplies into a distribution system are extremely limited.

Under these circumstances storage becomes extremely important. In response, Dominica is aiming to provide for at least 3 days' storage for communities in the event of a disaster and to restore water to 60% of the population within 7 days.

Under normal circumstances the suggested applicable storage volume would be 24 hours of normal per person consumption for the population to be served. However, under emergency conditions, consumption would have to be constrained and supplies restricted. In this event, the required storage volume would be whatever the number of days of restricted supply is to be at the restricted per person consumption rate.

Given the recent experiences of regional water utilities with drought conditions and the impact of rapid onset extreme events such as hurricanes, there appears to be renewed interest in the provision of storage in water distribution systems. The ability to finance upgrades is a serious constraint and water utilities are having to make hard decisions on how to motivate and prioritise their capital investments. In this respect, information on the nature and causes of interruptions would provide valuable input, providing a rational and evidenced based basis to support decision-making.

WATER STORAGE CHALLENGES BEING FACED IN THE CARIBBEAN

The effectiveness of human-made storage is a function of natural storage and catchment characteristics.

The specific catchment characteristics that influence runoff generation and soil erosion are vegetation, soil, land management, geology, slope and catchment size (Chorley 1969). Healthy watersheds offer multiple environmental services including the regulation of water flow, natural filtration, enhances the chemical properties of water and sediment control. In the same breadth watersheds attract investment opportunities including industries, agriculture ranging from slash and burn practices to small and large farming, tourism, housing and other developments. These are not always strategically interwoven within the watershed system to protect its ecosystem services. The approach to water resources management has broadened over time as we recognize the interdependence between the built and the natural environment.

Freshwater storage construction and upgrades can be high capital investments and to have these become obsolete due to degraded water quality from its source would be an extremely poor use of scarce resources. With poor land management practices and little source water protection, water quality is rapidly impacted and leads to increased cost for treatment as well as increased system operation and maintenance costs. Some islands through their environmental regulatory arms are taking mitigating actions to identify emerging contaminants and use their development approval process to stipulate the wastewater treatment, requirements for housing, industries etc. towards source water protection. These are also now embedded in law e.g. Jamaica's Water Resources Act speaks to Water Quality Control Areas. Unsustainable land use practices within watersheds also lead to degraded water quality, through increased silt loads and mobilisation of nutrients and other contaminants.

Sustainable Land Use Management clearly has a role to play in mitigating the adverse impacts. A typical approach has been through trying to implement protection measures restricting human activities in watersheds. However, these have often proven to be ineffective and difficult to enforce.

The growth of housing developments in Trinidad's Northern Range, the development of quarries and inappropriate agricultural practices have all contributed to adverse impacts on stream and river flows, water storage and water quality, pointing to a need to consider Integrated Water and Land Use Management as two sides of the same coin. Integrated Water and Land Use Management are however, easier to implement in theory than in practice – there are few examples of successful integration. Investments in watershed management is critical for the long-term sustainability of downstream storage infrastructure.

Poor water quality can put a strain on natural water bodies and relegate these sources to secondary usage or result in an entire source being unusable.

Natural surface water storage in wetlands, rivers etc. quickly respond to stressors within an unhealthy watershed. Take for example, the Fond D'Or Watershed that is the second largest watershed in St. Lucia and is the source of drinking and recreation water for approximately 7500 residents (St. Lucia Statistics Department, 2001). There have been concerns of deterioration in the quality of the Fond D'Or River water by numerous anthropogenic activities that rely on the same source of water particularly for livestock rearing.

Comparatively, groundwater resources are less susceptible to water quality degradation than surface water resources from anthropogenic pollution and turbidity impacts from storm events. However, in areas of poor sanitation systems and uncontrolled discharge of industrial effluent, groundwater resources are impacted. As groundwater sits below the subsurface and can be out of sight, out of mind, it is harder to track when impacted and more difficult and expensive to remediate. For example, the Kingston Basin in Jamaica is home to 40% of the population but only accounts for 1.5% of the water allocated by the Water Resources Authority (WRA) due to unusable wells from high nitrate levels from little to no sanitation systems in the past and high chloride levels from over pumping. This puts a strain on aquifer reserves with ensuing water shortages especially during drought periods.

Figure 8.
Dominica's Post Erika and Maria an Infrastructure Damage

An effective legal and regulatory framework are mechanisms to protect water resources availability.

Countries with an active and effective license permitting and allocation system have seen reduction in indiscriminate abstraction of resources. A caveat to this is that in many instances there is a flat fee for a license to abstract, which does not account for the overall volume abstracted and in turn the economic value of water. To counter these loopholes, WRA, Jamaica has implemented the volume-based fee system in 2017 that has shifted the traditional flat fee for a license to abstract water to a tariff type system where abstractors (including government run utility agencies) pay annually for the actual water abstracted from a permitted source. To give a clearer picture of the magnitude of the change in the fee structure, the initial flat fee was $410 USD ($60,000 Jamaican dollars) regardless of permitted volume; paying per volume abstracted can now be in the order of millions of Jamaican Dollars for large abstractors with multiple sources.

The WRA Act also gives the power to reduce license allocation where an abstractor is consistently using well below the permitted volume. The impact of this change is still being monitored and may not have translated into maximum aquifer benefits as yet as regularization by previously unpermitted abstractors is still ongoing. It is however the intention that this will drive greater water use efficiency through the implementation of innovative technology and strategies especially in the private sector where profit is the bottom line. These allow for more resource availability for natural storage and reservoir systems.

Loss of reservoir storage capacity is an issue.

Siltation on the Mona reservoir, one of the largest in the Greater Antilles, has decreased its capacity for storage by as much as 22% like many reservoirs throughout the Caribbean. In 2015, the International Development Fund provided funding to the Government of Jamaica for a focused set of pilot intervention areas identified to reduce deforestation pressures and improve soil/land management on agricultural areas above the National Water Commission's water intakes in the Hope-Yallahs Watershed which is the major flow contributor to the Mona Reservoir.

In 2010 and again in 2013 major storms created large landslides within the reservoir area of St Lucia's John Compton Dam. This resulted in a reduction of the capacity by 30% and the blocking of the lower intake level, further restricting what could be abstracted from the dam. The reduced storage and abstraction capacity have been a severe challenge to the water utility as it is the main source of supply for the northern half of St Lucia, home to the capital Castries, the area where a majority of the population lives and the location of many of the tourism facilities. In May 2020, St. Lucia's government declared a state of emergency due to the worsening water crisis as the Dam storage was depleted by the severe drought conditions. It is only in 2020, 10 years after the first loss of capacity that desilting work has begun. In part because of financial constraints and in part due to technical difficulties.

A pervasive issue that Caribbean water utilities continuously grapple with is the issue of non-revenue water from leakage through storage and distribution networks due to limited infrastructure maintenance, theft and unmetered sources. Non-revenue water is treated and distributed but does not contribute to the utilities' income. Some countries including Jamaica and Guyana are advancing towards addressing these issues through technology applications with on site meter reading and verification and accessing grants for capital upgrades. However there is still some way to go considering there is also limited inventory of the storage and distribution systems and their associated attributes.

Is there a missed opportunity for increased water security through dam and reservoir construction?

Many of the surface water fed supply schemes (e.g. in Grenada, St. Vincent and the Grenadines, St. Lucia and Dominica) were developed as run-of-the-river schemes. A part of the river flow is diverted and used as the source of supply. A typical supply system comprises a simple intake structure, a gravity fed supply line, a concrete or metal storage tank and gravity fed distribution pipelines with rudimentary primary level water treatment of screening for sediments followed by chlorination. Where base flows are greater than the amount being diverted this means of supply is perfectly adequate. Difficulties arise when the proportion of the flow being diverted becomes a significant part of the total flow. This can happen during the dry season or even more seriously during prolonged drought events.

This has been happening in some countries and has a twofold effect. The first is that supply is not able to satisfy the demand. This can be alleviated by introducing measures to decrease demand. The second is that reduced downstream flows have an adverse impact on ecosystems and on downstream users. It can sometimes be possible to retain water during periods of higher flow to provide some balancing out of the dry season flow. Adding storage capacity, if possible, would provide a way of regulating flow. As noted above, some countries have invested in dams to create storage, which means that they are better placed to cope with fluctuations.

Examples include the John Compton Dam in St Lucia and the Navet and Hillsborough Dams in Trinidad and Tobago. Here increased storage has added increased 'resilience'[1]. There is further multi-functional value in dams and reservoirs as displayed by the Rio Cobre system in Jamaica as an example of multi-use. Water is impounded on the Rio Cobre river for both irrigation and domestic supply; this structure also assists with regulating flow during extreme rainfall events. The cascade of dams on the Macal River in Belize not only store water for hydropower generation but also perform a flood control function.

However, these are large and costly structures with associated environmental impacts. They are not options that can be applied to the many small, run-of-the-river schemes on which many communities rely. It may in some cases be possible to create some additional storage but given the often paucity of flow discharge data, the challenges in calculating the potential safe yield and ability to meet demands, construction difficulties and the costs involved suggest that this option is going to be difficult to pursue. An added and emerging question is how to incorporate the impact of climate change.

Climate change will impact all forms of water storage – but by how much?

Climate change will invariably affect the function and usability of man-made and natural storage systems, albeit not all in the same way. Decreases in annual rainfall totals will reduce inflows to reservoirs and recharge to groundwater systems. Aquifers along the coasts have started to feel the impacts of saline intrusion based on sea level rise. The Caribbean accounts for seven of the world's top 36 water-stressed countries with Barbados in the top ten (FAO, 2016). The Food and Agriculture Organization defines countries like Barbados, Antigua and Barbuda, and St. Kitts and Nevis as water-scarce with less than 1000 m3 freshwater resources per capita. As the climate changes so are the increases in economic development, population growth and overall water demand which further exacerbates the situation. Infrastructure completely dependent on surface water resources in drought prone areas may feel the greatest shock, seeing some storage options becoming virtually unfeasible. Conversely, areas with projected increases in rainfall may become more important as catchment areas for reservoirs.

The severity of the 2009-2010 drought conditions highlighted deficiencies as significant losses were felt in key economic sectors throughout the Caribbean as infrastructure at the time were inadequate to buffer the impacts. This uncertainty jolted policy makers, water managers, the private sector and the general populace into evaluating new approaches to water resources management that underscored the value of storage based on the deficits experienced. St. Lucia's only major reservoir was depleted with impacts to 50% of the population, tourism and business sector; Antigua's largest surface water impoundment, the Potswork Dam was completely dry by March 2010; Grenada shipped 340,000 litres of drinking water to its dependency, Carriacou; in Barbados the Water Authority activated Stage 1 of its Drought Management Plan in March 2010 as a response to low aquifer levels; Trinidad's Caroni Arena and Navet reservoirs fell to almost half their usual volumes in April 2010 prompting farmers to pay a fee to WASA to extract water from rivers; by April 2011 Cuba, reported to be at one-fifth of their reservoir capacities with poor, leaking pipe networks exacerbating the situation; Jamaica, Dominica, and St. Lucia, reported significantly lower than normal flows in many of their streams (CIMH, FAO, 2016). This period also represented a paradigm shift in self sustainability and water use efficiency at thehousehold level.

[1] The Intergovernmental Panel on Climate Change (IPCC) defines resilience as "the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner." (IPCC, 2012).

Table 3. Climate Change Risks for Different Storage Types and Possible Socio-Economic Implications

Storage type	Risks associated with climate change	Social and economic implications
Reservoirs	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing the rate of reservoir depletion • Infrastructure damage due to higher flood peaks • Improved habitat for disease vectors (e.g., mosquitoes) • Increased risk of eutrophication and salinization • Increased siltation	• Increased failure to meet design specifications (irrigation and hydropower generation, etc.) • Increased costs due to the need to redesign infrastructure (e.g. spillways) • Increased risk of waterborne diseases (e.g., malaria)
Ponds/tanks	• Reduced inflow, resulting in longer periods between filling • Higher evaporation, increasing rates of pond/tank depletion • Infrastructure damage due to higher flood peaks • Improved habitat for disease vectors (e.g. mosquitoes) • Increased risk of eutrophication and salinization • Increased siltation	• Increased failure to provide water requirements of the community and households • Increased labor requirements and costs to repair structures • Increased risk of waterborne diseases (e.g., malaria)
Aquifers	• Reduced recharge, resulting from modified rainfall intensities • Reduced recharge, resulting from land-cover modification and increased soil moisture deficits • Saline intrusion in aquifers near the coast	• Falling water levels make it increasingly costly to access groundwater • Poor water quality makes groundwater unsuitable for use
Soil moisture	• Reduced infiltration, resulting from modified rainfall intensities • Waterlogging, resulting from modified rainfall intensities and duration • Longer dry periods, resulting from altered temporal distribution of rainfall • Depleted soil moisture, arising from higher evaporative demand • Soil erosion, resulting from modified rainfall intensities and duration • Reduced soil quality (including water-holding capacity and nutrient status), resulting from modified rainfall and temperature	• Decreased productivity – more frequent crop failures and reduction in yields

Modified from McCartney et al., 2013

The Region has been facing more severe and frequent low rainfall/drought episodes since 2010/11 with the situation increasing in intensity arguably since 2016. The 2020 calendar year has been no different with The Central Water and Sewerage Authority's (CWSA) in St. Vincent and the Grenadines (SVG) imposing water restrictions as a result of drought in May. Rainfall for April 2020 was 60 per cent below the average monthly figure, while rainfall in May fell from 248mm in 2019 to just 48 mm in 2020 translating to low flow in rivers in SVG. Saint Lucia declared a "water emergency" on May 18, 2020.

The Meteorological Service, Jamaica predicted a drier than normal period up to April 2020. In response, the Government of Jamaica announced strategies to renovate 20 catchment tanks systems and to install additional rainwater harvesting systems at 38 schools.

Interbasin transfer of resources to reservoirs can positively or negatively impact socio-economic development at the local level.

Let's consider the practice of shifting resources from one municipality to meet the demands of a larger rapidly developing urban space. In Jamaica, the allocation of the water by hydrological basin is negatively correlated with population density. The main source of water for decades to the Kingston Metropolitan Area (KMA) has been from the adjacent basins via the Rio Cobre river pipeline system and the Yallahs River via the Mona reservoir. The Yallahs River is the major surface water resource in the parish of St. Thomas. Water is captured in the upper regions of the Yallahs River and sent to the Mona Reservoir with little flow beyond the abstraction point to serve communities on the St. Thomas plains. Arguably, this has contributed to the slow socio-economic development within St. Thomas.

On a somewhat different scale Barbados may be said to operate a mini inter-basin transfer system by virtue of having a water distribution system that covers the whole island. In theory this allows it to switch sources of supply, whether groundwater or desalination, between distribution areas as a need may arise.

A growing water storage gap.

The amount of water available to us is not infinite and as the pressures of development, demographic changes and climate change become more evident, water will become an even more valuable and potentially even more scarce commodity. Within this framework, the current and future state of storage is not always highlighted. This is in part because to date water planning timescales have been measured in years as opposed to decades, biasing short-term expediency over long-term provision. One way to think about this is by considering future trends in the available supply, consumptive demand, uncertainties and variability, and what mechanisms to cope with these factors can be put in place. The gap between water is available and what is needed already exists and is expected to widen over time. The role of water sharing mechanisms has been discussed by Young (2019) but sharing too has a degree of reliance on storage in its many forms.

The provision of water storage is a complementary mechanism; not only should available supply be greater than the demand but there should be additional 'headroom' to account for natural fluctuations. Looking ahead it is highly likely that the water storage gap is growing in the Caribbean as population and industries expand, water resources decline as a result of human activities altering the water cycle and current storage capacities are diminished. Developments are growing in areas that have outgrown their current storage capacity or have little to no storage.

The gaps in storage will likely worsen as we experience more severe flooding and damages to infrastructure. The economic cost of the storage gap is alarming. Caribbean islands that are dominated by many small-scale community-based storage systems have not adequately mapped these and factored them in the storage continuum. In determining our water storage gap, we must first address current knowledge gaps, data gaps and issues on an ongoing basis considering that the storage gap is dynamic and available storage is likely decreasing. In other words, there is a potentially escalating critical uncertainty around long term water planning of which storage is an important consideration.

RESPONSE TO STORAGE CHALLENGES: PRACTICAL STORAGE SOLUTIONS

Storage solutions can provide multiple benefits but also have their disadvantages.

We have explored in previous sections the types of storage systems, characteristics and performance indicators, as well as, their potential risks to climatic shocks. Manmade infrastructure generally is pushed by technocrats and politicians alike as the solution for meeting all water demands. While we agree with the importance of these, we are missing an important link and opportunity for quantifying and maximizing the potential from nature-based solutions especially considering the high capital cost of structures and their susceptibility to damages from extreme weather events.

The United Nations World Water Development Report in 2018 advocated for Nature-based Solutions for Water (NBS). NBS use or mimic natural processes to enhance water availability (e.g., soil moisture retention, groundwater recharge), improve water quality (e.g., natural and constructed wetlands, riparian buffer strips), and reduce risks associated with water-related disasters and climate change (e.g., floodplain restoration, green roofs) (UN, 2018). Diversifying storage options through employing an appropriate mix should be examined when looking at the overall strategy to meet water demand. An integrated approach to storage requires conceptualizing storage as a provider of services rather than as a collection of individual storage facilities.

In principle, NBS for water has the potential to tackle many water resource management challenges, simultaneously contributing to both climate mitigation and adaptation and delivering multiple benefits for people and nature (UN 2018). NBS are however largely understudied and undervalued throughout the Caribbean. NBS remains under-utilized as water management remains heavily dominated by traditional, human built infrastructure.

Given groundwater's importance, it can be anticipated that Managed Aquifer Recharge (MAR) will increase in importance as one of the approaches to enhance water security in the Caribbean.

Groundwater recharge occurs when precipitation percolates through the soil layer into the unsaturated zone and into the underlying aquifers where it is stored (Lerner and Harris 2009). Recharge may take place remote from where water is abstracted, relying on flow through the aquifers, Guyana provides an example of this, the area where recharge of the coastal aquifer takes place is at least 35 km away from where water is abstracted. The process of aquifer recharge depends on a variety of variables such as the nature of the rainfall events, soil type, land cover and use, topography, catchment area, and natural variability between seasons and years. Changes in any of these will have an impact on recharge and hence the availability of groundwater.

The goal of aquifer management should be that the volume taken out should not be more than the recharge – which is where the importance of licenses and permits plays a major role. Obviously, there are many challenges in determining what that amount might be. Changes in the variables that govern recharge complicate the situation further. Amongst these, changes in land use particularly conversion to built-up areas (roads, buildings, car parks etc.), climate change and variability have the greatest impact on reducing recharge. One way to overcome this is through Managed Aquifer Recharge (MAR) (Dillon et al. 2014) or as it is sometimes referred to as Aquifer Storage and Recovery (ASR).

Although not widely practiced in the Caribbean, globally there are many examples of the practice (Page et al. 2018) and there is growing interest in the technique (Daus, A. 2019). In Jamaica a MAR project was initiated in 2016 and commissioned in 2017 with financing from the Inter-American Development Bank using surplus irrigation water from the Rio Cobre basin to reverse seawater intrusion, increase aquifer storage, and alleviate water restrictions during drought. In 2010, the Caribbean Environmental Health Institute (CEHI) in collaboration with the Antigua Public Utilities Authority (APUA) put forward proposals for MAR in Antigua to increase domestic water supplies (CEHI, 2010). Barbados' practice of constructing agricultural drainage wells to control flooding and reduce crop losses is also a form of aquifer recharge, although not their primary purpose. With the changes in farming practices, many of the drainage wells have not been maintained and have ceased to function.

Given the recent run of years of below average rainfall, policy makers in Barbados are looking at various means of boosting ASR. These include; restructuring the subsidies to farmers to maintain drainage wells so that there are greater incentives, encouragement of tilling practices to prevent the development of hardpan and encourage infiltration, utilising rainwater harvesting particularly in higher rainfall areas to improve groundwater recharge rates, limitations on impervious surfaces, infiltration of domestic stormwater in shallow on property wells, and infiltration of treated wastewater. Exactly how much of an impact these measures might have, and their cost effectiveness would have to be determined. Those areas that rely on groundwater aquifers for their water supply, and that are experiencing decreasing yields will have some challenging choices to be made as to how they might address the issue.

Guyana is highly endowed with water resources, mostly from surface water sources. High treatment cost of surface water sources resulted in Guyana meeting approximately 90% of its water demand to residents within the Coastal region from groundwater. The coastal aquifer is estimated to have an area of 18,000 km2, with 13,000 km2 of recharge area and 1,890 mm/year of precipitation (Ministry of the Presidency, 2013). This coastal groundwater system has three known aquifers and is also a transboundary aquifer with Suriname to the east and Venezuela to the west. Abstraction has almost doubled within the past ten years while demand varies from region to region along the coast (Franklin, 2020).

GWI (personal communication) has indicated that there is no imminent threat to saline upcoming in this coastal aquifer. However, with projected abstraction rates and the thinner nature of the aquifer along the fringes, a proactive approach is being taken in conceptualizing a managed aquifer recharge project as a mitigating measure to reduce the potential reduction in water levels. The Essequibo river would be the source of water for this MAR. It is proposed that the MAR would be in the natural recharge zone of the coastal plains.

Managed Aquifer Recharge is not a silver bullet to increasing groundwater storage;

There are many technical, operational, regulatory and economic questions to be answered. There is a requirement for a consistent and practical throughflow of water delivered to the MAR system to achieve substantial water recharge and improved water quality. The MAR project in Jamaica is highly dependent on flow from irrigation canals after the National Irrigation Commission has met the water supply for their customer base.

One of the challenges identified during the conceptual stage of the project was the ability to maintain a recharge and abstraction schedule that maximizes the recovery of recharge water. Anecdotal and some ad hoc data exists which gives early indication that the MAR may be achieving increasing groundwater storage in the Lower Rio Cobre Basin while pushing back the saline wedge. These results are not properly documented as the targeted and consistent pre- and post- groundwater monitoring regime was not implemented as initially planned. The Water Resources Authority has recognised this and formalized arrangements for an ongoing monitoring program with maintenance of the system by the Rural Water Supply Limited. They are taking an additional step to seek funding from the International Atomic Energy Agency to enhance monitoring using isotope hydrology techniques. MAR must be integrated with other water resources management strategies to realise the full benefits.

Irrigation water demand was reduced in the Lower Rio Cobre Basin due to a more efficient system as such some wells have been abandoned. Additionally, the Water Resources Authority (WRA) had placed a moratorium on groundwater abstraction from the Lower Rio Cobre Limestone aquifer and strictly enforcing the Water Resources Act's clause which states that there should be no pumping less than 1 metre above sea level. These factors most likely have contributed to driving back the saline wedge significantly.

Contrastingly Guyana will require a far greater understanding of their coastal aquifer system towards implementing an effective MAR project. There is an understanding of where the recharge areas are but there is no formal protection of these zones in terms of permitted development, legal designation etc. which means they could be vulnerable to human activities and impact the intended outcomes. Understanding the aquifer behaviour is very poor because there is very little data including information on recharge rates. GWI must take a holistic (eco-hydrological) approach to understanding the adjacent aquifer system in addition to the coastal aquifer, so there is probably some saline intrusion in the upper aquifer but if and when this affects the lower, exploited aquifer is unknown. There have been suggestions that GWI should scale back groundwater abstraction and make greater use of surface water for water supply and use the oil revenues to do this. With respect to Region 1, additional monitoring is required to understand current and project drawdown levels and the impacts from transboundary usage. This has been recognised and there is growing interest in the transboundary aquifer with Suriname and there are two potential projects being looked at, one with GEF.

In Barbados, the evidence that drainage wells make a noticeable addition to water resources is anecdotal as there has been no systematic hydrogeological investigations. It is certainly true that the drainage wells are successful in minimizing flooding and crop losses. Exactly how much of an impact the proposed measures might have and their cost effectiveness would have to be determined.

In addition, an effective system of monitoring and regulation to avoid 'gaming' of the incentives will need to be developed. However, the greatest hurdle to overcome will be getting the landowners and managers on board and willing to participate.

Rainwater harvesting as a water storage strategy.

Rainwater Harvesting (RWH) as a means of providing water for domestic and other purposes has a very long history going back millennia. Up to today, RWH continues to play an important role in water supply in countries across the Caribbean and in some places is the sole source of potable water supply. In the late 2000's Global Water Partnership-Caribbean (GWP-C) together with the Caribbean Environmental Health Institute (CEHI) championed and promoted RWH through a series of studies, papers, projects and outreach activities, building up a portfolio of best practices and practical advice. The principal focus was domestic water supply. One of the arguments put forward for RWH it is an adaptation strategy building resilience to climate change. At the same time the Food and Agricultural Organisation (FAO) started a similar promotion of RWH to support agricultural development and also as a climate adaptation strategy. More recently, there has been a change in emphasis. Whilst recognising that RWH has a role, the motivation for its promotion and adoption is that it can be a means of increasing resilience in the face of extreme events that disrupt utility water supplies and address overall issues of water security. The impetus for this may be traced back to the impact of Hurricane Tomas in 2010 and the Christmas Storm of December 2013 which led to widespread disruption of water services, particularly in St Lucia.

Accordingly, RWH at the household level provides a degree of insurance in the form of a back-up water supply for those occasions when the impact of extreme events or operational issues lead to prolonged interruptions in water supplies. This argument has been taken up and acted on in a variety of instances. In Dominica, RWH is being incorporated into community emergency shelters, PAHO has championed RWH as part of climate smart clinics and health care centres, in Trinidad and Tobago the National Institute of Higher Education, Research, Science and Technology (NIHERST) has been supporting the RWH installations in schools and community centres which act as disaster shelters for water scarce communities, and in St. Kitts and Nevis 17 RWH systems have been installed to ensure water security in vulnerable schools. Recently the Caribbean Community Climate Change Centre (CCCCC) helped in the rehabilitation and cleaning of community RWH & cisterns in the Grenadines. In Jamaica, several UN Agencies are working with the Government of Jamaica to support RWH in schools, farms, health clinics and community centres.

Whilst there are many handbooks and practical 'How to' guides for designing and implementing household RWH systems the uptake has not been what has been hoped for. Even in those jurisdictions where there are statutory requirements to install storage for rainwater, such as in The Bahamas, Barbados, etc. the actual use has been low. The issue is then not one of technology but rather of cost, maintenance, a lack of interest, and of incentives. The above examples highlight that to date the introduction of RWH schemes has relied on grant aid funding. There has been some concern on the part of health authorities concerned that improperly installed tanks could pose a public health risk and a breeding ground for disease spreading mosquitoes. To overcome this a recent study coordinated by CARPHA and funded through the Pilot Program for Climate Resilience investigated ways in which the costs of implementation could be mitigated, best practice developed, and making the argument for uptake at the household level.

This responds to the increasing realization of the need for incentives at the household level, for there to be building standards and codes of practice governing the installation of systems, and for there to be a robust system of public health surveillance. There has to be a clear responsibility for the operation and maintenance of RWH systems. Without these, the long-term sustainability and safety of RWH systems would remain open to question. A UN Human Security Trust Fund Project in Jamaica is also working to develop training materials specifically targeting end users and consumers.

Traditionally, water utilities have been reluctant to become involved with the provision of RWH systems, seeing them as a form of competition. After all, they are in the business of selling water to customers and widespread introduction of domestic RWH systems could impact their revenue streams. However, there are developments which are worth mentioning that illustrate that there could be a change in attitude. In Barbados, the water authority is seeking to roll out a Personal Tank Programme (PTP), as a response to interruptions in supply and hence to ensure water availability to affected households.

Figure 9. Rainwater Harvesting, Grenada

The PTP has two strands, one to support vulnerable households and the other to make low cost financing available to encourage uptake through a revolving fund. The catch is though that this is a loan which must be repaid, there are no other financial benefits, rebates or other incentives offered; households still must pay their water bill, interruption or not. Whilst some have suggested that this could be an extension of services provided by utilities, based on experience to date, only better off and sustainability minded households are likely to invest, in the absence of regulatory or financial incentives.

An alternative approach, which has not yet been trailed, might be for water utilities to consider RWH as a climate change adaptation in the form of distributed storage.

Climate change is expected to decrease water availability from existing sources and to increase variability, whilst water demand is anticipated to increase in most countries. Water utilities have several response options; whilst not dismissing the role of demand management for the supply side this means looking for additional sources.

Figure 10. Rainwater Harvesting, St. Lucia

Each of these has a cost, a potential yield and reliability. In circumstances where the economic cost of developing distributed storage harnessing rainwater is lower than other alternatives then this should be seriously considered as an option for a water utility. The implication being that the cost of implementation would be borne by the utility. Indeed, it could also be the case that households agreeing to participate would receive some form of incentive along the lines of a renewable energy Feed-in Tariff, for offset domestic use. For the utility, the potential benefits, apart from deferring the need to develop new sources, could be a reduction in operational costs such as treatment and energy. Of course, there are many caveats that would have to be addressed, the existing concerns over RWH among them, and as with innovation many issues to be addressed.

The harvesting of rainwater has been with us for a very long time. Traditional approaches whereby it forms part of household storage and supply look set to continue, and with growing concerns over climate change and water scarcity interest and uptake may well grow. However, there is at the same time an emerging, state-led approach which sees RWH as a disaster–resilience and risk reduction measure to support communities. Lastly, there is the transformative approach, outlined in the two paragraphs above, which redefines RWH as a business opportunity for water utilities to extend the scope of services they provide to customers and consumers. In this, water storage is reconceptualized from being a matter of private initiative at an individual level to a public initiative at the corporate level.

There is the push for rainwater harvesting systems to be mandatory in building codes. For example, by law all new houses must be equipped with rainwater storage infrastructure in Antigua and Barbuda, US Virgin Islands and Barbados. Further to this Jamaica's draft Rainwater Harvesting Planning Policy Guideline when approved by Cabinet will give local planning authorities direction on rainwater harvesting system to be included in building plans as a condition for approval for new residential and commercial constructions. Currently the National Environment Planning Agency in Jamaica in their development approval process recommends that all developers include plans for RWH systems for the environmental approval process and furthermore it is specifically mentioned in Jamaica's National Water Policy and Implementation Plan (MEGJC, 2019).

Private Sector must be engaged in the water supply/storage continuum.

The private sector (Breweries, Mines, Heavy Industry, Agriculture, Power Generation, Hotels) many times being large consumers of freshwater resources can offer a unique viewpoint to some of the fundamental concepts. In looking at the efficiency of self-provision versus utility supply, the growing need and expectation of reliable water supplies have driven technological innovation in water treatment, storage, and conveyance that has created new opportunities to integrate reclaimed water into the private sector water systems.

In many jurisdictions the national water utility company is the only one legally allowed to supply and sell potable water as the Caribbean has not caught up with the global trend of privatizing public utilities. The exception to this is limited to few countries such as Antigua and Cayman that allows desalination plants to sell to customers. The rigidity of supply and investments has not kept up with the needs of some growing industries many of which have chosen to implement on site storage to allow for seamless production continuity when there are breakdowns in the municipal supply system. Beyond on-site storage, relatively few others that have the necessary financial and technical resources have weaned themselves completely from municipal supply by having internal distribution systems and allocation rights to water sources. Total self-supply comes with legal, regulatory and financial challenges that the greater portion of smaller industries are unable to match
to be profitable.

Barbados Bottling Company (BBC) Experience

The concerns of the private sector around water security are illustrated by the case of the Barbados Bottling Company. The BBC is one of the largest consumers of water in Barbados and holds the Coca Cola franchise, which comes with several compliance requirements including ensuring long-term sustainability of their water supply – a key productive input. The approach adopted is to have a Source Vulnerability Assessment (SVA) and contingent on the outcomes implement a comprehensive protection plan for current and future production needs. Concerned with some of the challenges they were experiencing with respect to long term security of water supply the SVA considered additional and/or alternative sources of water supply. Including: sinking their own borehole and abstracting water, installing a desalination plant and extensive rainwater harvesting. As a result, along with agreements with the water provider increases in on-site storage were implemented.

Dominica's Experience with Tropical Storm Erika and Maria

Dominica Water and Sewerage Company Limited (DOWASCO) operates water supply systems in 44 water areas (WA). A typical supply system comprises a simple intake structure with rudimentary primary level water treatment. In 2015, following the impact of Tropical Storm Erika, the Rapid Damage & Impact Assessment (RDIA) estimated damages and losses to the water sector at US $16.8 million (EC $ 45.4 million) as flash flooding and landslides caused damage to or complete loss of water infrastructure, ultimately resulting in disruption to the entire water service (See Figure 6). By 2017, 43 of the 44 water systems in operation were rendered non-functional following the impact of Hurricane Maria. Limited access to safe drinking water coupled with the inadequate treatment and disposal of sewage raised considerable issues of sanitation and public health risks. These extreme events are occurring at a faster rate than Dominica can recover from the socio-economic impacts of the damages sustained. Water lock offs continued to be pervasive for years following Erika and Maria from failing infrastructure. Dominica's experience has been instructive and led to an evaluation of storage requirements in 2020. The storage deficit assessment for Dominica indicated that only 4 of the 44 WAs have sufficient storage to meet 'normal' interruptions. If an additional allowance was included for supply interruptions due to extreme events, then the deficit would be even greater. DOWASCO have indicated that they require additional distributed contingency storage (minimum requirement 3 day's storage) of approximately 8.1 million imperial gallons in total or 37,000 m3 as an adaptation measure for the safe provision of domestic water against climate induced interruption and disruptions associated with increased extreme events.

Does Wastewater re-use play a role in adequacy of upstream water storage?

Wastewater volume and flow is a function of the incoming water supply, any on site recycling which displaces the need for more of an incoming supply has a direct influence on the adequacy of the available upstream storage. Wastewater represents a large stock of untapped resources which if treated and reused for secondary purposes can lead to less reliance on freshwater resources and increased availability for storage. The challenge is the financial implications and access to affordable, innovative technology to treat wastewater to a consistently acceptable standard. There is growing interest for hotels to re-use wastewater in landscaping and golf courses and even for irrigation of cricket grounds in St. Lucia.

Financing future storage needs is a challenge.

Water infrastructure is capital intensive, with finance necessary to cover upfront construction costs that are typically repaid over long periods (Money, 2018). Most of the water infrastructure within the Caribbean is operationalized through public utility companies. The predominant financing model in the Caribbean is one whereby operation and maintenance costs are covered by revenue from tariffs but capital works are funded through loans guaranteed by governments and by government transfers (Cashman, 2014). Tariffs are predominantly low across the Region which results in limited finances to maintain, rehabilitate and upgrade the aging water infrastructure. Losses from these systems are high with average levels of Non-revenue water across the region being in excess of 50%. This coupled with challenges to collect tariffs particularly in unmetered zones where estimated billing is the norm, has along with other factors resulted in utilities being severely underfunded. Larger water infrastructure upgrades are generally funded through development agencies and international financial institutions such as the World Bank, CDB, IDB and in the case of climate related projects the Green Climate Fund. These funding sources are becoming more competitive to tap into with increased development not just regionally but globally. However, these agencies are at lengths to point out that finance is available but that there must be clear and well-prepared applications that they can consider.

There is opportunity in exploring more niche financing streams especially through public-private partnership. Several large private sector firms including breweries, manufacturers have gone the route of being self-sustainable with their own infrastructure. There is growing interest around how to leverage private sector participation through shared resources and programmes to meet both public and private water demand.

Another lens to look at this is that in the evaluation of where to divert funding, the measure of return is almost exclusively financial with the economic cost of the risk of not investing overlooked in the process. In other words, the co-benefits need to be better articulated and factored into the financial and economic analyses to demonstrate the wider returns on investment. This suggests that water utilities need to work more closely with the ministries responsible for finance and economic development to advance their cause.

Rose Hall Developments Ltd. Wastewater Reuse

The Rose Hall strip in Montego Bay, Jamaica is thriving with a large golf course, high end condominiums and hotels. Rose Hall Developments Ltd treats wastewater from hotels along the strip with the treated effluent stored in a 151,416 cubic metres (40-million gallon) lake then resold to the very hotels they service for irrigating their golf courses. A single golf course in this zone can use up to 1,325 cubic metres (350,000 gallons) of water per day so we can begin to realize the costs savings and reduction in reliance on the already depleting freshwater storage stock.

Strong governance arrangements on integrated storage are needed.

Many long-range development strategies throughout the Caribbean have underscored the importance of water resources management and well-functioning water services. The implementation of these strategies, nevertheless, will be the challenging aspect of the process. Water governance in the Caribbean has a distinct set of multi-level challenges including unclear policy objectives and strategies and monitoring mechanisms; as well as unpredictable investment climate (OECD, 2012). However, things are changing and countries are gradually starting to better integrate water sector development with future national economic development objectives. For example, Guyana in its Green State Development Strategy: Vision 2040 has recognised the need for good water governance and effective infrastructure to underpin development. This provides the start of a framework within which the role of the various forms of storage, their status, contribution to economic growth and environmental sustainability, and the future requirements are seen as an integral part of the maintenance, management and sustainability of a country's water resources and services.

LOOKING AHEAD

New approaches to building more resilient water systems:

This includes accurate determination of required storage volumes for not just current but future demands based on population growth and industrial development. Required storage volumes informs the decision-making process on the chosen supply infrastructure and necessary investment. Water storage systems designed with the primary purpose of providing bulk water supply can be assessed and evaluated according to their ability to meet pre-determined targets of water delivery (Lindstrom et. al, 2012). Each country determines how much storage is needed based on the needs of their economic sectors, population and environmental protection targets, the latter of which is oftentimes undervalued. Regardless of which IPCC climate change scenario that is taken, the overall storyline remains the same for projections of warmer and drier conditions in the Caribbean by mid-century. Water managers and decisions should have a proactive push to implement resilient actions around these projections to ensure adequate water availability for future use. Albeit each country level context will call for the use of different strategies.

Improved climate forecasting:

Advancements in climate forecasting will play a prominent role in managing freshwater storage inputs. There is also the need to enhance water stakeholders' ability to receive and utilize that information to better manage available water resources.

Integrating innovative freshwater storage services in the water management framework:

The approach to managing freshwater resources in the Caribbean must be integrated and resilient to counter these variabilities and ensure water for future development. Water storage will become an increasingly important part of the water sectors adaptation to climate change and climate variability. Grenada has been looking ahead and through the Green Climate Fund is carving out resilience measures to support the water sector by improving water use efficiency and increasing water availability. Some of the identified infrastructure investments will include building water storage capacities, drilling new wells and creating new rainwater harvesting systems. We should re-frame our thinking around integrating water, wastewater re-use and renewable energy (solar powered pumps) around reducing operating costs e.g. the potential role of solar pumps for water distribution systems.

Inventory of storage systems:

The types, locality, infrastructure typology, life span etc. of storage systems across the Caribbean are not very well documented. Further to that the interruption of services associated with these systems are not monitored and tracked. These are critical for the determination of the current and future state of our retention systems and the required maintenance needs and capital upgrades.

Cashman, Adrian. 2014. Water Security and Services in the Caribbean. CERMES, Barbados. Water 2014, 6, 1187-1203; doi:10.3390/w6051187.

CEHI. 2010. Managed Aquifer Recharge (MAR): Practical Techniques for the Caribbean. Caribbean Environmental Health Institute, Castries, St. Lucia.

Caribbean Institute for Meteorology and Hydrology (CIMH) and Food and Agriculture Organisation (FAO). 2016. Drought Characteristics and Management in the Caribbean. Rome, Italy.

Richard J. Chorley (Ed.), 1969. Water, Earth and Man. A synthesis of Hydrology, Geomorphology, and Socio–Economic Geography. DOI: https://doi.org/10.1017/S0016756800058970 Published online by Cambridge University Press: 01 May 2009.

Daus, Anthony. 2019. Aquifer Storage and Recovery: Improving Water Supply Security in the Caribbean Opportunities and Challenges. Discussion Paper IDB-DP-00712. Inter-American Development Bank, Washington DC.

Dillon, Peter, J., Pavelic, P., Page, D., Beringen, H. and J. Ward. 2009. Managed aquifer recharge, An introduction. Waterlines Report Series No. 13 National Water Commission, Australian Government.

Food and Agriculture Organization (FAO). 2016. "Regional Overview of South America, Central America and the Caribbean." Accessed October 29, 2020. (http://www.fao.org/aquastat/en/countries-and-basins/regional-overviews/south-centr-america-car/).

Food and Agriculture Organization (FAO). 2003. Review of World Water Resources by Country. Food and Agriculture Organization of The United Nations, Rome.

Fetter, Charles W. 2001. Applied Hydrogeology. 4th Edition. (1-16). Upper Saddle River, NJ: Prentice Hall.

Franklin, Angela. 2020. Groundwater Management Plan 2020 – 2030 - Coastal Aquifers of Guyana. Guyana Water Incorporated, Government of Guyana.

Geoghegan, Tighe. 2002. "Incentives for Watershed Management in St. Lucia: Results of a Brief Diagnostic." CANARI Technical Report No. 317, Caribbean Natural Resources Institute, Laventille, Trinidad.

Global Water Partnership. 2014. Integrated Water Resources Management in The Caribbean: The Challenges Facing Small Island Developing States. Technical focus paper.

Hirji, Rafik. and Davis, Richard. 2009. Environmental Flows in Water Resources Policies, Plans, and Projects: Case Studies. Environment department papers; no. 117. Natural resource management series. World Bank, Washington, DC.

Jones, Ian C., and Jay L. Banner. 2003. Estimating recharge thresholds in tropical karst island aquifers: Barbados, Puerto Rico and Guam. Journal of Hydrology 278 (1-4)131-143.

Jones, Ian C., Jay L. Banner, and John D. Humphrey. 2000 Estimating Recharge in A Tropical Karst Aquifer. Water Resources Research 36 (5): 1289-1299.

Lerner, David N., and Bob Harris. 2009. The Relationship Between Land Use and Groundwater Resources and Quality. Land Use Policy. 26 S265-S273.

Lindstrom A., Granit J. 2012. Large-Scale Water Storage in The Water, Energy and Food Nexus: Perspectives on Benefits, Risks and Best Practices. SIWI Paper 21. Stockholm International Water Institute. Stockholm, Sweden.

McCartney, M.; Rebelo, L-M.;Xenarios, S.; Smakhtin, V. 2013. Agricultural Water Storage in An Era of Climate Change: Assessing Need and Effectiveness in Africa. Colombo, Sri Lanka: International Water Management Institute (IWMI). 37p. (IWMI Research Report 152). doi:10.5337/2013.207.

MEGJC. 2019. National Water Policy and Implementation Plan. Ministry of Economic Growth and Job Creation, Jamaica.

.Money, Alex. 2018. Ten Actions for Financing Water Infrastructure World Water Council Report Financing. Water Infrastructure Task Force. World Water Council.

OECD (2012), Water Governance in Latin America and the Caribbean: A Multi-level Approach, OECD Studies on Water, OECD Publishing, Paris, https://doi.org/10.1787/9789264174542-en.

Page, D., Bekele, E., Vanderzalm, J., & Sidhu, J. (2018). "Managed Aquifer Recharge (MAR) In Sustainable Urban Water Management." Watermark, 10, 239AO, Rome.

Michaela Roberts, Nick Hanley, Sam Williams, Will Cresswell, Terrestrial degradation impacts on coral reef health: Evidence from the Caribbean, Ocean & Coastal Management, Volume 149, 2017, Pages 52-68.

Scalley, Tamara H. 2012. Freshwater Resources in the Insular Caribbean: An Environmental Perspective. Caribbean Studies Vol. 40, No. 2 (July - December 2012), 63-93.

Taylor, Michael A., Tannecia S. Stephenson, A. Anthony Chen, and Kimberly A. Stephenson. 2012. "Climate Change and the Caribbean: Review and Response". Caribbean Studies (this issue).

Taylor MA, Clarke LA, Centella A, Bezanilla A, Stephenson TS, Jones JJ, Campbell JD, Vichot A, Charlery J (2018) Future Caribbean climates in a world of rising temperatures: the 1.5 vs. 2.0 dilemma. J Clim 31(7):2907–2926. https://doi.org/10.1175/JCLI-D-17-0074.1.

UN (United Nations) 2018. Nature Based Solutions for Water. World Water Development Report 2018.https://www.unwater.org/publications/world-water-development-report-2018/.

USAID, 2018. Climate Risk Profile. Eastern and Southern Caribbean.

Young-George, Christine, Robin Mahon, and Janice Cumberbatch. 2007. "An Environmental Assessment of the Accommodation Sector in the Grenadine Islands. "CERMES Technical Report No. 13, Centre for Resource Management and Environmental Studies, University of the West Indies, Faculty of Pure and Applied Sciences, Cave Hill Campus, Barbados.

Young, Mike. 2019. Sharing water–The role of robust water-sharing arrangements in integrated water resources management. Global Water Partnership Perspective Paper. Stockholm. p.32.

Global Water Partnership-Caribbean (GWP-C) Secretariat
St. George's, Grenada
E-mail: info@gwp-caribbean.org
Website: www.gwp-caribbean.org

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