MANAGING WATER RESOURCES IN THE FACE OF CLIMATE CHANGE: A CARIBBEAN PERSPECTIVE

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ABSTRACT
The Caribbean faces inexorable climate change during the 21st century. This phenomenon will have a profound effect on the long-term sustainable socioeconomic development of the islands and is likely to jeopardize achievement of the Millennium Development Goals. All economic and social sectors will be adversely affected. The water resources sector on most islands is one that will be strongly impacted by climate change. Against a background of increasing demand for potable water, sea-level rise may lead to flooding of lowlands and seawater intrusion into coastal aquifers, while variability in climate may see more intense rainstorms resulting both in increased run-off leading to increased flooding and reduced recharge leading to aquifer depletion. Such impacts will have a negative ripple effect on other vital aspects of regional economies such as the tourism, recreational, agricultural and industrial sectors. Unfortunately, adequate management of water resources on many Caribbean islands is sorely lacking. In many cases baseline data that may be used to track changes is sparse or non-existent. This paper explores the probable effect climate change will have on water resources in the Caribbean, the fall-out from these effects and strategies for mitigating potential negative impacts.

INTRODUCTION

One of the major scientific challenges of the latter part of the 20th century and start of the 21st century is global climate change and its potential impacts on civilization. The general consensus of the scientific committee, and an important conclusion of the February 2007 report issued by the Intergovernmental Panel on Climate Change (IPCC, 2007), is that global temperatures are increasing and this increase is driving a number of phenomena including the much discussed global sea-level rise. Global climate change and increasing climate variability are expected to impact all sectors within the Caribbean with the anticipated onset of impacts varying from locality to locality. Assessments to determine the potential effects of these phenomena on the socio-economic development of regional countries are currently taking place in Caribbean based projects such as the Mainstreaming the Adaptation to Climate Change (MACC) initiative. Included in these studies are analyses to determine the impacts of climate change on water resources across the region. The need to understand the consequences of climate change with respect to water resources is not based solely on the view that water is a public good that needs to be protected (UN Millennium Goal # 7) but is also motivated by the need to quantify the current and future economic value of water resources within a national context. This pragmatic view recognizes that in small-island developing states policies and decisions related to resource allocations will be driven by competing economic considerations. In the case of water, such decisions and policies can significantly influence the cost of water and in so doing affect poverty alleviation (see Millennium Development Goal # 1). The impacts of climate change and the economic value of water resources will form the basis for the development of adaptation strategies with regards to the sustainable management of regional and national water resources. These strategies are expected to couple sustainable resource management with future demand management.

EVIDENCE FOR GLOBAL WARMING

A considerable body of evidence has been collected to investigate whether global warming is occurring and, if it is, to establish its cause. Global observational data compiled to date indicate human-induced climate changes are occurring. Since 1860, mean global air temperature has increased by approximately 0.6^0 C (+/- 0.2^0 C). In the Northern Hemisphere, average temperatures during the 20^{th} Century have been the warmest for any century in the past 1000 years, with the 1990s being the warmest decade on record (IPCC, 2001). During the 20^{th} Century, temperatures in the Caribbean and Pacific Ocean regions increased by about 1^0 C (i.e. 0.1^0 C per decade), thus exceeding the global average since 1860 (Nurse and Sem, 2001). These observations are generally supported by outputs from global climate models.

Although there has been no consistent trend in global precipitation change over the same period, some regional patterns have been identified. During the 20^{th} Century mid- and high-latitude regions recorded precipitation increased at a rate of approximately 1 % per decade. Along with this increase, a higher incidence of extreme precipitation events was observed (IPCC, 2001a). Available data averaged for the Caribbean does not exhibit a consistent temporal or spatial rainfall trend, however, recent downscaled model outputs from the Hadley Centre's PRECIS model, project a tendency towards drying, with a higher number of dry days and fewer consecutive wet days for the region.[1] These projections correlate well with the finding that warm phases of El Nino Southern Oscillation, which are associated with below-average rainfall in the Atlantic, are becoming more frequent and intense (IPCC, 2001; Lal, 2004). The 1987/88 El Nino episode, the most intense on record, was accompanied by widespread drought in the Caribbean, with Guyana experiencing the worst effects.

Findings from glacial studies demonstrate that widespread melting of mountain glaciers is resulting from global warming. Recent research based on measurements on all continents shows that during the period 1980-2001, mountain glaciers have retreated by more than 6 metres, on average. Significant rates of melting are also being recorded by instrumentation on ice caps and shelves. For instance between 1980 and 2003, the thickness of the Arctic ice sheet decreased from 15 metres to approximately 8 meters.

Global sea-level rise is a consequence of warmer ocean temperatures and increasing meltwater from glaciers. The rate of global sea-level rise during the 20th Century was approximately 10 times higher than the average rate for the last 3000 years (IPCC, 2001). Sea levels in the Caribbean region have risen at a rate of approximately 1mm yr^{-1} during the 20^{th} Century; a rate that is however lower than the global average. The rate of sea-level rise relative to land elevation is however complicated by the fact that topographic elevations on some Caribbean islands are also changing as a result of tectonic processes and land subsidence. For example, Miller (2005) demonstrated that in Trinidad the sea-level in the north of the island is rising at roughly 1mm yr^{-1} (the average for the region), however, in the south sea-level appears to be rising at approximately 4mm yr^{-1}. This apparent rate of sea-level rise is not comforting for small island developing states within the Caribbean region given that global mean sea levels are projected to continue rising by around 5 mm yr^{-1} during the 21^{st} Century.

While long term trends in global climate are important, short term variability that may be superimposed on local and regional long term trends is also important due their near-real-time impacts on national and regional economies. Such variability may be sub-seasonal or seasonal

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[1] The PRECIS model was developed by the Hadley Centre, a unit of the United Kingdom Meteorological Office. The model has a resolution of 25 km over the Eastern Caribbean and 50 km for the entire Caribbean Basin, and incorporates IPCC SRES scenarios.

in nature (e.g., annual wet and dry season variations) or may persist over several years as in the case of the changes in climate that result from the El Nino/Southern Oscillation cycle which is responsible for drier than normal conditions across the Caribbean during the summer. Within the context of climate variability there is particular concern about the increasing frequency of what were previously viewed as extreme events and their impacts on national and regional economies. The recent extensive flooding in Guyana during the 2005 and 2006 represent cases where extreme events occurred within a short time period. In both cases, extremely high rainfalls occurred, with the rainfall in January 2005 representing the highest single month total since 1888. The financial losses to the agricultural sector in Guyana that resulted from these events were USD 55 million and USD 22.5 million respectively. These represent significant losses to the Guyanese economy as agriculture accounted for 35.4 percent of Guyana's gross domestic product during 2004.

As noted in the previous paragraphs, climate change and climate variability are expected to have a significant impact on socioeconomic development of the Caribbean region if mitigative and adaptation strategies are not implemented in the near future. In particular, climate change and climate variability are expected to impact (i) key economic sectors such as tourism, agriculture, recreational activities, and energy among others and (ii) key social sectors such as water, health care, and security among others. Impacts in the social sectors are expected to impact economic activities and vice versa.

The impacts to local and regional water resources due to climate change will be significant. Water resources in the Caribbean region include both surface and subsurface waters with the relative importance of each, from an economic perspective, varying from island to island. In Barbados for example, groundwater is the primary source of water for all socio-economc activities and, as a result, it has significant economic value. However, in many of the Windward Islands, greater economic value is attached to surface water relative to groundwater. In the latter case, this relative importance is exemplified by the fact that little groundwater is withdrawn and in many instances little information on existing groundwater resources exist. Climate change is often seen as a future threat to water resources on many English-speaking Caribbean islands when compared with current threats. For example, many aquifers are constantly under threat from pollution from agricultural chemicals and human waste, over utilization, and reduced recharge that results from increased run-off due to changes in land use patterns. Furthermore, many Caribbean islands will continue to experience population growth during the 21st Century such that the competition for land and water will stress both quantity and quality of available water resources.

Given these challenges, and the additional threats posed by climate change, management of water resources on Caribbean islands will become more difficult due to the complex interactions between the various threats. Mitigation will require skilled personnel, knowledge of existing resources including economic valuations of resources, and appropriate management strategies and policies. Unfortunately, IICA (1999) indicated that there is a significant lack of water resources professionals within the Caribbean region and this is contributing to poor water resources management on many islands.

CLIMATE AND WATER RESOURCES

Climate and water resources are intimately connected through the hydrologic cycle which defines the transfer of water from the oceans to groundwater and surface water storage. The hydrologic cycle accounts for:

- Evaporation from the oceans
- Condensation of water vapour
- Precipitation in the form of snow and rain
- Run-off to lakes and surface water impoundments
- Infiltration into the subsurface
- Percolation into aquifers
- Evapotranspiration from the near surface

Equations 1 and 2 represent the water balance equations for groundwater and surface water respectively:

$$\Delta GW_s = P - ET - SW_{ro} + GW_i - GW_o \qquad (1)$$

$$\Delta SW_s = P - ET + S_i - S_o + G_i - G_o \qquad (2)$$

Where P represents precipitation, ET represents evapotranspiration, SW_{ro} represents surface water run-off, ΔGW_s represents change in subsurface storage, GW_i and GW_o represents groundwater inflows into and groundwater outflows from the system respectively, ΔSW_s represents the change in surface water storage, S_i represents the surface water inflows into the system, S_o represents surface water outflows from the system, G_i represents groundwater inflows into the system and G_o represents outflows from the system to the groundwater system. Note that S_i and S_o are related to the SW_{ro}.

The water balance equations and their links to the weather and climate therefore provide the basis for assessing the impacts of climate change on water resources. Equation 1 and 2 reinforce that that groundwater and surface water budgets are strongly influenced by precipitation, surface runoff, and evapotranspiration rates and, as a result, will be sensitive to changes in climate. While the relationships expressed appear relatively straightforward, couplings between the various variables can be complex. For example, for the same volume of precipitation, increasing the intensity of the precipitation will increase surface run-off and reduce the subsurface storage. The equations further emphasize the fact that key variables in water budget calculations are strongly dependent on climatic variables. The link between precipitation and groundwater and surface water storage is obvious from Equations 1 and 2. However, the influence of high temperatures and low relative humidity on water losses from soils and ponds via evapotranspiration although often not fully appreciated outside of the agricultural community, is a growing concern given the predictions of increasing temperature and drier future conditions.

The relationship between the quantity of precipitation and water availability is intuitive. However, rainfall intensity is also an important consideration in water budget calculations as it is positively correlated to run-off. Field observations and numerical modeling studies have shown that increasing rainfall intensity increases run-off thereby increasing surface water storage at the expense of groundwater storage (equations 1 and 2).

The budget calculations presented above provide volumetric estimates of the water available in groundwater and surface water systems. The calculations do not reflect the quality of water within the system and hence the potential utilization of the system. While increased run-off may increase the volume of water in surface water bodies, the same process could result in the degradation of the resource due to increased siltation and chemical loading.

IPCC PREDICTIONS REGARDING FUTURE GLOBAL CLIMATE

Table 1 summarizes some of the important climate change projections from IPCC (2007). These projections are expected to have varying degrees of impact on various sectors of Caribbean economies and are expected to affect water resources on all Caribbean countries. In particular, the report concludes that

- Probable temperature rise by the end of the century will be between 1.8 ^{o}C and 4.0 ^{o}C (3.2-7.2 ^{o}F) with the possible temperature rise by the end of the century ranging between 1.1 ^{o}C and 6.4 ^{o}C (2-11.5 ^{o}F)
- Sea levels are likely to rise by 28-43cm

Table 1: Future Climate Change Projections

(Extracted from Table SPM-1, Intergovernmental Panel on Climate Change: Climate Change 2007: The Physical Science Basis; Summary for Policymakers)

Phenomenon and Direction of Trend	**Likelihood of future trends based on projections for 21st century using SRES Scenarios**
Warmer and fewer cold days and nights over most land areas	Virtually certain
Warmer and more frequent hot days and nights over most land areas	Virtually certain
Warm spells / heat waves. Frequency increases over most land areas	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Very likely
Area affected by drought increases	Likely
Intense tropical cyclone activity increases	Likely
Increased incidence of extreme high sea-level (excludes tsunamis)	Likely

CLIMATE CHANGE AND WATER RESOURCES

The impacts of climate change on water resources management in the Caribbean are tied to the demand for water and the ability of water utilities to supply water from natural and anthropogenic sources. On most Caribbean islands, groundwater and surface water are the primary sources of water used to meet public and industrial demands. However, in countries such as Antigua and Barbuda and the Bahamas, water supplied from desalination is the primary source of potable water. The ability of utilities to supply water in the future will be strongly influenced by the impacts of climate change on the hydrologic cycle.

Climate change is expected to influence the demand for water by the public and industry in the future. Rising temperatures and changing rainfall patterns are likely to increase the demand for water by households, farmers, tourism, manufacturers and the recreation industry among others. Extensive studies to quantity the likely impacts of future climate change and climate variability on water resources in the Caribbean are not available, however, efforts such as the MACC which is ongoing are attempting to address this shortcoming. This section discusses the likely impacts of climate change on groundwater and surface resources.

CLIMATE CHANGE AND GROUNDWATER RESOURCES

Climate change and climate variability will increase the risk to already vulnerable groundwater resources. In particular, future climate change and climate variability are likely to impact the quantity and quality of groundwater resources. The speed at which these impacts will occur will be controlled by the location of the aquifer (inland versus coastal), local hydrogeologic conditions (including soil characteristics, whether aquifers are confined or unconfined, the size of the aquifer etc), the forcing climatic conditions, and the degree of utilization of the resource. It is expected that water-scarce islands such as Barbados, which rely exclusively on groundwater to meet the national water demand will be severely impact by effects of climate change on groundwater resources.

Equation 1 implies the amount of water stored in the subsurface is dependent on precipitation and surface runoff. Preliminary climate change and climate variability scenarios for the Caribbean region, indicate that rainfall in the region will become intense and dry spells will become more pronounced. The amount of precipitation received annually is, however, not expected to change significantly. Increased rainfall intensity, is expected to lead to increased surface runoff thereby reducing infiltration and potential aquifer charge. Construction of residential developments, recreational facilities, and roadways in the future are expected to further enhance surface runoff. In karst terrains some of the increased run-off may be captured by sinkholes thereby contributing to aquifer recharge. Aquifer recharge schemes of this type are currently being experimented with in Jamaica. However, as will be discussed in this section this approach can result in aquifer degradation if not carefully managed. The potential sensitivity of aquifer recharge to precipitation is summarized in Sandstrom (1995) who showed that a 15 percent reduction in rainfall resulted in a 40-50 percent reduction in recharge in an aquifer located in the central Tanzania. Similar studies for aquifers in the Caribbean are not readily available at this time, however, outputs from the MACC project and subsequent studies are expected to provide countries will the tools necessary to perform similar studies.

Daily temperatures are expected to increase under future climate change scenarios. This warming trend is evident in data collected in Barbados during the period 1960 to 2000 which show that both daytime and night-time temperatures have increased (Farrell et al. 2007). Increasing temperature is expected to increase evapotranspiration rates thereby reducing soil moisture, infiltration and aquifer recharge. In clay type soils, increasing temperatures coupled with prolonged dry spells will lead to desiccation cracking that will further enhance soil moisture loss. The impacts of increasing temperatures on recharge in aquifers in the Caribbean is not documented, however, a qualitative understanding of the effects of increasing temperatures on recharge may be inferred through careful examination of climate and waterlevel records at aquifers.

The above discussion is primarily applicable to unconfined aquifers, that is, aquifers that have no overlying impermeable strata, are generally close to the ground surface and, as a result, are strongly coupled to atmospheric forcing functions. Confined aquifers on the contrary generally lie deeper in the subsurface and are generally less susceptible to climate and weather phenomena. As a result, these systems may contain old water, and may be less susceptible to the immediate impacts of climate change and climate variability.

Climate change will not only influence the quantity of water entering aquifer systems, but may also reduce the quality of water within aquifers. In coastal environments for example, changing recharge patterns, including reduced long-term recharge and/or temporally variably recharge, coupled with rising sea-level will increase the likelihood of seawater intruding into coastal aquifers thereby degrading the water quality in the aquifers. As noted previously, erosion and sediment transport may become common features of high intensity precipitation. In karst regions, this raises the potential for recharge water to transport sediments and other contaminants (e.g., pesticides and fertilizers) into the subsurface thereby contaminating aquifers. As a result, the consequences of climate change and increased climate variability can be a reduction in groundwater quality.

CLIMATE CHANGE AND SURFACE WATER RESOURCES

Surface water resources are the most vulnerable water resources with respect to climate change and climate variability. Rivers, small lakes, and small impoundments represent the primary surface water bodies in the Caribbean. Surface water resources are the primary sources of potable water in countries such as St. Vincent, St. Lucia, Dominica among others. On Antigua, surface water contained in the Potworks Reservoir is an important component of the water supply system, but not the primary component.

As is evident from Equation 2, surface water resources are influenced by precipitation, runoff, evaporation, and exchanges with the underlying groundwater system. Because of their direct connection with the atmosphere, surface water resources are extremely susceptible to the impacts of climate change and climate variability. This susceptibility was demonstrated in 2003 when the Potworks Reservoir in Antigua went dry after a period of drought. Under future climate change scenarios for the eastern Caribbean region that project among other things increasing rainfall intensity and increasing consecutive dry days, and increasing day and night time temperatures, it is anticipated that surface water systems will experience increasingly variable steam flows and reduced waterlevels in lakes and other surface water features. These volumetric changes may threaten the long-term sustainability of surface water bodies as reliable sources of water.

Maintaining the quality of surface water bodies will also prove challenging under climate change and increasing climate variability particularly when high intensity rainfalls may generate significant surface runoff that may carry significant sediment loads containing pesticides, fertilizers, and wastes. The high sediment loads may increase siltation in steams lakes and impoundments. Agrochemicals and wastes transported into rivers and other water bodies may significantly degrade water quality.

POLICY AND LEGAL FRAMEWORKS

Water stress in the Caribbean is becoming a significant challenge for many sectors. The situation is made worse where poor management practices collide with declining availability occasioned by climate change and climate variability. Factors such as increasing rates of abstraction as a consequence of growing water demand, pollution from agro-chemicals and other contaminants, inefficient and inadequate water storage facilities, failure to exploit recycling technologies and implement water-use efficiency measures all compound the problem.

Most Caribbean countries lack a comprehensive water resources management policy and legislative framework. Institutional arrangements are often fragmented, entities have overlapping responsibilities, there is no clear coordination mechanism, and in many cases institutions are self-regulating. In addition, management practices and technologies are often inefficient, and there is a general lack of incentives for encouraging water use efficiency and conservation. It is therefore reassuring to note that some countries, notably Jamaica, St. Lucia, Barbados and Trinidad and Tobago have recently begun to implement strategies that seek to incorporate key tenets of integrated water resources management (IWRM).

Clearly there is no single prescription for achieving efficient water management, as approaches will of necessity vary from place to place and must be appropriate to local circumstances. However, there is an emerging consensus from the literature that there are certain critical policy elements that ought to be considered in the design of an effective strategy. These include but are not limited to the following:

- Demand-side management, which may include incentives (and sanctions, where appropriate) for conservation and use optimization;
- Comprehensive assessment of existing and future demands, by sector;
- Assessment, repair and replacement of aging infrastructure;
- Forecasting and risk assessment of *extreme events*, i.e. droughts and floods, which impact communities and sectors in different ways, and hence require different management approaches;
- Resolution of allocation issues such as trade-offs, use rights and user-conflict, e.g. potable use vs. irrigation needs; domestic supply vs. sale of water to cruise ships, etc.;
- Investment in research and development not only with respect to augmentation and 'new' technologies, but also with a view to optimizing the distribution system, and reducing operational costs without compromising quality of service;
- Monitoring for quality assurance and control;
- Implementation of integrated watershed management practices, which can play an important role in the rationalization of resource use and allocation and protection of sources (both surface and groundwater);
- Rationalization and updating of legislation, paying attention to effective enforcement.

Finally, no policy, however well intentioned and conceived, will achieve the desired outcome if stakeholder education is not an institutionalized element of the implementation process. This may require strategies aimed at effecting behavioural and attitudinal change, dispelling false notions (e.g. that the resource is '*limitless*') and enhancing public awareness and understanding of the 'true' cost of providing water, arguably one of the most undervalued natural resources.

EDUCATION, TRAINING, AND RESEARCH AND DEVELOPMENT

Development of mitigation and adaptation strategies to protect water resources on Caribbean islands is required if national socio-economic goals are to be attained. However, in recognition of the limited financial resources such strategies must be designed and implemented in a cost-effective manner. An important impediment is the lack of skilled water resources professionals within the region.

The technical expertise required to mitigate existing water resources problems and to develop sustainable water resources programmes generally is not available in most Caribbean islands. Furthermore, in many water resources agencies, important decisions related to water resources management are made by individuals with minimal formal training in the important core scientific and engineering disciplines. As a result, the scientific and engineering studies needed are often inadequate or poorly done. This inevitably results in significant liabilities given the emerging threats posed by (i) changing land use patterns, (ii) increasing demands for water from multiple stakeholders including agricultural, industrial, and recreational users, and (iii) emerging pollution threats from pharmaceutical products and pathogens, all likely to be acerbated by climate change.

IICA (1999) made the following recommendations that should be acted upon so as to improve each island's ability to manage its water resources:

- Establishment of politically independent national bodies to formulate policy related to the sustainable management of water resources;
- Integration of databases that support water resources and environmental management;
- Strengthening of institutional capacity in water management organizations;
- Development of local research and development programmes within water resources management agencies;
- Establishment of market based frameworks that support the balanced distribution of water and the establishment of policies that promote equity;
- Development and implementation of regulations, policies, and laws that protect water resources.

Of these, institutional strengthening is perhaps the most important as it provides a mechanism through which some of the other recommendations can be achieved. However, the level of institutional capacity building required to implement the IICA (1999) recommendations demands a significant financial investment that may be excessive from a cost benefit perspective when compared with other national priorities.

A collective regional approach is one through which all of the Caribbean SIDS can benefit. A regional research, development, implementation and training group specializing in various aspects of water resources management (e.g., resource exploration, characterization, development, protection, and valuation) could be instituted. All Caribbean SIDS would have equal access to the expertise of the group with islands with less developed water management systems reaping the most significant benefits initially. The group would be responsible for

- Advising local and regional government agencies on regulations, laws, and policies related to
    - Sustainable management of water resources
    - Development and implementation of strategies for protecting water resources on Caribbean islands

- Development of training and research and development programmes tailored for specific needs of the various islands. The Group would have to have
    - close working relationships with managerial and professional staff in the various water management agencies in the region
    - thorough understanding of the various challenges facing each water management agency in the region
    - a proactive approach to identification of potential water management problems
    - multi-disciplinary experience

- Identifying funding opportunities that could benefit water resources activities in the Caribbean region including collaborations with local, regional, and international organizations

- Providing technical support to agencies wishing to apply for loans and grants to support water resources related activities

The use of central organizations to support water resources is a widely used approach. For example, in the United States the U.S. Geological Survey provides technical expertise in water resources management to states where such expertise is lacking.

The CIMH and the UWI Cave Hill Campus could house the group, as its activities would complement those of both organizations. The CIMH is a regional training institution mandated to train the region's meteorologists and hydrologists and the hydrology programme provides some of the services listed as key objectives of the proposed group. The UWI Cave Hill Campus primarily functions as a teaching, research and development institution with much of its efforts geared to meeting the needs of the region. At the moment, the Campus is in the process of developing an undergraduate programme in Environmental Science which includes aspects of Geology, Hydrology, Hydrogeology, Groundwater Modeling and Applied Geophysics among courses relevant to water resource management. The advantage of housing the group at UWI would be access to UWI's facilities and human resources in science, law, social sciences, business, and environment. Such an interdisciplinary mix is essential to water resources management.

PATH FORWARD

The demand for water by countries in the Caribbean is expected to increase due to population increase, increased agricultural and industrial productivity, and the growth of recreational and tourism industries. Unfortunately, future climate change and climate variability will likely have negative impacts on the quality and quantity of water available from natural sources. Meeting future water demand given the threats to water resources posed by climate change will require significant improvements to water resources management across the region. This will require significant national and regional investments to support (i) capacity building initiatives using regional and national institutions, (ii) development of legal and policy frameworks to facilitate improved management frameworks, (iii) increased environmental monitoring and resources assessments, and (iv) increased data collection, analysis, and storage. While the effects of climate change on water resources are being addresses in some regional programmes, significant effort will be required to mainstream the results from the ongoing studies.

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