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CLIMATE CHANGE ADAPTATION AND WATER POLICY

LESSONS FROM SINGAPORE

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Climate Change Adaptation and Water Policy: Lessons from Singapore

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ABSTRACT
Asian countries with large populations concentrated in coastal cities are particularly vulnerable to climate change impacts, such as sea level rise. This, in turn, can adversely affect water resources as a result of flooding, coastal erosion, water scarcity etc. Singapore has been hailed for its progressive water policies and practices, which were developed to overcome its natural resource disadvantage (limited resource base) and to achieve self-sufficiency. Certainly, Singapore's geopolitical situation may have provided an atmosphere conducive to the development of progressive policies; however, it is worth exploring how Singapore is preparing for climate change adaptation, as this may allow other cities/countries to learn from Singapore's experience. The paper evaluates the contribution of Singapore's water policies and practices to climate change adaptation, and examines whether they can support the development of adaptation strategies in the water sector for other similarly situated cities in vulnerable countries. Copyright © 2013 John Wiley & Sons, Ltd and ERP Environment

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Introduction

CLIMATE CHANGE POLICY, BOTH NATIONAL AND INTERNATIONAL, HAS FOCUSED ON MITIGATION (BY REDUCING greenhouse gas emissions). However, as some climate change is inevitable (due to past greenhouse gas emissions), the need to adapt to existing climate variability has been recognized. Adaptation is also necessary to prepare for anticipated climate changes. Singapore is situated in Southeast Asia, one of the regions most vulnerable to climate change. The occurrence of extreme and challenging weather events has significantly influenced awareness of, and concern about, the potential impacts of climate change.

This paper examines the existing climate change adaptation measures for Singapore's water sector. The next section provides a background to climate change adaptation in the water sector. This is followed by an overview of water supply management in Singapore. The subsequent sections provide an overview of the state of knowledge concerning the impacts of climate change on the water sector, and the existing adaptation measures. Finally, the last section draws some conclusions.

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Climate Change Adaptation in the Water Sector

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) projects an increase in global temperatures by 1.1–6.4 °C over 1990 levels, and global mean sea levels by 18–59 cm by around 2100,[1] depending on future scenarios of varying global emissions. The IPCC report also projects an increase in the frequency of temperature extremes, heat waves and heavy rainfall events (Meehl *et al.*, 2007). Some of the identified regional impacts of climate change for Southeast Asia include a warming trend similar to the projected global mean temperature rise, a sea level rise likely to be close to the global mean, an increase in annual rainfall, an increase in the frequency of extreme warm and wet seasons and a decrease in the frequency of extreme dry seasons, and an increase in extreme rainfall and winds associated with tropical cyclones (Christensen *et al.*, 2007).

Climate change is likely to affect water resources and their management. A large proportion of solar energy drives the hydrological cycle (evaporation and subsequent precipitation) and higher greenhouse gas concentrations in the atmosphere increase the availability of solar energy, which intensifies the cycle (IPCC, 2007). Increases in global temperatures will cause thermal expansion of sea water and significant melting of glaciers, ice-caps and land ice. The resulting sea level rise may cause land loss due to inundation and erosion, increased flooding during storm surges (when seawater is pushed toward the shore by the force of the winds swirling around the storm) and rainstorms, and the intrusion of saltwater into aquifers, estuaries and wetlands (see Titus, 1993). Other climate change impacts, which may interact with sea level rise, include changing storm frequency and intensity, changing patterns of run-off and more intense rainfall events (Ludwig and Moench, 2009; Nicholls *et al.*, 1995).

The IPCC defines adaptation as an 'adjustment in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts' (McCarthy *et al.*, 2001, p. 982). Adaptive capacity refers to the 'ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (IPCC, 2007). The United Nations Framework Convention on Climate Change of 1994 (UNFCCC) (Article 4.1) and the Kyoto Protocol of 1998 (Article 10(b)) include non-legally binding commitments of parties to formulate, cooperate on, and implement 'measures to facilitate adequate adaptation' to the impacts of climate change.

Arnell and Delaney (2006, pp. 243–244) have identified several adaptation measures in the water supply sector. These include the following.

(i) *Supply side*. New sources or more efficient use of existing sources: new or enhanced reservoirs, groundwater development, bulk water transfers, artificial aquifer recharge, aquifer storage recovery (treated water), desalination. Improvements in resource utilization: conjunctive use of sources, improvements to supply network linkages, resource sharing, seasonal forecasting. Improvements in distribution and treatment: improvements to raw water treatment capacity and capacity of distribution network.
(ii) *Demand side*. Leakage reduction, water efficient equipment and fittings, promotion of more efficient use through education and tariff structures, control over location of new development, water reuse and recycling, managing garden use, and use of rainwater.

However, climate change is one among several pressures on water resources (others include population growth, urbanization, economic development and land use change). Therefore, it may be difficult to determine whether water resources are affected by climate change or other impacts. In such a situation, the adoption of 'no-regret' adaptation measures, where the non-climate-related (economic and environmental) benefits exceed the cost of implementation (de Bruin *et al.*, 2009, p. 29), may be appropriate. Such measures are beneficial irrespective of future climate change. In the short term, such measures represent appropriate adjustments to anticipated climate changes and make good water management sense, as these are most likely to be implemented (de Loe *et al.*, 2001, p. 241).

Climate change is a global phenomenon with regional political, economic and physical impacts and implications. However, adaptation depends on regional and local geographical and economic diversity and the knowledge and assessment of the projected impacts at the specific level. Further, the willingness to adapt must be accompanied

[1]This estimate does not include the full effects of changes in the rate of ice sheets melting in Antarctica and Greenland, where there is enough ice on land to raise the average global sea level by about 65 m.

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by the ability to adapt. In practice, adaptive capacity is often constrained by physical, financial, socio-political and institutional factors (see Arnell and Charlton, 2009). Moreover, not all adaptation measures are benign – for example, some of them may increase greenhouse gas emissions.

Water Resource Management in Singapore: an Overview

The Republic of Singapore is a small but densely populated island nation in the South China Sea. The total land area is 710.3 square kilometers, the total population is 4.99 million people and the population density is 7022 per square kilometer. The main features of Singapore's climate are the relatively high but stable temperature throughout the year due to its close proximity to the Equator (1°18' or 130 km north), and high humidity and abundant annual rainfall of 1921 mm (MTI, 2010). Nevertheless, Singapore is a water scarce country (Tortajada, 2006). The annual renewable surface water is 0.6 cubic kilometers. There are no artificial aquifers or groundwater. Although Singapore receives an annual rainfall, the land area for storage is finite. In terms of freshwater availability, Singapore is ranked 170 out of 190 countries (UNESCO, 2006).

The responsibility for the management of the water cycle in Singapore, including potable water, sewage or wastewater treatment, and storm water drainage, is vested in the national water agency, the Public Utilities Board (PUB), a statutory body under the Ministry of Environment and Water Resources (MEWR). As Singapore is a land-scarce country, unlike several other Asian countries where water for irrigation is a key aspect of water management policies, water supply for domestic and non-domestic use is the primary focus of the domestic water policy.

Faced with the challenge of meeting the increasing domestic demand for water (1.3 million m³/day in 2008), and to address the concerns arising from the natural limits of Singapore's water resources and its dependence on Malaysia for water supply, PUB has developed the integrated 'Four National Taps' strategy leveraging Singapore's technological sophistication and bureaucratic effectiveness. The promotion of the three other taps (in addition to imported water), that is local catchment water, NEWater and desalinated water, has led to the diversification of domestic sources of water; it also guarantees self-sufficiency in the long term. A detailed explanation is available elsewhere (see, for example, Tortajada, 2006; Khoo, 2009; Tan, 2009) but some aspects of PUB's water strategy are briefly discussed in this section. For the purpose of this paper, they may be described as 'no-regrets' adaptation measures because, although they were developed in response to other concerns (discussed above), they are relevant for climate change adaptation in the water sector.

In the past, Singapore has struggled to protect the quantity and quality of its only natural source of water – rainfall – due to a geographic limitation, that is availability of land. More recently, it has adopted a long-term *catchment approach* to collect rainwater through an extensive network of drains, canals, rivers and storm water collection ponds (7000 kilometers or 4340 miles) and to channel it to 17 reservoirs for storage.[2] New technology, such as the variable salinity plant, has been used to harness water from marginal and fringe catchments near the shoreline and to expand the water catchment area to 90 percent of Singapore's land area (PUB, 2010b). The Singapore Green Plan 2012 aims to increase Singapore's water catchment areas from half to two-thirds of the total land area by 2011 (MEWR, 2009).

NEWater or reclaimed water is recycled/treated wastewater (sewage or used water) that undergoes conventional water treatment processes as well as stringent purification and treatment processes using advanced dual-membrane (microfiltration and reverse osmosis) and ultraviolet technologies (Singh, 2005). NEWater was launched in 2003. It is currently supplied from five plants (in Ulu Pandan, Kranji, Seletar, Bedok and Changi) and it can meet 30 percent of domestic water demand (about 50 mgd or 190 000 m³/day). In order to increase the share of NEWater to meet 40 percent of demand by 2020 and 50 percent of demand by 2060, the government has proposed increasing the capacity of the Changi plant and the construction of an additional NEWater plant (PUB, 2010b).

[2]These are the Bedok, Jurong Lake, Kranji, Lower Peirce, Lower Seletar, MacRitchie, Marina, Murai, Pandan, Poyan, Pulau Tekong, Punggol, Sarimbun, Serangoon, Tengeh, Upper Peirce and Upper Seletar reservoirs.

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Desalination is an essential component of Singapore's strategy to expand the domestic sources of water supply.[3] The SingSpring Seawater Plant in Tuas is a reverse osmosis membrane desalination plant that commenced operations in September 2005 and it meets 10 percent of the total water supply requirement. In July 2010, PUB issued an open tender for Singapore's second and largest reverse osmosis desalination plant (PUB, 2010a). PUB plans to expand Singapore's desalination capacity by almost 10-fold to meet at least 30 percent of Singapore's water demand in the long term. The government has identified five coastal sites for desalination plants, with the objective of bringing the installed capacity to one million m^3/day by 2060 (GWI, 2010).

Impacts of Climate Change on the Water Sector in Singapore

The dynamic nature of climate change underscores the importance of information gathering and modeling climate change impacts at the national, provincial and local levels. Singapore recognizes the importance of continually improved understanding of the detailed effects and resulting impacts of climate change in order to facilitate the identification of new, and review of existing, adaptation measures. Therefore, in 2007, the National Environment Agency (NEA), in consultation with other government agencies, commissioned a study, led by the Tropical Marine Science Institute of the National University of Singapore, to assess the long-term impacts of climate change on Singapore up to the year 2100 (Srinivas, 2006).

Phase I, which concluded in 2010, has identified the expected impacts of climate change in Singapore to include an increase in the average daily temperature between 2.7 and 4.4 degree Celsius (from the current average temperature of 26.8 degree Celsius), and sea level rise between 24 and 65 cm by the year 2100. However, there is no discernible trend in rainfall patterns (MEWR, 2010a, 2010b). Phase 2 will be completed in 2013 and it will investigate the impacts of climate change on urban temperature profile and energy consumption of buildings, public health, and biodiversity.

Climate change presents both significant challenges and potential opportunities for the water sector in Singapore. The National Climate Change Strategy 2008 (Strategy or NCCS) represents Singapore's 'holistic' and 'comprehensive' national policy for climate change mitigation and adaptation. The Strategy identifies the following potential impacts of climate change on the water sector: increased flooding, coastal land loss and water resource scarcity (MEWR, 2008, p. 7).

Coastal Erosion and Land Loss

Low-lying coastal regions and islands are the most vulnerable to sea level rise (see Ng and Mendelsohn, 2005). Much of Singapore is less than 15 meters above sea level, with a relatively flat coastline of 180 km (MTI, 2010).[4] Given its limited land availability, the entire population of Singapore lives within 100 km of the coast. Several essential infrastructure facilities are built less than two meters above sea level, on reclaimed land, including the airport, ports, commercial and residential buildings and roads (Arnold, 2007). Therefore, land loss and coastal erosion resulting from sea level rise could have implications for Singapore (MEWR, 2008, p. 8).

Flooding

Another consequence of sea level rise will be that rainwater cannot be drained into the sea. This may aggravate inland flooding in some areas during storm surges and rainstorms (MEWR, 2008). Sea level rise and increase in rainfall may also exacerbate the occurrence of extreme weather events. Singapore has experienced a significant decrease in annual rainfall over the past three decades, but with more intense rainfall during the monsoon season, leading to flooding (WWF, 2009).

[3]Desalination technologies can be classified by their separation mechanism into thermal and membrane based desalination (Fritzmann *et al.*, 2007).(i) Thermal desalination separates salt from water by evaporation and condensation (for example, multi-stage flash distillation, multi-effect distillation and vapor compression distillation).(ii) In membrane desalination, water diffuses through a membrane, while salts are almost completely retained (for example, reverse osmosis, nanofiltration and electrodialysis).

[4]The highest point (Bukit Timah Hill) is situated 165 meters above sea level.

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Water Supply

The main features of Singapore's climate are the relatively high but stable temperature throughout the year due to its close proximity to the Equator (1°18' or 130 km north), and high humidity and abundant rainfall (MTI, 2010, p. 15). Increase in temperature as a result of climate change will lead to more loss by evaporation, which may affect water demand and PUB's ability to meet the demand.

Local catchment water is stored in reservoirs. Unpredictability in rainfall may cause difficulties in capacity planning of water resources and affect the amount of water stored in reservoirs. Sea level rise and increase in rainfall may affect the reliability and safety of reservoirs. For example, several reservoirs are located adjacent to the coast and therefore, they may be prone to water contamination from seawater intrusion. However, the Strategy argues that this is unlikely, as most of the reservoir dams are much higher than the projected sea level rise and the gate structures can be raised (MEWR, 2008, p. 9).

Climate Change Adaptation Initiatives in Singapore

Institutional and Policy Framework

Singapore became a party to the UNFCCC in 2005 and the Kyoto Protocol in 2006 and it is a non-Annex I (developing) country. In accordance with the requirements of the UNFCCC, Singapore submitted its second national communication in November 2010. At the national level, the government has engaged in the development and implementation of an appropriate institutional and policy framework. MEWR serves as the national focal point for the UNFCCC. The National Climate Change Committee (NCCC), established in 2007, is responsible for the development and implementation of policies, plans and measures for climate change mitigation and adaptation. Its mandate includes understanding Singapore's vulnerability to climate change (NCCC, 2007).

The National Climate Change Secretariat, which was established under the Prime Minister's Office on 1 July 2010, coordinates climate change policies across government agencies. It supports the international negotiations and also coordinates domestic mitigation and adaptation responses to climate change through an Inter-Ministerial Committee on Climate Change (Tan, 2010). An inter-ministry Adaptation Taskforce, led by the Ministry of National Development, is responsible for reviewing the sufficiency of existing adaptation measures and identifying new measures.

Adaptation Measures for the Water Sector

Singapore's adaptation policy relies on existing water practices and technologies, which are the result of past environmental and development planning, and includes a commitment to the development of new adaptation measures.

Coastal Erosion and Land Loss

According to the Strategy, 70–80 percent of Singapore's coastal areas are protected against coastal erosion by hard wall or stone embankments; the rest are natural areas, such as beaches and mangroves. Other protection measures may include strengthening and reinforcement of existing revetments (which protect against erosion) and different coastal defense systems (MEWR, 2008). Sea level rise can also lead to loss of mangroves, which may aggravate coastal erosion. However, policymakers have recognized the importance of mangroves as an effective natural adaptation measure. National Parks (NParks) is developing pre-emptive management strategies to counter mangrove erosion at some coastal areas (MEWR, 2008).

Flooding

In the short to medium term, the existing infrastructure is expected to provide an adequate buffer against the projected sea level rise (MEWR, 2010b). The Strategy identifies several measures that have been undertaken by PUB in order to reduce the possibility of increased inland flooding. Since 1991, new reclamation projects are required to be built to a platform level (or general ground level of a proposed development) of 125 cm above the

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highest recorded tide level (that is, 66 cm higher than the IPCC's highest projection of 59 cm) (MEWR, 2008). PUB is exploring the possibility of further increasing this requirement.

Although they were not specifically formulated for climate change adaptation, PUB's drainage infrastructure policies have led to a significant reduction in flood-prone areas from 3178 ha in the 1970s to 98 ha in 2010 (Chang, 2010). In order to further reduce the flood-prone areas to less than 40 ha by 2013, PUB is developing and improving the infrastructure, including the widening and deepening of drains and canals, and the completion of the Marina Barrage, which will act as a tidal barrier to keep out the high tides, as well as other flood alleviation projects (MEWR, 2008). The PUB is also expanding the network of water level sensors (from 32 to 90) in order to improve response to the impact of floods. It is conducting a study to consider the revision of drainage design standards to cater for heavier storms (MEWR, 2010b).

Water Supply

Although PUB's water strategy was not initiated in response to climate change, it performs an important role in adaptation to climate change insofar as water supply is concerned. NEWater and desalination – the two water technologies that are not rainfall dependent – are an integral part of Singapore's climate change adaptation policy. They diversify and increase the resilience of water supply, and supplement reservoir stocks in the event of extended dry spells (MEWR, 2008, p. 9).

However, NEWater and desalination are engineering and technical solutions; just as they cannot, on their own, achieve self-sufficiency for Singapore, over-reliance for adaptation to climate change is misplaced. A substantial amount of energy is used for pumping raw and treated water, and for treating raw water and sewage effluent. The price and availability of energy is, therefore, a key cost and determinant of how supplies are provided to the public, and future price and availability will influence changes in the way water is supplied (Arnell and Delaney, 2006). The desalination process involves high costs, it is energy intensive and its ecological footprint (for example, impact on ocean biodiversity) may be considerable. Research efforts are ongoing to find ways to reduce the energy consumption so as to lower its overall treatment cost.

Further, in order to complement supply-side measures, PUB has implemented non-physical water infrastructure, or a combination of water demand management strategies, which include water pricing, regulations and public education. These measures can perform the role of soft technologies for climate change adaptation in the water sector, which can lead to long-term behavioral changes with significant adaptation potential.

Discussion

The Strategy relies heavily on the IPCC's projections in order to determine Singapore's climate-change-readiness. This trend is also reflected in the NEA's vulnerability study. However, it is difficult to assess the likely risk posed by climate change and recent studies argue that the IPCC's estimates are conservative (see, for example, Arnold, 2007). The Strategy adopts a flexible approach and it is committed to research into better vulnerability assessments and development of adaptation technologies to improve the understanding of climate change effects and to address vulnerabilities more effectively.

Climate change is dynamic in nature and the future impacts cannot be predicted with certainty. The Strategy recognizes that existing adaptation measures can only address 'certain' potential impacts of climate change (MEWR, 2008). It does not consider the potentially negative spillovers for Singapore, for example, as a result of serious disruptions to food production in neighboring countries, because climatic extremes may affect water inputs (see Hamilton-Hart, 2006, in the context of mitigation).

It may be argued that, although the Strategy includes several initiatives, actual aims are missing. In the context of coastal erosion and land loss, for example, the Strategy states that the government will 'look at' adapting to sea level rise through the protection of the foreshore and coastal areas, 'as the need arises'. The adoption of such an approach is partly attributable to the fact that the costs and benefits of adaptation measures can be estimated with reasonable accuracy for only a limited number of options (de Bruin *et al.*, 2009, p. 37). Knowledge gaps and missing or unreliable data have also contributed to the adoption of this reactive approach.

The Strategy further illustrates the adaptive management approach of the government. For instance, the government agencies have committed to cooperate to assess the potential impacts, regularly review the sufficiency of existing

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adaptation measures, identify new measures ‘as necessary’ and establish national systems to actively monitor and manage impacts of climate change (MEWR, 2008, p. ii). The Strategy will also be periodically reviewed, to reflect technological advances, further evidence on climate change science and the evolving international climate change negotiations (MEWR, 2008).

Concluding Remarks

Although Singapore lacks access to natural sources of water, significant progress has been made towards ‘closing the loop’ and achieving water self-sufficiency. Tortajada (2006, p. 229) attributes the successful management of Singapore’s water and wastewater to ‘its concurrent emphasis on supply and demand management, wastewater and storm water management, institutional effectiveness and creating an enabling environment, which includes a strong political will, effective legal and regulatory frameworks and an experienced and motivated workforce’. The presence of a supportive environment for research and development of new technologies and the availability of financial resources have been integral to Singapore’s water management framework and, more recently, the development of climate change adaptation measures for the water sector, as highlighted in the National Climate Change Strategy.

Although the challenges posed by climate change are widely recognized, the scale of the implemented adaptation measures is constrained due to several considerations. These include uncertainty in the magnitude of future climate change, climate change being seen as one amongst several pressures, and the limited effects of climate change over the short-term planning horizon relative to other pressures etc. However, instead of resorting to ‘no action’, the Strategy commits to adaptation, by deploying pre-existing water technologies and operational measures and committing to the development of further adaptation measures, as the need arises. However, the approach is mostly reactive and reflective of the general uncertainty surrounding climate change and its potential impacts.

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