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Institutional capacity and policy options for integrated urban water management: a Singapore case study

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Abstract

Singapore is an exemplary model of integrated water management, according to the World Health Organization, and its experiences can be shared with others. Water security is not just the government's responsibility but has become everyone's business. Singapore has been selected as a case study for integrated urban water management (IUWM), and the methodologies used in Singapore, a developed city state, may be applicable elsewhere. An integrated regulatory framework, sound policies to control and implement programmes, public–private partnership in water services delivery, and stakeholder participation at all levels are necessary to make integrated water resource management successful. This paper demonstrates how Singapore has successfully turned its vulnerability with regard to water into a strength. Singapore can achieve greater sustainability if it promotes rooftop rainwater harvesting as a decentralized, dual-mode water supply system for non-potable use.

Keywords: Integrated water resource management; Political will; Security; Stakeholders' commitment; Storm water harvesting; Sustainability

1. Introduction

In 1992, in Dublin at the International Conference on Water and the Environment, a global consensus was developed on how to manage water resources holistically and sustainably. Singapore adopted the Dublin Principles on Integrated Water Resources Management (IWRM). At the 2nd World Water Forum in 2000, in The Hague, it became obvious that everyone needs to participate to achieve water security (Rijsberman, 2000). The development and management of freshwater resources can only be brought about by commitment, from the highest governmental levels to the lowest community level, involving significant investments, public education, legislative and institutional changes, technology and capacity building.

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Singapore has been selected as a case study on diversified IWRM to demonstrate how political stability, societal leadership, political will, and public–private partnership are important ingredients in the achievement of water security and sustainability. Singapore's population is projected to grow to 6.5 million over the next 40 to 50 years to sustain continuing dynamic economic growth (Associated Press, 2007). To achieve this, it must meet demand for increased water consumption from the residential, commercial and industrial sectors. Singapore has now achieved near self-sufficiency through careful planning and leveraging of technology. It relies heavily on technology to produce recycled used water (NEWater) and desalinated water as an additional water source, and will have a robust water supply for a long time. Singapore, before 2002 when it only had two "National Taps"—the reservoirs and imported water, was considered a water-scarce country because of its limited land area to catch rainfall. Its annual average rainfall of 2,400 mm is well above the global average of 1,050 mm (Table 1) (Kog *et al.*, 2002; MEWR, 2005b). Singapore's water catchment will increase from one-half to two-thirds the size of the

Table 1. Key environmental statistics (2004–2007).

	Unit	2004	2005	2006	2007
*Water resource management**					
Drinking water (% access)	%		100	100	100
Adequate sanitation (% access)	%		100	100	100
Drinking water quality (meeting WHO standard)	%		99.96	99.99	99.96
Water consumption as % of water demand met by total water resources	%		100	100	100
Unaccounted for water	%		5.0	4.5	4.4
*Water supply**					
No. raw water reservoirs in Singapore	–		14	14	14
No. rivers	–		32	32	32
No. desalination plants	–		1	1	1
No. storm water ponds	–		15	15	15
Potable water sales in Singapore:					
Domestic	‘000 m^3/day		694	702	724
Non-domestic	‘000 m^3/day		512	528	524
Total	‘000 m^3/day		1,206	1,230	1,248
No. of NEWater plants	–		3	3	4
Sale of NEWater	‘000 m^3/day		73	81	134
Sale of Industrial Water	‘000 m^3/day		107	112	80
Volume of used water treated	‘000 m^3/day		1,352	1,399	1,469
*Water demand**					
Domestic water consumption per capita	Litres/day	162	160	158	157
		1965	1985	2005	2008
Singapore population†	Million	1.89	2.74	4.03	4.84
Land area‡	m^2	670	670	689	707
		1970s	1980s	1990s	2005
Flood-prone areas§	Hectares	3,180	1,520	280	150
Rainfall (annual average)§	mm	2,400			

* MEWR (2008).
† Singstat (2008).
‡ NationMaster (2005).
§ MEWR (2005b).

island with the Marina Reservoir, which was completed in June 2008, and the Punggol–Serangoon Reservoir, which is hoped to be completed by end of 2009 (PUB, 2005; MEWR, 2008). Through technological advances, Singapore hopes to extend its water-capturing areas to 90% of Singapore to serve as water catchment. If rooftop rainwater harvesting (RWH) is implemented as a decentralized, dual-mode water supply system, this target could easily be met. Presently 50% of fresh water is from local catchments, and more than 40% is imported water from Malaysia. The Public Utilities Board (PUB), Singapore's national Water Agency, adopted the 'Four National Taps' strategy to increase water resources (MEWR, 2005a). Singapore's institutional structure and capacity have evolved and transformed over the decades, particularly the policies responsible for success and the lessons that might be of value to the rest of the world. Singapore has changed dramatically from a conventional single water supply (i.e. reservoir) system into the present diversified water resources system (i.e. water from local catchment, imported water, recycled used water and desalinated water). The research summarized in this paper suggests that Singapore can achieve greater sustainability by introducing rooftop RWH as an additional decentralized, dual-mode freshwater source as this has not yet been exploited on a significant scale.

2. Evolution of institutional capacities and diversification of water supply

The Singapore Municipality provided water when Singapore was first founded in 1819. The first piped water was made possible when Singapore's oldest reservoir, the MacRitchie Reservoir, was built. This was followed in 1910 by the Kalang River Reservoir (renamed Pierce Reservoir in 1922) and the Seletar Reservoir in 1920 (Kwa & Joey, 2002). The City Council took over the Municipal Commission's responsibilities when Singapore acquired city status in 1951. PUB, inaugurated in 1963, assumed this responsibility. Singapore's water supply capacity has been developed by the Water Agency since independence in 1965.

Singapore's focus is on capturing and storing surface water, as it does not have significant underground water. The Western Catchment Scheme, started in 1977 and completed in 1981 at a cost of S$67 million (Singapore dollars), dammed the river estuaries of of Murai, Poyan, Sarimbun and Tengeh in the western part of Singapore (Dudley & Stolton, 2003). The Sungei Seletar/Bedok Water Scheme was completed in 1986 by creating the Lower Seletar and Bedok Reservoirs (Kwa & Joey, 2002). Its unique feature was the construction of nine storm water collection stations to tap storm runoffs from the surrounding urbanized catchments. The reservoirs and storm water collection ponds enable Singapore to collect on average about 680,000 m^3 of rainfall daily (Lee, 2005). With daily water consumption at 1.2 million m^3 per day, Singapore's local catchment can supply about 50% of Singapore's daily water needs; this does not include direct rooftop RWH for non-potable use.

Singapore first received a water supply from Johor in 1932 when the Gunong Pulai Scheme was started. Singapore receives half of its approximate 300 million gallons/day (mgd) (1.36 m^3/day) usage from Johor, and another 150 mgd (0.68 m^3/day) from its Central Catchment Reservoirs. During the City Council years (1951–1963), the 1961 (Tebrau and Scudai Water) and 1962 (Johor River) Agreements (Table 2) were signed with the State Government of Johor. In 1990, Singapore also signed the Linggiu Dam Agreement with Malaysia. Over S$1 billion (i.e. US$500 million) had been spent on the Johor water projects to obtain water supply from Malaysia (Ministry of Information, 2003). Malaysia and Singapore have yet to agree on raw water pricing when the 1961 and 1962 Agreements expire in 2011

Table 2. 1961 and 1962 water agreements with Malaysia (Source: Singapore Ministry of Information, Communication and the Arts, 2003).

	1961 Agreement: Price revision in 25 years and arbitration	1962 Agreement: Price revision in 25 years and arbitration	Combined Agreements
Singapore	Johor to supply 100 mgd (0.46 million m^3/day) of raw water from Sungei Tebrau and Sungei Skudai for 50 years at cost: RM0.03 Ringgit for every 4,546 m^3 (1,000 gallons).	Johor to supply 250 mgd (1.15 million m^3/day) of raw water from Sungei Johor for 99 years at cost: RM0.03 Ringgit for every 4,546 m^3 (1,000 gallons).	Allows water drawing up to 350 mgd (1.61 million m^3/day).
Johor	Johor to pay Singapore M RM0.5t for every 4,546 m^3 (1,000 gallons) of treated water, which costs Singapore RM2.40 Ringgit to treat for every 4,546 m^3 (1,000 gallons).	Johor pays Singapore RM0.50 for every 4,546 m^3 (1,000 gallons) of treated water, which costs Singapore RM2.40 Ringgit to treat for every 4,546 m^3 (1,000 gallons)	N/A
	1961 Agreement: On expiry in 2011	1962 Agreement: On expiry in 2061	N/A
Singapore	No provision of raw water; Johor willing to supply same 100 mgd (0.46 million m^3/day) of treated water, if Singapore desires.	Johor will take over treatment plant at Sungei Johor, and is willing to supply to Singapore: i) 100 mdg (0.466 million m^3/day) of raw water; ii) 250 mdg (0.15 million m^3/day) of treated water.	N/A

and 2061 (Lim, 2003). Singapore has looked elsewhere, as Malaysia has threatened to cut off its water supply at various times (whenever specific diplomatic, economic or political stances ran contrary to Malaysia's interests) since its acrimonious separation from Malaysia in 1965.

In 1991, a bi-lateral water agreement was signed with Indonesia to develop water resources on the Riau province to supply water to Singapore for 50 years (Kog, 2001; Kwa & Joey, 2002). Total investments in the Riau projects would amount to US$10.3 billion over the life span of their development (Straits Times, 1993). This would also make Singapore vulnerable (Kog, 2004). As in 2002, Singapore only had two national taps: local catchment and imported water from Malaysia. Because of its vulnerability in terms of water, the Water Agency developed a new plan to increase water self-sufficiency for the post-2011 period, by increasing efficient water management, implementing new water-related policies, investing heavily in water technologies such as desalination, reuse of wastewater and catchment management. Technologies were harnessed to produce NEWater and desalinated water as Singapore's third and fourth national taps.

3. Policy options

Sound water policy is Singapore's top priority because it is crucial to Singapore's survival. Planning for water policies started from the outset, coordinated by the Prime Minister's Office. According to the Chairman of the World Water Commission on Water for the 21st Century, almost all countries today have inadequate water policies, as water use is unsustainable in many places (Serageldin, 1999). If everyone learned how to live with existing resources and planned better for the future, water problems could be managed (International Institute of Sustainable Development (IIOSD), 1998). The World Bank postulates that government is the essential force behind successful water policy, strategy, planning and implementation (IBRD, 2006). To implement different elements of its water policies, a key component of Singapore's water resource management is institutional reform to concentrate all water-related administration under one roof.

3.1. Institutional reform

In the past, water supply and sewage treatment were managed separately by different institutions. To implement the IWRM strategy, PUB was reconstituted as a single water authority in 2001 to have control over the complete water cycle. The Sewerage and Drainage Departments of the Ministry of Environment (MOE) were integrated with PUB's Water Department to form the new PUB, which was transferred to the MOE from the Ministry of Trade and Industry (PUB, 2001). The reconstituted Water Agency was a comprehensive water authority whose responsibilities extended to include sewage treatment and reuse, flood control, water resources and supply, with control over the entire water loop (PUB, 2001). The Ministry of Environment and Water Resources (MEWR) was formed on 1 July 2002 to replace MOE, and the PUB became part of MEWR. The newly established MEWR has full responsibility for water-related affairs, policy formulation, planning and infrastructure. It eliminates administrative barriers in water management and makes implementation effective and efficient. The Water Agency, MEWR and other government agencies' emphasis is now on sustainability with the people–private–public sectors (the 3P Partnership) working with the Water Agency to achieve environmental sustainability (see Section 3.6).

3.2. Integration with other sector policies

Singapore's water management involves the integration of land use planning with water resource management. The Urban Redevelopment Authority (URA) has an active role in national planning and industrial estate development where water is an important element. In addition to the URA, the Water Agency works closely with the Housing & Development Board (HDB), National Environmental Agency (NEA), Jurong Town Corporation, Land Transport Authority and other governmental agencies.

Singapore does not have a combined sewage system. The separate sewage system allows used water to be collected, treated and reclaimed to produce NEWater. The separate waterways are kept clean and they have become a key source of Singapore's water supply. Considering the multi-faceted challenges involved in technical inputs, cost-effectiveness, social acceptability, environmental protection and public health concerns, an effective integrated policy is necessary (Livingston *et al.*, 2004). Singapore is successful in its water and wastewater management because of its concurrent emphasis on supply and demand management, wastewater and storm water management, institutional effectiveness and an enabling environment (Tortajada, 2006b).

3.3. Supply management

Surface water resource will always be an important source of water supply, as Singapore does not have significant natural groundwater or aquifers (Kwa & Joey, 2002). Maximizing the local catchment is one facet of the strategy to increase water resources. In the 1960s and 1970s, the Water Agency adopted a strategy of building new reservoirs and storm water ponds to expand water supplies. Through coordination between the various government agencies in land use planning, housing, environment, trade and industry, and transportation, a massive 10-year clean-up programme for the Singapore River was launched. The clean-up was significant as it facilitated the development of more water catchment areas. Singapore's 14 reservoirs will be increased to 17 by 2009 to serve a population of 4.5 million people (CIA, 2006). To maximize storage capacity, an Integrated Reservoir Scheme, completed in 2007 at a cost of S$18 million, connects the 14 reservoirs together through a system of pumps and pipelines, where excess water is pumped from one reservoir to another for storage when the capacity of the first is exceeded. This helps maximize the yield capacity of the reservoirs (MEWR, 2005b; MEWR, 2008).

NEWater is the pillar of Singapore's water supply diversification strategy. It is the result of an important paradigm shift, where wastewater is viewed as an important resource to be recycled and reused (Khoo, 2006). A new term, 'used water', was substituted for 'sewage' to encourage the public to look at water as a renewable resource. NEWater is aimed partly to replace imported water under the 1961 Agreement, since 20% of water supply could be replaced through this method. With four NEWater plants currently in operation, it has already exceeded its target to meet 15% of Singapore's water demand by 2010 (PUB, 2008b). When Changi NEWater plant is completed in 2010, NEWater will be able to meet 30% of Singapore's water needs by the year 2011 (PUB, 2008b). NEWater is primarily for the wafer fabrication plants which need ultra-pure water for wafer manufacturing processes. This achievement is a first in the world (Tao *et al.*, 2006). Increased demand for NEWater from the commercial and industrial sectors will release more potable water (Table 1); it is hoped that NEWater will meet a 2.5% target for water consumption, for indirect potable use by 2011 (UNEP & GEC, 2005). Social acceptance and institutional adaptation are critical in the acceptance of technological innovation (Frew & Marriner, 2007). NEWater's evolution has spanned more than three decades from the first NEWater Masterplan in 1972 (PUB, 2005), and was introduced after much research and preparation. In contrast, when Australia's driest state, Queensland, proposed the use of recycled wastewater to add to its drinking water supply, it was rejected publicly even though it is already used for irrigation (Mcguirk, 2007). Critics claimed that the rejection was mainly out of fear (Manners & Dowson, 2006; Frew & Marriner, 2007). The Australian Prime Minister's Office's provision of A$10 billion (US$7.7 billion) to tackle the problem was also inadequate (BBC, 2007). Singapore's public acceptance is high because there was open engagement on the necessity of accepting reclaimed water to supplement Singapore's water supply.

3.4. Demand management

During the last two decades, the IWRM has put a comprehensive demand management policy in place, with a multi-prong approach to water conservation to keep consumption levels in check. This approach includes public education, water pricing, mandatory water conservation requirements, a Water Efficiency Labelling Scheme (WELS) in homes, and efficient management of water distribution (Australian Government, 2006; PUB & SEC, 2006). Per capita domestic water consumption decreased from 176 litres per day in 1994 to 157 litres per day in 2007 (Figure 1) (Kwa & Joey, 2002).

Singapore's water tariff recovers the full cost of production and distribution. All homes and industries are metered for water charges. A water conservation tax is levied by the government to reflect the limited supply of water and the higher incremental cost of additional supplies. The current tariffs levied have not been increased since July 2000, and are summarized in Table 3. Mandatory measures include the use of low capacity flushing cisterns and constant flow regulators (Kwa & Joey, 2002; Khoo, 2006). Labelling

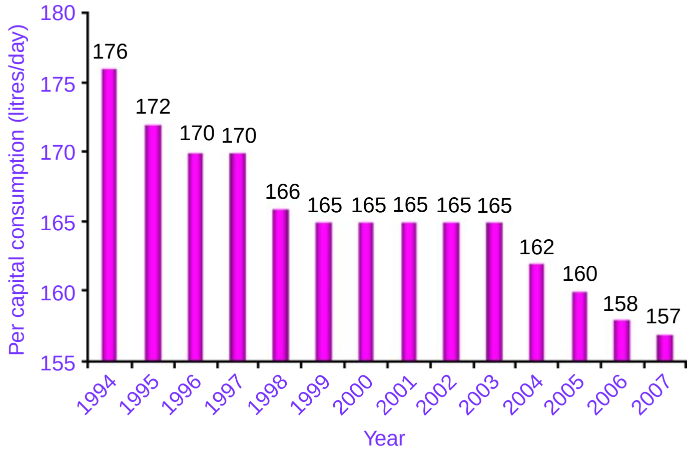

Fig. 1. Singapore per capita consumption of water (1994–2007). (Source: MEWR State of the Environment 2005 and 2008 Reports; PUB Financial Report 2007/2008).

in WELS has been mandatory for taps, flushing cisterns and urinals since July 2009 (PUB, 2008b). Results have been encouraging, as domestic water consumption per capita fell from 165 litres per day in 2003 to 160 litres per day in 2005 (Figure 1) (Khoo, 2006).

Public awareness is promoted through education, fiscal incentives and disincentives, and legislation. Incentives are offered to encourage private sector initiatives in wastewater recycling and reuse. The Water Efficiency Fund provides companies with financial incentives to look into efficient ways of managing water demand and to develop alternative water sources (PUB, 2008b). The tariff for industrial water is eight times lower than that for potable water, and liberal tax rebates are provided for factories that install water-saving plants under the 1994 Economic Expansion Incentives (Relief from Income Tax) Act (Chapter 86, section 67(e)) (Yap, 1995).

Vigorous on-going water mains replacement, leak detection, and accurate metering have resulted in lowering unaccounted-for water (UFW) from 11% in the 1980s to 10.6% in 1989, and to 5.2% in 2004 (Figure 2) (NEA, 2005). With this integrated approach, Singapore's domestic water consumption compares very favourably with that of other countries. It was reduced from 162 litres per capita per day (lcd) in 2004 to 160 lcd in 2005 (Figure 1), with Amsterdam at 156, Hong Kong 203, Sydney 254, Tokyo 268 and Los Angeles 440 lcd. The present target is domestic water consumption of 155 lcd by 2012 (PUB, 2006; MEWR, 2008).

3.5. Harness technologies

The Water Agency's goal is to help technology development and take a lead in harnessing water technologies to achieve sustainability. Some S$30 million had already been invested in R&D projects by PUB, which contributed to Singapore's 'four national taps' strategy to provide adequate water supply (MEWR, 2004). Desalination, reverse osmosis, membrane technology and their declining costs have enabled cities like Singapore to solve their water problems (Koh, 2008). Desalination costs fell from US$ 1.80/m^3 in 1997/1998 to about US$ 0.70/m^3 by 2001. They may fall further, making desalination as attractive as recycling, which presently is 50–60% cheaper than desalination (Koh, 2008). Singapore's

Table 3. Water tariffs (1997–2006) (Tortajada, 2006a).

Tariff category	Consumption block (m^3 per month)	Before 1 July 1997 Tariff (cents/m^3)	Before 1 July 1997 WCT (%)	Before 1 July 1997 WBF (cents/m^3)	Effective 1 July 1997 Tariff (cents/m^3)	Effective 1 July 1997 WCT (%)	Effective 1 July 1997 WBF (cents/m^3)
Domestic	1 to 20	56	0	10	73	10	15
	20 to 40	80	15	10	90	20	15
	Above 40	117	15	10	121	25	15
Non-domestic	All units	117	20	22	117	25	32
Shipping	All units	207	20	–	199	25	–

Tariff category	Consumption block (m^3 per month)	Effective 1 July 1998 Tariff (cents/m^3)	Effective 1 July 1998 WCT (%)	Effective 1 July 1998 WBF (cents/m^3)	Effective 1 July 1999 Tariff (cents/m^3)	Effective 1 July 1999 WCT (%)	Effective 1 July 1999 WBF (cents/m^3)	Effective 1 July 2000 Tariff (cents/m^3)	Effective 1 July 2000 WCT (%)	Effective 1 July 2000 WBF (cents/m^3)
Domestic	1 to 20	87	20	20	103	25	25	117	30	30
	20 to 40	98	25	20	106	30	25	117	30	30
	Above 40	124	35	20	133	40	25	140	45	30
Non-domestic	All units	117	25	42	117	30	51	117	30	60
Shipping	All units	199	25	–	192	30	–	192	30	–

1. Water Conservation Tax (WCT): levied by the government to reinforce water conservation;
2. Water Borne Fee (WBF) and Sanitary Appliance Fee (SAF): statutory charges prescribed under the Statutory Appliances and Water Charges Regulations to offset the cost of treating used water and for the maintenance and extension of the public sewage system. SAF is S$3 per sanitary fitting per month;
3. WBF and SAF charges are inclusive of goods and services tax.

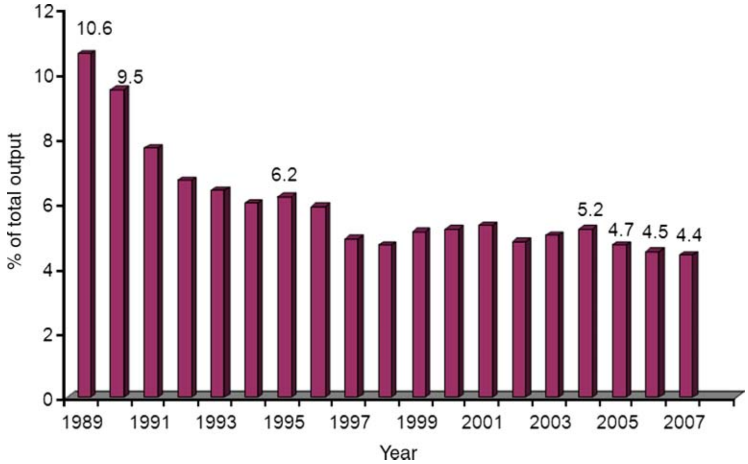

Fig. 2. Singapore unaccounted-for water (1984–2007). (Source: PUB Annual Reports 1989/1990 to 2007/2008; MEWR State of the Environment 2005 Report).

Tuas Desalination Plant, at a cost of S$200 million (US$120 million) in 2005, is the largest seawater reverse osmosis (SWRO) project in Asia, and one of the largest in the world. It produces 10% of Singapore's national water demand. The desalinated water cost in the first year of operation was S$0.78/$m^3$ (US$0.49/$m^3$), the world's lowest for desalinated seawater (Black & Veatch, 2006), in one of the most energy-efficient SWRO plants ever built (Tortajada, 2006a). Desalination costs are reasonable when compared to the construction costs of catchments and reservoirs. The Bedok/Sungei Seletar Reservoir Scheme cost S$11.35/$m^3$, five to eight times higher than the cost in less built up regions in Malaysia or Indonesia (Yap, 1995).

Singapore's NEWater application is the world's largest non-potable wastewater reuse system (World Bank & IBRD, 2006). Its NEWater strategy created the template for all water agencies that are looking to introduce potable water reuse (PUB, 2008a). The Deep Tunnel Sewerage System (DTSS) is cutting edge technology, the world's longest tunnel excavated by earth pressure balanced shield tunnelling (Sato *et al.*, 2004). At a cost of S$3.65 billion in the first phase of the project, the DTSS was constructed to provide Singapore with a long-term sustainable solution through used water collection, treatment and disposal for the next 100 years (MEWR, 2008; PUB, 2008b). It is more cost effective than the renewal and expansion of the existing system, and phases out six existing wastewater reclamation plants and 139 pumping stations, freeing about 1,000 hectares of prime land for development (Koo, 2004, Chiang *et al.*, 2005). The DTSS closes the water loop as every drop of used water is collected for producing NEWater (Chiang *et al.*, 2005).

3.6. 3P partnership and stakeholders' commitment

Through the 3P (people–private–public sector) Partnership approach, people (the general public) are encouraged to take ownership of water. The 3P Partnership approach includes stakeholders' commitment and private–public–partnerships (PPP). Stakeholders are those with a stake in water allocation, water use, water management, land use, economic development, social welfare and environmental protection. The goal is to maximize available water resources without compromising the sustainability of a healthy ecosystem (Kabir, 2004). Publicity, education and inclusion of all stakeholders (e.g. politicians, experts and the general public) in the decision-making process are the key elements of successful design and implementation of water or wastewater projects (Ashley *et al.*, 2001). Since much technical expertise exists there, Singapore's Water Agency involves the private sector to play a greater role in providing essential services through the PPP (see Section 3.7). The Active, Beautiful, Clean (ABC) Water programme is a major initiative involving the 3P Partnership, which has become an umbrella programme, to keep waterways clean. The catchments, reservoirs and waterways are integrated with the 3P Partnership to be managed holistically. The 3P Partnership is critical in the river clean-up, as these waterways would flow into the reservoir. Singapore's drainage infrastructure is well developed as more than S$1.2 billion has been spent by the MOE since 1984 to widen and deepen the drains and canals (Table 4 and Figure 3) (MEWR, 2000). The S$226 million barrage, part of a comprehensive flood control scheme, will reduce flood-prone areas further, from the current 150 hectares to 85 hectares (Table 1) (PUB, 2004). This is part of a significant development, with flood-prone areas being reduced from about 3,200 hectares in the 1970s to only 238 hectares in 2000 (Table 1) (MEWR, 2000; MOE, 2000).

3.7. Private–public partnership

PPP, launched in 2004, is the Singapore government's best sourcing framework for all government projects costing over S$50 million (MOF, 2004a; Ellis, 2007). Governments traditionally drew on government revenue to pay for public infrastructure and services. They now utilize partnerships between the public and private sector to bring more private money into the provision of public infrastructure and services (Blake, 2004). The advantages for the government are that private firms are an important financial source, the risks are transferred to the private firms, and government can use the private firms' management and technical expertise. The pros for the private firms are the huge potential profit returns; London Underground's average profit margins, for example, were estimated to be 5% (average industry norm is 3–4%) (Finn *et al.*, 2007). No statistics are available on profit margins for Singapore's NEWater and desalination PPP projects. The disadvantages of PPP include whether for-profit organizations can truly provide safe and efficient levels of water delivery service, whether government's public accountability is lost, and general problems associated with the co-ordination of the different sectors. PPP must demonstrate good management of actual or perceived conflicts of interest. The public authority must always act with the utmost probity and with transparent internal and external working processes. The question to ask is whether PPP is actually delivering, and not whether a PPP was the right or wrong way to approach the project in the first place.

The PPP challenges are long procurement timescales, high bid costs, inflexible long-term contracts, inadequate explanations of project requirements and optimal risk allocation. There are political risks, government performance risks, environment and safety risks, construction risks, technical operation risks, revenue risks in existing and newly built facilities, and financial risks (Audige, 2005; LATC, 2005). In addition to the risks listed in Singapore's PPP handbook, allocation of responsibilities for changes in law/tax, site risks, technological changes and *force majeure* should also be considered (MOF, 2004b). Singapore's PPP has succeeded because of transparency, fair competition, reasonable profit for the investor, a dependable regulatory environment and political commitment to PPP at all government levels, which is key to its success. There was careful planning in the early stages with the right professionals being involved at the right time. The Singapore government provided seed money, research

Table 4. Five years' summaries of capital expenditure for the PUB Board and its subsidiaries. (Source: PUB, 2007/2008).

	2003: 12 months (Jan–Dec) S$ million	2004: 12 months (Jan–Dec) S$ million	2005: 12 months (Jan–Dec) S$ million	2006: 15 months (Jan 2006–Mar 2007) S$ million	2007: 12 months (Apr 2007–Mar 2008) S$ million
PUB funded					
Water	214.8	95.8	36.4	106.7	177.8
NEWater	89.6	58.4	45.7	46.7	82.7
Used water	0.0	0.0	31.2	20.0	23.2
Others	3.5	0.7	0.2	5.4	0.9
*Government funded**					
Used water	695.0	801.4	700.6	632.0	256.0
Drainage	120.5	81.8	76.9	141.5	114.2
PUB	1,123.40	1,038.1	891.0	952.3	654.8
PUBC	2.7	15.0	1.5	1.8	1.4
Group	1,126.1	1,039.6	892.5	954.1	656.2

* Government funded capital expenditure are for projects belonging to the Government.

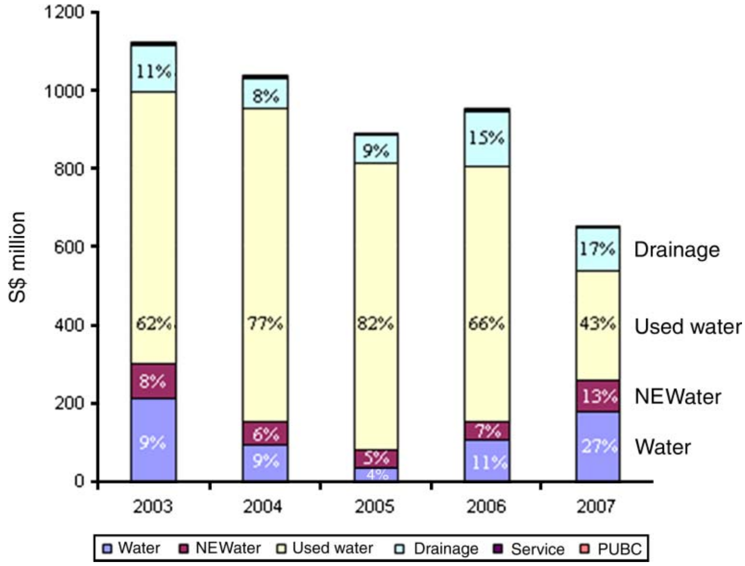

Fig. 3. Five years' summaries of capital expenditure for the PUB Board and its subsidiaries.

funds and even test-bedding facilities for the private sector. To create a competitive environment, competition by tender bidding in Singapore is based on meritocracy in cost, quality and delivery. Opportunistic behaviour cannot be allowed if PPPs are to finance public services better than the public sector. PPP is not to be at the expense of public funding (Hall, 2007). Some of the best water agencies, like PUB, are in the public sector, as only 4% of the urban population is served by private water operators (Koh, 2008). Singapore's Water Agency acted as an intermediary, linking academia with the corporate world. It is the first in the world to use a 16-inch (40.6 cm) reverse osmosis membrane, pioneered by its home-grown water company for use in producing reclaimed water (PUB, 2007). There is better asset utilization as Singapore Water Agency shares its facilities as test-bedding sites with a third-party innovator.

England and Wales has pursued a full divestiture to the private sector (Jones, 2000). In the US, the public sector still largely dominates where there is a part-public, part-private ownership structure, as in many OECD countries (OECD, 2003). In Singapore, the government still retains final responsibility for setting and enforcing performance standards, ensuring poor people have access to affordable water services (Rijsberman, 2000). Public agencies remain responsible for the initial allocation of water, regulation and monitoring of water quality (Dinar, 1998). The Singapore government's role remains crucial in providing a strong regulating and enabling environment. Public support is essential for successful implementation of the wastewater reuse projects (Friedler & Lahav, 2006). Singapore's PPP success in the desalination and NEWater projects is due to political and public support.

4. Dual water supply system

Rooftop RWH is a low technology, cost-effective, reliable source of water supply and should seriously be considered, as it is under-used in Singapore. As more than 80% of Singapore's population live in high-rise public housing, rooftops areas represent a significant potential catchment for rainwater collection. To promote rooftop RWH, mandatory provision in Singapore's Building Code is necessary. In Taiwan, a new provision was recently added into the National Building Code where RWH for building is stipulated as necessary under specified conditions (Cheng, 2004). When acceptable, an ordinance is usually passed, requiring all building constructions to include RWH facilities. Tax rebate incentives, found in Texas, Hawaii, the Caribbean islands, Australia, Germany and other European countries, are offered if the owner adds a RWH system to an existing building. If RWH is to be implemented, a new water paradigm is necessary for Singapore to promote rooftop RWH as a decentralised, dual-mode water supply system for non-potable use. Major barriers to change are the present law and regulations, and public health concerns about a possible dengue fever outbreak because of mosquitoes breeding in water containers.

Hong Kong is one of the world's few coastal cities that has adopted a dual water supply system for non-potable use (i.e. a seawater system for toilet flushing) (Tang *et al.*, 2006). Hong Kong has recently looked at a feasibility study to extend seawater supply into districts where potable water is still used for toilet flushing. Besides seawater, raw (untreated) freshwater and reclaimed water are also being considered for toilet flushing in these districts. In the Singapore scenario, case studies can be developed on the cost-effectiveness of promoting rooftop RWH for non-potable use. The results will determine the sustainability of using rooftop RWH as a decentralized, dual-mode water supply system for non-potable use.

5. Conclusion

Singapore's success in IUWM is unquestionable, with decreased domestic water consumption per capita, reduction in UFW, and a decrease in flood-prone areas. There is no 'one size fits all' solution to IUWM. Singapore's experience indicates that IUWM can be achieved with political will, good governance and a coherent water policy. Its integrated approach to water management has encompassed proper land use planning, judicial investments in infrastructure for water supply and used water, pollution control measures, and use of technology and public education, amongst others (Khoo, 2006). Singapore's success is due to decades of sustained, methodical development of water policy, public support and institutional reform, all of which have played a crucial role. Singapore can go one step further to achieve greater sustainability, if rooftop RWH is also implemented as a decentralized, dual-mode water supply system for non-potable use.

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