

Catching Rainfall in Marina Bay: Water Necessity, Policy, and Innovation in Singapore

By Silvia Schmid

As a small island-nation with few natural resources, Singapore has limited potential for self-sufficiency. Historically, efficient land use planning has been of particular importance due to the country's diminutive size, and innovative solutions have been championed to deal with fundamental public infrastructure development including waste management treatment plants, parks, and water facilities and reservoirs. Planners in Singapore must be proactive and inventive, devising efficient strategies for multiple land uses and placing more urgency on solutions to long-term challenges often deferred by other nations. Singapore's circumstances and responses have proved that "necessity is the mother of invention"; the country is home to an increasing number of "smart city" projects such as the country's offshore landfill, Palau Semakau, the first of its kind in the world of offshore waste management.^{1,2} More recently, Singapore demonstrated its innovative use of green infrastructure with the Garden by the Bay project, a series of vertically-growing gardens around tall steel trunks.³ Still, the most impressive smart project to date in the country is the construction of the Marina Barrage and Reservoir in 2010, one of the greatest advancements in water management technology. The multipurpose Marina Barrage and Reservoir serves as both a supply of drinking water and a means of flood defense. Most importantly, however, it is a giant display of the fundamental message of water conservation and protection, reinforcing the connection between aquatic systems and everyday life.

Water Shortages and Vision

Singapore became aware of fresh water shortages before much of the rest of the world.⁴ The country has a growing population of almost five million and an economy as big as Hong Kong's.⁵ To maximize the limited land, the government has strictly defined which zones are to be urbanized, and urban areas are of extremely high-density; nevertheless, what land is left for natural resources is still insufficient to sustain the population. Fresh water supply has been historically scarce, and the country has been importing drinking water from Malaysia as a way to provide for its fast growing populace.⁶ In the 2000s Singapore initiated drastic measures to improve its water supply with a Master Plan called ABC Waters: Active, Beautiful, and Clean, which includes more than 100 projects to protect water systems and improve water infrastructure.^{7,8} One of the most vital objectives was the diversification of water sources into "Four National Taps" for the supply of drinking water: along with the imports from Malaysia, Singapore would also desalinate marine water, recycle water from treated sewage and collect local rainfall.⁹ The island developed the Variable Salinity Plant, Asia's largest desalination facility using reverse osmosis membrane technology to produce drinking water.¹⁰ In addition, engineers designed a deep tunnel "superhighway" for the collection of raw sewage from through-

out the entire island, transporting the contents to an advanced sewage treatment plant also producing potable water.¹¹ The third initiative centered on the creation of a phenomenally innovative reservoir to extend water catchment.¹² While all three achievements are praiseworthy, the present paper focuses on the latter, the Marina Barrage and Reservoir, which also links all of the initiatives together and has become a new symbol for innovative water management.

The Marina Reservoir is a supply of freshwater located in Marina Bay next to Singapore's business district. Marina Bay is formed by the main island's largest estuary, the Marina Channel, and is home to many new development initiatives in the entertainment industry.¹³ The development project for the Marina Reservoir and Barrage was designed by Minister Mentor Lee Kuan Yew who, in 1987, had the idea of creating a unique "focal point" in the city in the form of an attractive "lake", which would also act as a freshwater reservoir.¹⁴ Because Singapore does not have enough space to collect rainfall, Mr. Kuan Yew devised a way to enlarge the island's catchment area by barricading the Marina Bay water zone to create a reservoir within the bay. The project was finally started in 2004.

The Infrastructure

The project was completed in two phases: first, with the construction of the barrage in 2008, and, second, with the process of natural replacement of salty water by rainwater in the reservoir. The Marina Barrage, an imposing dam built across the 350-metre wide Marina Channel, is designed to separate fresh water from the salty waters of the South Chinese Sea.¹⁵ On one side, it blocks freshwater flowing from multiple rivers from being dispersed into the sea. On the other side, the barrage prevents seawater from entering the bay, avoiding the contamination of the freshwater supply. In Appendix A, I describe the barrage's mechanism in detail and provide illustrations.

Author Silvia Schmid is a graduate student in the University of Pennsylvania's Master of Environmental Studies. Her contact is sschmid@wharton.upenn.edu.

***IGEL is a Wharton-led, Penn-wide initiative to facilitate research, events and curriculum on business sustainability. IGEL Research Briefs are written by students on relevant issues in business and the environment and do not represent the views of Penn, Wharton or IGEL. Learn more at <http://environment.wharton.upenn.edu>*



Marina Barrage, Reservoir and installation building, view from the sea.

The reservoir, with a catchment area of 10,000 ha and a surface body area of 240 hectares, is the nation's 15th reservoir, and supplies 10% of national demand.^{16,17} It also serves to recharge the larger capacity Upper Peirce Reservoir, located in the center of the island, by pumping fresh water through a 13.32km network of underground pipes.¹⁸ Together with Serangoon and Punggol, two new reservoirs constructed with similar barrages, the Marina Reservoir has achieved a water drainage basin spanning two-thirds of the country's total land area in 2011.^{19,20} Singapore is one of few nations in the world to harvest storm water on such a large scale for drinking water supply.²¹

Functions and Advantages

Although fresh water supplies are scarce on the island, flooding is extremely severe during the monsoon season. "The problem in Singapore is always water, either too little or too much" explains Yap Kheng Guan, a director of Public Utilities Board (PUB), Singapore's water agency.²² Therefore, to increase freshwater reserves, the collection of rainfall in a large catchment area is crucial, especially during the monsoon season. In addition to supplying fresh water, the Marina Barrage's complex infrastructure also serves as a flood control system: if the water level in the reservoir rises too high, pumps will distribute the water to other storage reservoirs.²³ Furthermore, in case of heavy rainfall during high tide, drainage pumps will flush excess water out to sea.²⁴ The infrastructure complements other flood prevention measures in Singapore to avoid the contamination of water bodies from sewage and urban runoff. Two separate systems already in place collect sewer and storm water respectively.²⁵

The Marina Barrage will also serve another important function, as it will help the island fend off sea level rise caused by climate change.²⁶ Because of its size and unique characteristics, like its incredibly high-density development, Singapore has had difficulties designing mitigation measures, such as the use of alternative energy sources. Wind, tidal, and geothermal sources are effectively nonexistent and, although solar energy would be a viable renewable source, the island is too small for large enough photovoltaic or concentrating solar power installations.²⁷ Consequently, Singapore is focused on energy efficiency and adaptation strategies. The Marina Barrage will protect the bay and other nearby low-lying areas from sea-level rise and related consequences such as saltwater intrusion, and it also will maintain a steady supply of freshwater regardless of change in rainfall patterns.²⁸ As a result of the barrage's successful flooding

defense mechanism, the government is even contemplating the construction of a complete seawall around the entire island to protect it from sea level rise.²⁹

As a manmade infrastructure challenging the land use limits imposed by nature, the Marina Barrage and Reservoir represents a technological breakthrough in reservoir creation. Planners and engineers overcame a succession of obstacles throughout the water project's development process. One of the principal challenges was cleaning up the Singapore River that had been severely contaminated by point sources, such as factories, as well as by farm and urban runoff and other non-point sources.³⁰ Highly advanced technology was designed to treat water from urbanized areas and to make improvements in desalination expertise to make the water drinkable.³¹ Further complications presented themselves during construction. At first, the barrage was unstable due to the presence of "marine clay" in the foundation, and rocks were needed to reinforce the base of the dam. In addition, central to the development of the city's enormous entertainment center, the dam needed to double as a large pedestrian bridge connecting the bay's south and east shores, therefore the infrastructure needed to be multifunctional and aesthetically pleasing to conform with the rest of Marina Bay's sophisticated development.³²

The Marina Barrage and Reservoir gained international recognition in 2010 by winning the prestigious Design Research Award at the International Water Association's Asia Pacific Regional Project Innovation Awards (Singapore's Variable Salinity plant also won the Applied Research Award).³³ As well as providing a fresh water supply and a flood defense mechanism, the Marina Barrage maintains an equal water level in the reservoir year round, allowing for kayaking, sailing and an assortment of other recreational uses. The reservoir has also been used to host large events like the 2010 Singapore International Water Festival and the Singapore International Water Week, with thousands of tourists and observers visiting from around the world.³⁴ The barrage itself has been the site of other "mega" events as well, including the Army Half Marathon and National Day celebrations.³⁵

The double land use of the reservoir –a recreational spot that also serves to improve the nation's various water concerns– contributes to the appeal of the infrastructure, which, in turn, helps facilitate a more informed connection between people and nature, particularly water's essential and multifarious role in daily life. When citizens appreciate the reservoir, they are more likely to cherish the water and take ownership of it, thus dimin-



Marina Barrage (in red), Marina Channel and Estuary.

ishing their inclination to pollute or vandalize it.³⁶ Singapore has successfully established water security as not only the responsibility of government, but also that of each individual.³⁷ The educational function of the Marina Barrage and Reservoir is further reinforced by the barrage's installation building, which hosts a sustainability gallery with an interactive multimedia exhibition, a green roof, and a 1200 m² photovoltaic installation, the nation's largest.^{38,39} The Marina Bay has also attracted private companies as sponsors for water-related projects around the reservoir, among them the soy sauce giant Kikkoman Corporation, which donated \$1 million to the nearby Gardens by the Bay project that filtrates water through complex water circulation systems and special plants before it enters the reservoir.⁴⁰ Moreover, Singapore's efforts to become a "living laboratory" for smart water management and planning have attracted local and foreign firms in the smart urban technology sector to develop, promote, and inaugurate their products in the country.⁴¹

Water Policy in Singapore

As the centerpiece of Singapore's exhaustive water management infrastructure, the Marina Barrage and Reservoir was designed to compliment the nation's many pre-existing initiatives. The entire water cycle of Singapore is currently managed by only one agency, PUB, which enables a holistic approach to water management encompassing a variety of functions ranging from supply and demand management to advanced technological systems.⁴² Beyond the ABC Waters Master Plan and the Four National Taps project, PUB has also focused on the "3P Approach": conserving, valuing and enjoying waters.⁴³ According to most indicators, PUB's overall performance ranks in the top 5% of all urban water utilities in the world.⁴⁴ Notable achievements include having 100% of the system metered, providing 100% of the population with access to drinking water, and suffering only 5% water losses.⁴⁵ Using smart sensor technology, PUB is able to quickly detect leaks in piping and immediately isolate leaking networks.⁴⁶ One advantage for PUB is that 85% of Singaporeans live in public housing, which presents fewer challenges when monitoring and maintaining water infrastructure.⁴⁷

While PUB is accountable for managing water supply, the Ministry of the Environment and Water Resources (MOEWR) was recently established to assume responsibility for water re-

lated affairs –from policy formulation to infrastructure planning – in order to make implementation more efficient.⁴⁸ To date, the MOEWR has reduced water consumption through the implementation of conservation policies. With a view to limit consumption, Singapore enforces a Water Conservation Tax of 30% that increases to 45% if domestic consumption surpasses 40 m³ per month/connection.⁴⁹ In stark contrast, U.S. water pricing is based on an inverted block rate, where prices decrease when water consumption increases.⁵⁰ Additionally, the MOEWR imposes Water Borne Fees and Sanitary Appliances fees, designed to offset the cost of recycling water in treatment plants.⁵¹ Even though the monthly household water bill doubled between 1995 and 2004, average consumption has steadily declined, suggesting that these policies are effectively encouraging water conservation.⁵² It is also important to note that, in addition to its efficacy, this instrument for demand management has been fair; poor citizens receive a subsidy for their water expenses, a step forward for Singapore's typically anti-welfare government.^{53,54}

In terms of water quality, the Pollution Control Department (a division of the National Environmental Agency) conducts quarterly evaluations of water quality in both inland and coastal bodies and in both catchment and non-catchment areas.⁵⁵ Results from physical, chemical and microbiological analyses have shown very low levels of pollution since 2002 in reservoirs, rivers, streams, as well as in coastal waters.⁵⁶ However, it is imperative to bear in mind that analyses and total maximum daily loads for pollution control are relatively easy to identify in a country only 3.5 times the size of Washington D.C.⁵⁷ Singapore's tiny dimensions clearly contribute to effective water monitoring, including its additional precautionary planning for the prevention of oil and chemical spills in the Malacca and Singapore Straits.⁵⁸

The differences in water policy between Singapore and the U.S. extend well beyond conservation taxes and inverted block rates. When comparing governmental doctrines, policies and legislative enforcement, several disparities quickly emerge. First, when it comes to valuing clean water supply, in the Western U.S. the public seems to "have accepted the destruction of rivers and aquatic ecosystems as the inevitable price of progress".⁵⁹ Singapore has demonstrated the opposite philosophy. For example, the Singaporean government has used a successful scheme of water allocation that promoted infill and has limited sprawl through extremely high-density development.⁶⁰ This is one of many indications that the country has placed high value on the welfare of its water cycle in recognition of the fact that the entire nation's health and economic development largely depend on this resource.

Second, the enforcement of water regulation compliance differs greatly between the two countries. In the U.S., violations to the Clean Water Act (CWA) of 1972 are rising while enforcement by the Environmental Protection Agency (EPA) is decreasing.⁶¹ The situation is quite different in Singapore, where legislation enforcement for water supply and quality, for pollution control as well as water extraction, is strictly implemented.⁶² There, the public sewerage system is currently serving all industrial estates and the vast majority of residential estates; wastewater is to be discharged into the public sewerage if available, otherwise it needs to be treated to high standards before being discharged into streams or other waterways.⁶³ Water pol-

luters must pay hefty prices for effluent discharge permits similar to those of the National Pollutant Discharge Elimination System of the CWA, and violating the limits brings guaranteed fees of US\$4,000-8,000.^{64,65} As a result, few are inclined to violate these regulations.^{66,67} Regarding water extraction, usage is 100% metered in Singapore, and the installation of certain conservation devices, such as water saving taps, is mandatory throughout the country.⁶⁸ In the U.S., on the other hand, some states do not set limits on water extraction quantities. In Maine, for example, this has led to excessive water extraction and abuse by some private entities, predominantly Poland Spring and other bottled water companies.⁶⁹

A look at the coordination between governmental agencies in the two countries also reveals contrasts in the handling of drinking water safety. In Singapore, the government has strongly supported water policy strategy, integrating land use planning in order to tackle pollution problems at an early stage; improved coordination and communication between government agencies has helped ensure water management success in part by reducing conflicts of interest between departments.⁷⁰ In comparison, the EPA used to wield more power with the CWA and the Safe Drinking Water Act (1974), but its regulatory authority has been increasingly whittled down and is likely to diminish even further in the event of a GOP victory in the next presidential election. An egregious example of this has been the lack of regulation and proper monitoring of natural gas drilling practices under the SDWA, dating back to 2005 when the EPA was stripped of supervisory control of the industry with the Halliburton Loophole.⁷¹ Although Singapore has not yet found itself dealing with an enormous supply of cheap, domestic energy, it seems unlikely that the country's water regulation would be disregarded for energy production.

Finally, another difference between the nations can be perceived on an ethical/utilitarian level. The EPA has been aiming to protect wellheads and watersheds through the Wellhead Protection Program, which distances contaminating land uses and activities from the wells, and displays public signs to alert and inform citizens about responsible behavior when entering a particularly sensitive water resource area.⁷² This is not the case in Singapore, where almost a sixth of all the land acts as a catchment area for the Marina Reservoir, a main source of potable water, and thus responsibility for water safety is felt ubiquitously throughout the nation. This becomes increasingly important as PUB hopes to make 90% of Singapore into water catchment areas.⁷³ Instead of a riparian or a prior appropriation doctrine, Singapore relies entirely on a public trust doctrine, where the government administers and regulates water issues in the public interest.^{74,75}



Marina Reservoir and Bay, view from the sea.

Together these examples represent only a few of the many discrepancies between American and Singaporean regulatory approaches to clean water and safe drinking sources, and they are not representative of the entire spectrum of views within both countries. They do, however, serve to exhibit the nations' divergent trends of action and the polarity in their attitudes regarding the valuation and protection of water as a scarce resource.

Barriers and Recommendations for Improvement

Although the Marina Barrage and Reservoir has been considerably successful as an innovative solution to water management, there are several drawbacks and obstacles to be noted. First, the water quality of the reservoir will only be as clean as the citizens of Singapore will allow it to be. Despite the previously mentioned improving public attitude, there will always be the problem of polluters as well as the possibility of contaminant leaks.⁷⁶ Moreover, clean water becomes particularly difficult to maintain when the catchment area is the most urbanized and densely built in the world.^{77,78} This is particularly consequential at construction sites where discharged water draining into the waterways is often silty or muddy, dirtying the reservoir's water and also making it less aesthetically pleasant as a recreational site.⁷⁹ In addition, samples of water catchments before entering the reservoir have shown concentrations of many emerging organic contaminants, including pharmaceuticals and endocrine disrupting compounds.⁸⁰ These are thought to originate from non-point sources such as urban and storm water runoff, and will eventually increase concentrations in the Marina Reservoir.

A second disadvantage of this project is its limited adaptability to other countries, chiefly in relation to polluting behavior. Singapore is known for its exceptionally strict and unique regulations on civil conduct, such as fines of over US\$1,000 for parking a bicycle in a non-parking zone, a ban on chewing gum that is non-therapeutic, and the ability of any citizen to make an arrest.⁸¹ Citizen environmental stewardship is much more prominent than in other countries. Protecting bodies of water from runoff may not be such a priority in countries where the citizenry's sense of responsibility is lower, or where such strict policies condemning pollution of water bodies are traditionally lacking. For example, New York City has protected its watershed in the Catskill Mountains and severely limited development by buying land and protection easements, and has allocated funds for renovating or replacing septic tanks and other existing infrastructure.⁸² The city's actions were largely necessitated because the local residents do not feel an ownership over the water supply and, with few rules in place, have little incentive to protect water destined for New York City. Conversely, Singapore's holistic water system encompasses every citizen in the nation and, as mentioned before, responsibility for protecting water supply is everybody's business. These prospective impediments to its replication in other countries do not devalue the project's significance in its home nation, but do potentially dampen the global impact of Singapore's innovative planning strategies and technologies.

A third critique of the Marina Barrage is that the infrastructure severely disrupts the Marina Bay coastal area and estuary. Estuaries are delicate areas with wetlands performing a variety of tasks essential to the welfare of an ecosystem. The creation

of most of Singapore’s reservoirs has helped to preserve bio-diverse ecosystems, but the Marina Reservoir will have a negative impact, as species will be challenged to adapt to the change in salinity and will lose access to the sea.⁸³ A study on the Marina basin recorded 139 fish species, including four endangered, and predicts that only 25 of the species will survive in fresh water, and 17 others will survive but not be able to breed without access to the sea.⁸⁴ It remains difficult to predict many of the other environmental impacts of the Marina Reservoir, but the location should be monitored closely to gain a better insight into the many changes that will surely occur.

On the topic of potential improvements to the Marina Barrage and Reservoir, there are several promising possibilities. First, in order to reuse more water before sending it to the treatment plants, Singapore could promote the harvesting of rooftop rain-water feeding into a dual-mode supply system for gray water use.⁸⁵ Second, while the Marina Barrage is an impressive structure, its lack of natural resilience could prove problematic; it is likely, as Tom Horton suggests in his book “Turning the Tide: Saving the Chesapeake Bay”, that people are “putting too much faith in (...) human structures”.⁸⁶ Complementing the structure with natural resilience, like Horton’s idea of creating new wetlands with dredging fillings, could also help prevent flooding and restore some of the natural services provided by the ecosystems damaged by the closing of the estuary. Third, studies for new barrages should investigate the possibility of tidal energy generation, as a way of producing some of the power used by the infrastructure’s gates and pumps. Finally, an extensive analysis of pervious and impervious surfaces in the reservoir’s catchment area could help further reduce pollution and improve storm water management.

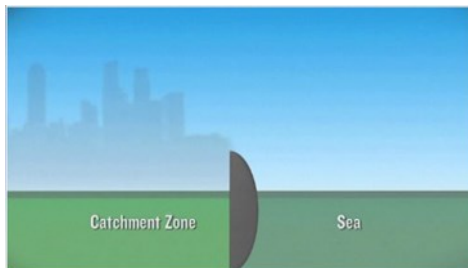
Conclusion

Singapore’s pioneering and versatile Marina Barrage and Reservoir provides an essential fresh water supply, alleviates flooding, and even serves as a recreational facility. The project

also demonstrates that holistic planning and collaboration between public agencies, private entities and the citizenry can together attain a more intelligent use of a scarce resource like water. It is clear that the necessary conditions for the successful realization and continuation of such a project are the product of an entire nation’s loyalty to strict water safety regulations. For that reason, it is important to view the Marina Barrage and Reservoir not only as a novel piece of physical infrastructure, but also as a symbol of the political and social infrastructure that enabled its fulfillment.

Appendix A: The Marina Barrage and Reservoir Mechanism

The Marina Barrage divides fresh water in the Marina Bay Reservoir from the salty waters of the South Chinese Sea. Incorporated in the barrage are nine large steel gates, each more than 30 meters tall, that can be raised or lowered depending on the need. As the water level in the reservoir rises, the gates angle downwards, releasing water out to sea but preventing the entry of water from the sea into the reservoir. Additionally, seven advanced large drainage turbines, installed near the bottom of the barrage, can also rapidly pump water out to sea. When the barrage was first erected, the reservoir contained a mixture of freshwater and seawater. The second part of the project was thus the removal of salt water from the reservoir. The desalination of the reservoir’s initial water was achieved through the natural process of replacement by rainwater, which began in April 2009.⁸⁷ The process lasted more than 15 months and reduced the concentrations of salt water from approximately 35,000 mg/l to around 2,000 mg/l.⁸⁸ At a cost of \$226 million, the bay has become a freshwater reservoir with a steady water level, ready to pipe water to treatment plants processing it into potable water.⁸⁹ The reservoir is cleaned daily to remove any littler and maintain a high quality of drinking water.⁹⁰



Left: Marina Barrage mechanism, showing vertical “closed” gates.
Right: Marina Barrage, with “closed” gates.



Left: Marina Barrage mechanism, showing diagonally tilted “open” gates.
Right: Marina Barrage, with “open” gates; excess water from the reservoir is



References for Images

Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
Public Utilities Board (PUB), Singapore's National Water Agency. Marina Barrage. 3 in 1 Benefits. <<http://www.pub.gov.sg/marina/Pages/3-in-1-benefits.aspx>> [accessed 10/5/2011].

References

- 1 Hoshaw, L. (8/15/2011). Refuse Collects Here, but Visitors and Wildlife Can Breathe Free <<http://www.nytimes.com/2011/08/16/science/16landfill.html?scp=1&sq=semakau&st=Search>> [accessed 10/5/2011].
- 2 The Economist. (11/4/2010). Living on a platform. For cities to become truly smart, everything must be connected. <<http://www.economist.com/node/17388308>> [accessed 10/5/2011].
- 3 Kolesnikov-Jessop, S. (7/28/2011). An Urban Jungle for the 21st Century. <<http://www.nytimes.com/2011/07/29/business/global/an-urban-jungle-for-the-21st-century.html?ref=energy-environment>> [accessed 10/5/2011].
- 4 Moseman, A. Plumbing the Planet: The 5 Biggest Projects Taking on the World's Water Supply. Popular Mechanics. <<http://www.popularmechanics.com/science/environment/water/4302532>> [accessed 10/5/2011].
- 5 The Economist. (11/4/2010). Every drop counts. Utilities are getting wise to smart meters and grids. <<http://www.economist.com/node/17388318>> [accessed 10/5/2011].
- 6 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 7 Public Utilities Board (PUB), Singapore's National Water Agency. ABC Waters Programme. <<http://www.pub.gov.sg/abcwaters/Pages/default.aspx>> [accessed 10/5/2011].
- 8 Sustainable Cities. Singapore: Active Living with Clean Water. <<http://sustainablecities.dk/en/city-projects/cases/singapore-active-living-with-clean-water>> [accessed 10/5/2011].
- 9 Ministry of the Environment and Water Resources. Policies: Water for all. <<http://app.mewr.gov.sg/web/Contents/Contents.aspx?ContId=960>> [accessed 10/5/2011].
- 10 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 11 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 12 Moseman, A. Plumbing the Planet: The 5 Biggest Projects Taking on the World's Water Supply. Popular Mechanics. <<http://www.popularmechanics.com/science/environment/water/4302532>> [accessed 10/5/2011].
- 13 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 14 Haoxiang, C. (11/21/2010). A reservoir 23 years in the making; Launch of Marina Reservoir is fruition of MM Lee's vision of freshwater lake in city. The Straits Times (Singapore). [accessed 10/5/2011].
- 15 Public Utilities Board (PUB), Singapore's National Water Agency. Marina Barrage. 3 in 1 Benefits. <<http://www.pub.gov.sg/marina/Pages/3-in-1-benefits.aspx>> [accessed 10/5/2011].
- 16 Public Utilities Board (PUB), Singapore's National Water Agency. Press Release. Marina barrage celebrates its one millionth visitor. <http://www.news.gov.sg/public/sgpc/en/media_releases/agencies/pub/press_release/P-20100530-1.print.html?AuthKey=> [accessed 10/5/2011].
- 17 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 18 Gunasingham, A. (4/10/2010). Marina Reservoir to be ready by year-end; but another dry spell may delay this as rain is needed to dilute salt content. The Straits Times (Singapore). [accessed 10/5/2011].
- 19 Public Utilities Board (PUB), Singapore's National Water Agency. Marina Barrage. 3 in 1 Benefits. <<http://www.pub.gov.sg/marina/Pages/3-in-1-benefits.aspx>> [accessed 10/5/2011].
- 20 Gunasingham, A. (4/10/2010). Marina Reservoir to be ready by year-end; but another dry spell may delay this as rain is needed to dilute salt content. The Straits Times (Singapore). [accessed 10/5/2011].
- 21 Public Utilities Board (PUB), Singapore's National Water Agency. Marina Reservoir. <<http://www.pub.gov.sg/Marina/Pages/mr.aspx>> [accessed 10/5/2011].
- 22 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 23 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 24 Public Utilities Board (PUB), Singapore's National Water Agency. (10/23/2008). Singapore's first reservoir in the city realized. <<http://www.pub.gov.sg/Marina/Pages/5.aspx>> [accessed 10/7/2011].
- 25 Public Utilities Board (PUB), Singapore's National Water Agency. Drainage. <<http://www.pub.gov.sg/general/drainageworks/Pages/default.aspx>>
- 26 National Climate Change Secretariat Prime Minister's Office, Singapore. Action Taken on Climate Change. National Circumstances. <http://www.iwa-pia.org/pia_winners_2010.html> [accessed 10/7/2011].
- 27 National Climate Change Secretariat. Action Taken on Climate Change. National Circumstances. <<http://app.nccs.gov.sg/page.aspx?pageid=113>> [accessed 10/7/2011].
- 28 Ministry of the Environment and Water Resources. (3/1/2008). Singapore's National Climate Change Strategy. <app.mewr.gov.sg/data/ImgUpd/NCCS_Full_Version.pdf> [accessed 10/5/2011].
- 29 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 30 Haoxiang, C. (11/21/2010). A reservoir 23 years in the making; Launch of Marina Reservoir is fruition of MM Lee's vision of freshwater lake in city. The Straits Times (Singapore). [accessed 10/5/2011].
- 31 Haoxiang, C. (11/21/2010). A reservoir 23 years in the making; Launch of Marina Reservoir is fruition of MM Lee's vision of freshwater lake in city. The Straits Times (Singapore). [accessed 10/5/2011].

- 32 Discovery Channel. (7/24/2010). Man Made Marvels. Marina Barrage Videos 1-11. <<http://www.yourdiscovery.com/video/playlists/marina-barrage/#player>> [accessed 10/5/2011].
- 33 International Water Association. (6/30/2010). Excellence in Asia Pacific Water Engineering Projects Recognised - Announcing the Regional Winners of the 2010 IWA Project Innovation Awards. <<http://www.iwahq.org/contentsuite/upload/iwa/Document/PIA%20Asia%20Pacific%20Winners%202010%20Release.pdf>> [accessed 10/5/2011].
- 34 Public Utilities Board (PUB), Singapore's National Water Agency. Press Release. Marina barrage celebrates its one millionth visitor. <http://www.news.gov.sg/public/sgpc/en/media_releases/agencies/pub/press_release/P-20100530-1.print.html?AuthKey=>> [accessed 10/5/2011].
- 35 Public Utilities Board (PUB), Singapore's National Water Agency. Press Release. Marina barrage celebrates its one millionth visitor. <http://www.news.gov.sg/public/sgpc/en/media_releases/agencies/pub/press_release/P-20100530-1.print.html?AuthKey=>> [accessed 10/5/2011].
- 36 Public Utilities Board (PUB), Singapore's National Water Agency. (10/23/2008). Singapore's first reservoir in the city realized. <<http://www.pub.gov.sg/Marina/Pages/5.aspx>> [accessed 10/7/2011].
- 37 Deh Chien Chen, Cedo Maksimovic and Nikolaos Voulvoulis. Institutional capacity and policy options for integrated urban water management: a Singapore case study. *Water policy*:2011, vol. 13(1), 53-68.
- 38 Sustainable Cities. Singapore: Active Living with Clean Water. <<http://sustainablecities.dk/en/city-projects/cases/singapore-active-living-with-clean-water>> [accessed 10/5/2011].
- 39 Public Utilities Board (PUB), Singapore's National Water Agency. Singapore's first reservoir in the city realized. <<http://www.pub.gov.sg/Marina/Pages/5.aspx>> [accessed 10/5/2011].
- 40 Lim, J. (11/2/2010). Kikkoman donates \$1m for Marina Bay lake; Soya sauce maker chose project as clean water is key to its trade. *The Straits Times* (Singapore). [accessed 10/7/2011].
- 41 *The Economist*. (11/4/2010). Living on a platform. For cities to become truly smart, everything must be connected. <<http://www.economist.com/node/17388308>> [accessed 10/5/2011].
- 42 Sustainable Cities. Singapore: Active Living with Clean Water. <<http://sustainablecities.dk/en/city-projects/cases/singapore-active-living-with-clean-water>> [accessed 10/5/2011].
- 43 Public Utilities Board (PUB), Singapore's National Water Agency. Water Planning and Management. Singapore International Water Week.
- 44 Tortajada C. Water management in Singapore. *International Journal of Water Resources Development*: 2006, vol. 22(2), 227-240.
- 45 Tortajada C. Water management in Singapore. *International Journal of Water Resources Development*: 2006, vol. 22(2), 227-240.
- 46 *The Economist*. (11/4/2010). Making Every Drop Count. Utilities are getting wise to smart meters and grids. <www.economist.com/node/17388318> [accessed 10/11/2011].
- 47 Chin, L. (2004). Public Housing Governance in Singapore: Current Issues and Challenges. National University of Singapore. <www.housingauthority.gov.hk/hdw/ihc/pdf/phgslc.pdf> [accessed 10/11/2011].
- 48 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 49 Tortajada C. Water management in Singapore. *International Journal of Water Resources Development*: 2006, vol. 22(2), 227-240.
- 50 Daniels, T, Daniels, K. (2003). *The Environmental Planning Handbook for Sustainable communities and Regions*. Chicago: American Planning Association Planners Press, p. 86.
- 51 Tortajada C. Water management in Singapore. *International Journal of Water Resources Development*: 2006, vol. 22(2), 227-240.
- 52 Tortajada C. Water management in Singapore. *International Journal of Water Resources Development*: 2006, vol. 22(2), 227-240.
- 53 Tortajada C. Water management in Singapore. *International Journal of Water Resources Development*: 2006, vol. 22(2), 227-240.
- 54 *The Economist*. (2/13/2010). Welfare in Singapore. The stingy nanny. The city-state stays strict with the needy. <<http://www.economist.com/node/15524092>> [accessed 10/5/2011].
- 55 National Environmental Agency. Environmental Protection Division. (2005). Annual Report. <www.nea.gov.sg/cms/pcd/EPDAnnualReport2005.pdf> [accessed 10/11/2011].
- 56 National Environmental Agency. Environmental Protection Division. (2005). Annual Report. <www.nea.gov.sg/cms/pcd/EPDAnnualReport2005.pdf> [accessed 10/11/2011].
- 57 Central Intelligence Agency. The World Factbook: Singapore. <<https://www.cia.gov/library/publications/the-world-factbook/geos/sn.html>> [accessed 10/11/2011].
- 58 Zengkun, F. (7/7/2011). NEA project to monitor coastal waters. *The Straits Time Singapore*. [accessed 10/11/2011].
- 59 Babbit, B. (2005). *Cities in the Wilderness*. Washington DC: Island Press, p. 129.
- 60 Babbit, B. (2005). *Cities in the Wilderness*. Washington DC: Island Press, p. 127.
- 61 Daniels, T. (10/11/2011). Lecture. Environmental Planning (CPLN 531).
- 62 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 63 Singapore National Environment Agency. Water Pollution. <http://app2.nea.gov.sg/topics_waterpollution.aspx> [accessed 10/11/2011].
- 64 Singapore National Environment Agency. Water Pollution. <http://app2.nea.gov.sg/topics_waterpollution.aspx> [accessed 10/11/2011].
- 65 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 66 Singapore National Environment Agency. Water Pollution. <http://app2.nea.gov.sg/topics_waterpollution.aspx> [accessed 10/11/2011].

- 67 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 68 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 69 Soechtig, S, Lindsey, J. (2009). Tapped. <<http://www.tappedthemovie.com/>> [accessed 10/11/2011].
- 70 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 71 N.Y. Times Editorial. The Halliburton Loophole, <http://www.nytimes.com/2009/11/03/opinion/03tue3.html>, 12/10/2010.
- 72 Daniels, T, Daniels, K. (2003). The Environmental Planning Handbook for Sustainable communities and Regions. Chicago: American Planning Association Planners Press, p. 89.
- 73 Chan, W. (11/20/2010). Marina Reservoir to supply 10% of water needs. <<http://www.channelnewsasia.com/stories/singaporelocalnews/view/1094602/1.html>> [accessed 10/5/2011].
- 74 Daniels, T, Daniels, K. (2003). The Environmental Planning Handbook for Sustainable communities and Regions. Chicago: American Planning Association Planners Press, p. 83.
- 75 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 76 Haoxiang, C. (11/21/2010). A reservoir 23 years in the making; Launch of Marina Reservoir is fruition of MM Lee's vision of freshwater lake in city. The Straits Times (Singapore). [accessed 10/5/2011].
- 77 Public Utilities Board (PUB), Singapore's National Water Agency. Press Release. Marina barrage celebrates its one millionth visitor. <http://www.news.gov.sg/public/sgpc/en/media_releases/agencies/pub/press_release/P-20100530-1.print.html?AuthKey=> [accessed 10/5/2011].
- 78 Gunasingham, A. (4/10/2010). Marina Reservoir to be ready by year-end; But another dry spell may delay this as rain is needed to dilute salt content. The Straits Times (Singapore). [accessed 10/5/2011].
- 79 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 80 The World Bank. Environment and Social Development East Asia and Pacific Region (7/1/2006). Dealing with Water Scarcity in Singapore: Institutions, Strategies, and Enforcement. <http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/WRM_Singapore_experience_EN.pdf>. [accessed 10/11/2011].
- 81 Yonglan, X, Fei, L, Amrita, P, Yew-Hoong Gin, K, Reinhard, M. Occurrence of emerging organic contaminants in a tropical urban catchment in Singapore. Chemosphere: 2011, vol. 83(7), 963-969.
- 82 Severgnini, B. (11/15/2007). Le fatue tentazioni di Singapore. <<http://www.corriere.it/solferino/severgnini/07-11-15/01.spm>> [accessed 10/5/2011].
- 83 Daniels, T. (10/11/2011). Lecture. Environmental Planning (CPLN 531).
- 84 Biodiversity Portal of Singapore. The diversity of life on Earth. Chapter VIII: Singapore, an interesting case study. <<http://www.biodiversity.sg/biodiversity-information/view-slideshow/singapore-an-interesting-case-study/>> [accessed 10/5/2011].
- 85 Hui, TH, Low, MEY, Peng, KKK. Fishes of the marina basin, Singapore, before the erection of the Marina barrage. The Raffles bulletin of zoology: 2010, vol. 58(1), 137-144.
- 86 Deh Chien Chen, Cedo Maksimovic and Nikolaos Voulvoulis. Institutional capacity and policy options for integrated urban water management: a Singapore case study. Water policy: 2011, vol. 13(1), 53-68.
- 87 Horton, T. (2003). Turning the Tide: Saving the Chesapeake Bay. Washington DC: Island press, p. 304.
- 88 Public Utilities Board (PUB), Singapore's National Water Agency. Marina Barrage. 3 in 1 Benefits. <<http://www.pub.gov.sg/marina/Pages/3-in-1-benefits.aspx>> [accessed 10/5/2011].
- 89 Gunasingham, A. (4/10/2010). Marina Reservoir to be ready by year-end; but another dry spell may delay this as rain is needed to dilute salt content. The Straits Times (Singapore). [accessed 10/5/2011].
- 90 Chew, V. (11/10/2008). Marina Reservoir. National Library Board Singapore. <http://infopedia.nl.sg/articles/SIP_1388_2008-11-22.html> [accessed 10/13/2011].