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Coastal Reservoir Strategy and Its Applications

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1. Introduction

While the world's population tripled in the 20th century, the use of renewable water resources has grown six-fold [1]. It is estimated that the world population will enlarge by another 40 to 50 % in the following fifty years. The demand for water will be increasing resulted by the population growth combined with industrialization and urbanization, which will have serious consequences on the environment. According to WHO/UNICEF Joint Monitoring Programme (JMP) (2012 Update), 780 million people lack access to an improved water source; approximately one in nine people [2]. Water stress causes deterioration of fresh water resources in terms of quantity (aquifer over-exploitation, dry rivers, etc.) and quality (eutrophication, organic matter pollution, saline intrusion, etc.). In the Developing World, women and children walk miles to get water. The UN estimates that the average is 40 pounds of water carried 4 miles (18 kg-6 km). This takes hours, people can't attend school/work, deforms the spine and can leave women vulnerable to assault [3]. Figure 1 showed the state of water shortages based on synthetic evaluation of water management using for agriculture in 2007.

As about 66% of the world population would be confronted with water-shortage by 2025 [5]; the water from aquifers, which provide water for one-third of the world's population, are being used out before nature can complement them [6]. Water scarcity is already a focus of attention all over the world [7]. For example, the Southwest and Midwest areas of the USA and Australia are vulnerable to water scarcity [8]. In Australia, water allocations for irrigation have caused a conspicuous decline in rainfall and runoff in the past decades [9]. Figure 2 shows drinking water as the substance to transform in a social life. Many indigenous peoples also depend very much on natural resources and live in ecosystems especially vulnerable to the effects of climate change, such as small island developing states, arctic regions and high altitudes [10].

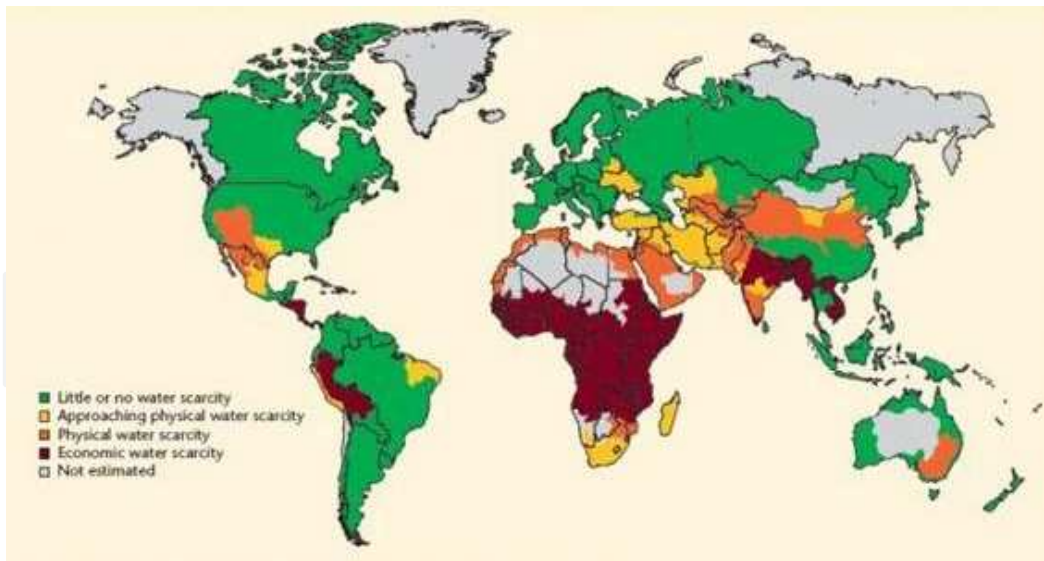


Figure 1. Water scarcity based on synthetic evaluation of water management using for Agriculture in 2007 [4]



Figure 2. Drinking water as the substance to transform a life [11]

The shortage of fresh water reserves is a world-wide problem nowadays, which can lead to a global crisis. Firstly, it can cause agricultural crisis. 70–85 percent of water use is for agriculture, and it is assessed that the most imperilling agricultural growth is 20 percent of global grain production won't have enough water to irrigate in the future. Connected with spatial and temporal variations, water is not always available, which means there is scarcer water particularly for large concentrations of people consumption, enterprises and some other uses. Furthermore, it leads to environmental crisis. In Water and Nature, the more critical statement has been come out that the increasing of using water resource can reduce the amount of water available for industrial and agricultural development, more seriously that can exert a far-reaching influence on aquatic ecosystems and their dependent species. Environmental balances are disturbed and cannot play their roles like before [12]. More than 260 river basins are shared by two or more countries in the world. The lack of water can lead to transboundary tensions. As time passes, a series of conflicts come out, which increases regional instability, such as The Parana La Plata, the Aral Sea, the Jordan and the Danube.

Today, approximately 3 billion people — about half of the world's population — live within 200 kilometers of a coastline. By 2025, that figure is likely to double. In many countries, populations in coastal areas are growing faster than those in non-coastal areas. Take the example of China, the world's most populous nation. Of China's 1.2 billion people, close to 60% live in 12 coastal provinces, along the Yangtze River valley, and in two coastal municipalities — Shanghai and Tianjin. Along China's 18,000 kilometers of continental coastline, population densities average between 110 and 1,600 per square kilometer. In some coastal cities such as Shanghai, China's largest with 17 million inhabitants, population densities average over 2,000 per square kilometer. From 1990 to 2015, people flock to coastal cities continuously, especially in the past ten years, the number of migrated population is more and more bigger. Figure 3 [13] shows the population changes by 5 years (from 1990-2015) in Low elevation coastal zones (LECZ is a continuous strip along coastal areas whose altitude is less than 10m). In the United States, over 50 percent of the nation's population lives in only less than 20 percent of the U.S. coastal area (excluding Alaska) in 2010 [14]. Australia has experienced the same situation. Australia's coastal population has been growing faster than the population of the rest of the country for some time [15] (see Figure 4) and is expected to increase by another one million people over the next 15 years [16]. Up to 50 percent of the population in northern Africa and Bangladesh lives in coastal areas; along the Nile Delta, the population density reaches 500 to 1,000 people per square kilometre [17]. The high concentration of people in coastal regions has produced many economic benefits. But the combined effects of booming population growth and economic and technological development have aggravated the need for water.

Ban Ki-moon warns: "A shortage of water resources could spell increased conflicts in the future. Population growth will make the problem worse. So will the climate change. As the global economy grows, so will its thirst. Many more conflicts lie just over the horizon." [4]

With the current state of affairs, correct measures are needed to be taken to avoid the crisis to be worsening. There is an increasing awareness that our freshwater resources are limited and need to be noticed quantity and quality. "The time for solutions" is put forward in The 6th World Water Forum. This study summarized the overall situation of water solutions in the past and proposed a new waters strategy-coastal reservoir.

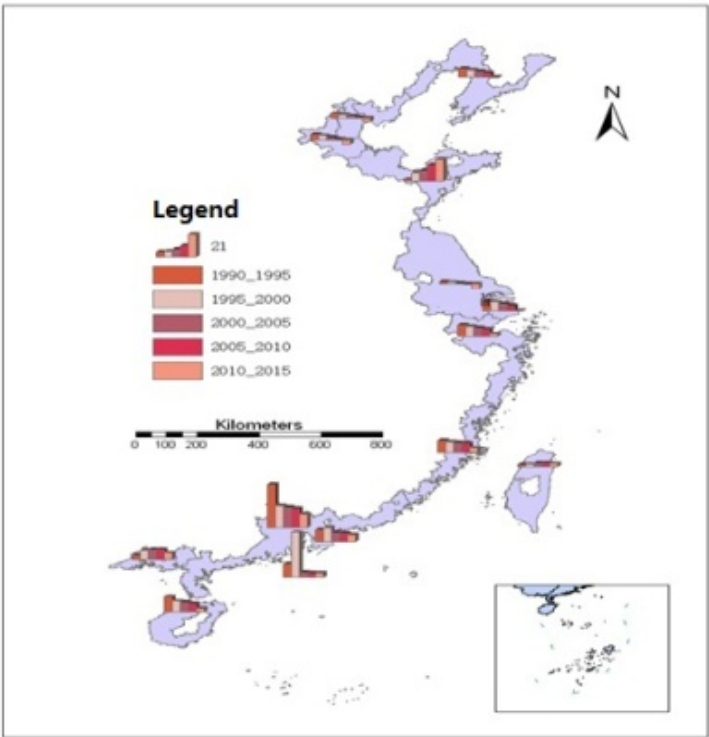


Figure 3. Coastal Population in China

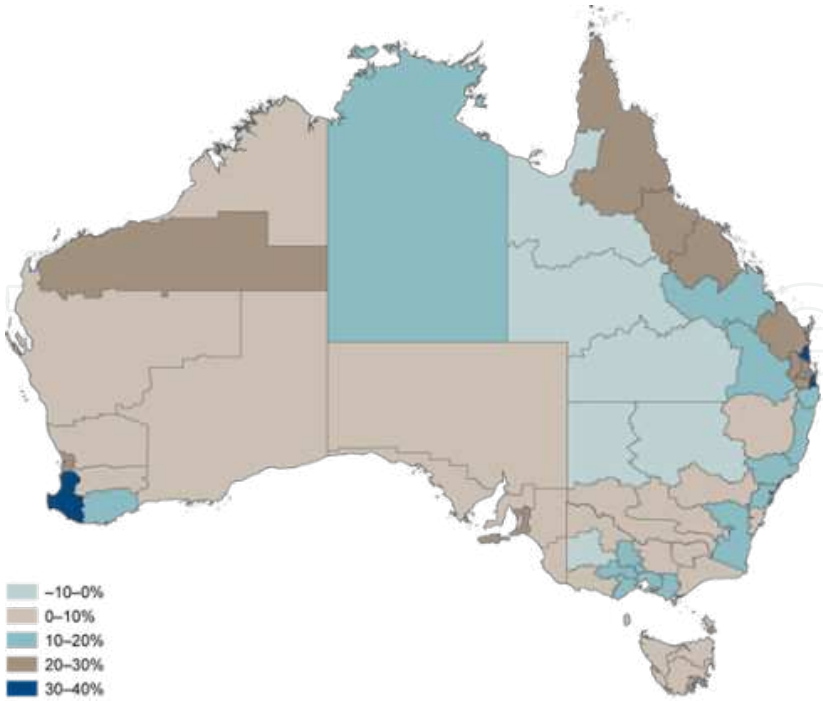


Figure 4. Coastal Population in Australia

2. Current water solutions

There are mainly several kinds of water supply options in the world, for example, groundwater, on-land reservoir, desalination of seawater, reuse of wastewater, Diversion of water from a remote source. They have their own characters.

Groundwater generally has higher chemical, physical and biological quality than surface waters. This higher quality means that groundwater usually requires lower levels of treatment, and the treatment process is therefore cheaper. But Groundwater is harder to locate than surface water. The location of groundwater may require the use of sophisticated equipment. But groundwater resources in the world are almost fully developed, and in some cases they are already considered overdeveloped. The groundwater sources that could potentially be developed in the world are so small that it would not be economically viable to do so. Therefore, the next preferable water supply source must be considered.

The water quality in on-land dams is higher than that of the water from all the alternative sources except groundwater. But surface waters are more susceptible to pollution than groundwater. They are difficult to protect from contamination (such as waterborne diseases and chemicals that enter from surface runoff and upstream discharges). The water quality is also not as consistent. For instance, turbidity and temperature fluctuate, often depending on the amount of precipitation. Surface water requires more treatment than groundwater and is therefore more expensive to utilise. This water supply source relies on rainfall. There are also usually a limited number of dam sites available because the construction of dams requires the correct combination of topography and geology. This is due to a lack of appropriate sites for the construction of dams. For example in Australia, after two centuries of development, there are almost no new dam sites left with good combination of topography and geology. Soil erosion also keeps reducing the storage capacity of the world's on-land reservoirs by more than 1% annually. For example, on-land reservoirs were subjected to very high siltation rates which are comparable to overseas extreme siltation rates in Australia [18]. In the future, soil erosion and reservoir sedimentation rates would be accelerated due to the severity of storms and rains as a result of global warming [10]. This means that almost all existing on-land reservoirs may lose its capacity in about 100 years. Therefore, the next water source option should be considered.

The first desalination plant by the multi-stage flash (MSF) evaporation process installed in 1964 in Lanzarote(Canary Islands) to over 700 desalination plants existing nowadays [19].Desalination technologies account for a worldwide production capacity of 24.5 million m³/day [20], the cost decreased to \$0.50-0.80/m³ desalinated water and even to 0.20-0.35 \$/m³ for treatment of brackish water [21]. However, they have potential negative impacts [22]. These are mainly attributed to the concentrate and chemical discharges, which may impair coastal water quality and affect marine life, and air pollutant emissions attributed to the energy demand of the processes. A key concern of desalination plants are the concentrate and chemical discharges to the marine environment, which may have adverse effects on water and sediment quality, impair marine life and the functioning and intactness of coastal ecosystems [22]. WHO [23] provided a general overview on the composition and effects of the

waste discharges in their guidance document. Lattemann [22, 24] and MEDRC [25] discussed details of the negative impacts. Reverse osmosis (RO), a commonly used desalination technology, is significantly more expensive than the standard treatment of fresh-water for potable use [20]. Furthermore, desalination technologies have the risk of oil pollution [26]. Most of the noise is produced by the high-pressure pumps and by the turbines used for energy restoration [27]. Desalination of seawater does not rely on rainfall (it is a climate resilient water source). Desalination plants are located on the coast, and as mentioned earlier this is where the majority of the water demand is expected to be located. But the treatment process would have high energy requirements as well as high operating and maintenance costs because of the high concentrations of contaminants that would have to be removed. For instance, seawater is usually 30 times more saline than the sewage effluent that would need to be treated to produce PRW (QWC, 2008). The concentrate stream produced by the desalination process can have detrimental environmental impacts. This could be a significant problem if the desalination plants were located on the coast, because the discharge would be released into a place, which is maybe a very sensitive marine environment. Therefore, other water supply options need to be considered.

Diversion of water from a remote source does not depend on local rainfall or local water quality. But this water source would have very high construction costs. For instance, the government of Queensland in Australia has considered diverting water supplies from North Eastern NSW, but this was found to be not economically viable. There were also numerous social, environmental and interstate issues that were considered to be insurmountable (QWC, 2008). Water could potentially be diverted from Northern Queensland. However, this would involve very high construction costs and should only be considered if no alternative water sources are available locally.

Reuse of wastewater does not depend directly on rainfall. But the levels of contaminants are higher than for the previous water supply options. Therefore, the cost of operating the treatment process would be higher. It is a common practice to discharge untreated sewage directly into bodies of water or put onto agricultural land, causing significant health and economic risks [28]. There could also be public perception problems with the reuse of wastewater (this is often referred to as the 'Yuk Factor').

Stormwater harvesting is used in house yards, streets and parks, but there are several shortages. CM Goonrey et al. exam the technical feasibility of using stormwater as an alternative supply source in an existing urban area [29]. Firstly, its storage capacity is very small due to the structural constraints; then its water quality may be not very good as the water comes from densely populated areas, and its cost is also very high as precious land is used to store the storm water.

Now in the world, many people try to find ways to solve water scarcity, however, on the other hand, too much stormwater and flood can't be neglected. The former management policies lead to vast amount of floodwater being discharged into the sea. Drought and lack of water emerge during dry season. It is obvious that new waters storages are in demand in the country. The coastal reservoir is to solve water storage of the next generation. It is a dam in the sea at the mouth of river or near it. It catches water in the bottom of the stream [30]. The

building imitates the natural freshwater lake with a sustainable flow of fresh water from the river. Such reservoirs were already used in the Asian countries – Singapore, Hong Kong, China – and they are considered as very successful alternative to traditional dams.

"There is a water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people - and the environment - suffer badly." — World Water Vision Report

3. Coastal reservoir

A Coastal Reservoir is a freshwater reservoir located in the sea at the mouth of a river with a sustainable annual river flow [31]. All a costal reservoir needs to be effective is an impermeable barrier between the fresh river water and the salty sea water. Yang outlined three guidelines for the successful construction of a coastal reservoir. The first guideline is separation, meaning the successful separation of clean river from polluted water and salt water. Next is protection, meaning the protection of collected fresh water against polluted river water and external pollution. Last is prevention, meaning the successfully prevention of salt water intrusion into the stored fresh water; weather that be through permeability or large tidal events.

Compared with water from seawater desalination processes, catchment runoff is a natural resource, which is cost-saving and water quality as the basic guarantee, is more closed to drinking water. Different from the on-land catchment runoff proposal, coastal reservoir harvests the catchment runoff in the sea, its water sources from a river and the reservoir has the potential to catch all runoff from a catchment. The coastal reservoir can be classified into various categories, in terms of location, barrage, and water quality etc. Existing freshwater lakes or lagoons on the shore can be regarded as special or natural coastal reservoirs. The main differences between coastal reservoirs and on-land reservoirs are summarized in Table1.

Item	On-land Reservoir	Coastal Reservoir
Dam-site	Valley(limited area)	Coast(inside/outside river mouth)
Water level	Above sea level	At sea level
Pressure	High pressure	Low pressure but with wave surge
Seepage	By head difference	By density difference
Pollutant	Land based	Land-based and seawater
Land acquisition	High	Low
Water supply	By gravity	By pump

Table 1. Differences between on-land Reservoirs and Coastal Reservoirs

Table 1 shows when constructed they share many similarities to inland reservoirs but due to the presence of water on either side which have almost the same density the hard barrier does not need to be constructed as strong as an inland reservoir does (material costs are a lot lower).

3.1. Existing coastal reservoirs

The first coastal reservoir was built in Zuider Zee, Netherlands in 1932, named IJsselmeer with water area of 1240 km². At that time, people mainly enclose sea area to set up land with getting water as a fringe benefit. During the late 20th century and early 21st century, these are predominantly man made instances of coastal reservoirs with accelerated dilution of salt water to form viable storage and catchment of potable water.

The construction of these coastal reservoirs involves forming a dam wall, usually of solid material across the point where a river or lake enters the ocean. Salt water dammed in the reservoir is then pumped out to aid the speed in which water is diluted to form fresh water. As this reservoir is formed at sea level, maximum flow will occur and full use of the catchment inflows feeding the river or lake will be made. Ordinary storage reservoirs that involve river dams also house water from catchment inflows however these reservoirs are commonly located further upstream which allows all water below the dam to be released into the ocean. This type of Coastal Reservoir is being used in Singapore, South Korea, Hong Kong and China. Currently, there exist many coastal reservoirs in the world as listed in Table2.

Name	Catchment (km ²)	Dam length(m)	Capacity (million m ³)	Year completed	Country/river
Qingcaosha	66.26	48786	435	2011	China/ Yangtze
Saemanguem		33900	530	2010	South Korea
Sihwa	56.5	12400	323	1994	South Korea
Marina Barrage		350	42.5	2008	Singapore
Chenhang				1992	China/Shanghai
Yu Huan	166	1080	64.1	1998	China/Zhejiang
Baogang				1985	China/Shanghai
Plover Cove	45.9	2000	230	1968	Hong kong

Table 2. Existing Coastal Reservoirs in the World

3.2. The types and functions of coastal reservoir

The coastal reservoir can be classified into various categories, in terms of location, barrage, and water quality etc. According to the geographical location, it can be divided to estuary reservoir, intertidal reservoir, gulf reservoir. According to the water quality, it can be divided to drinking water reservoir with good quality, freshwater reservoir for agricultural/

industrial purpose with moderate quality, sewage reservoir, ballast water reservoir, etc. According to the dam body, it can be divided to concrete dam, earth dam and soft dam reservoirs. And it also can be divided to natural and artificial, for example, Saemangeum coastal reservoir, South Korea, which is a huge project of the century.

Coastal reservoir can be used to provide water to three main parts, irrigation, industrial and domestic water using. For example, Chenhong Reservoir, which is located in Yangtze River Estuary of China, mainly provides drinking water for north area of Shanghai (see Figure.5). Baogang Reservoir, which is located in Yangtze River Estuary of China, plays an important role in providing industrial water to keep Baoshan Steel going on (see Figure5).

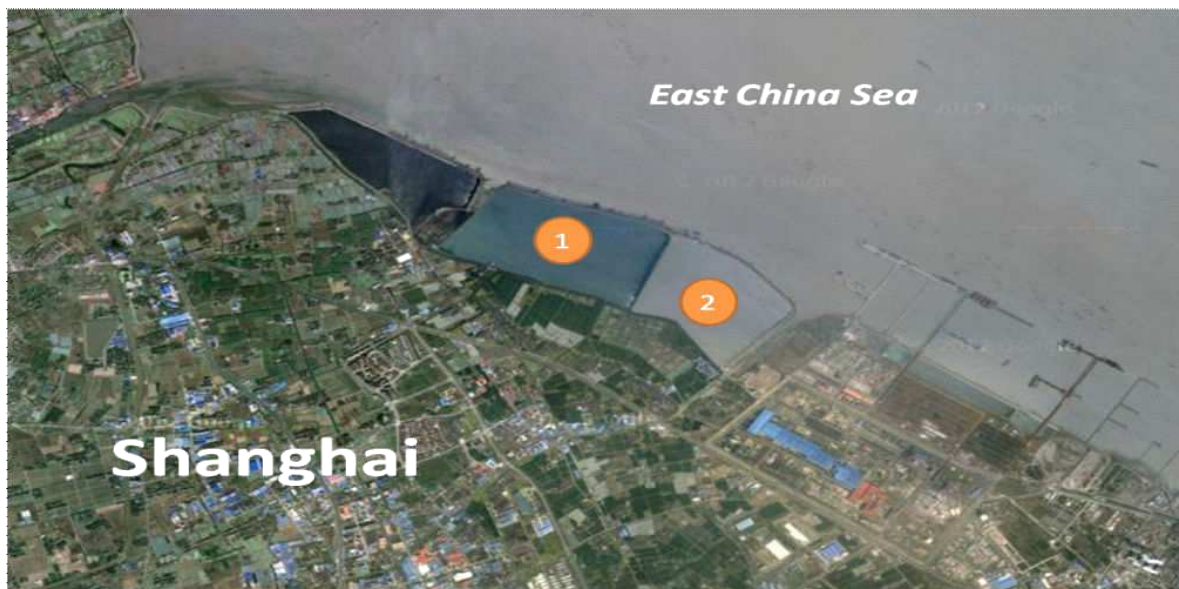


Figure 5. Baogang and Chenhong Reservoir (1 is Baogang Reservoir and 2 is Chenhong Reservoir)

3.3. Plover cove reservoir in Hong Kong

Plover Cove Reservoir, located within Plover Cove Country Park, in the northeastern New Territories, is the largest reservoir in Hong Kong in terms of area, and the second-largest in terms of volume. It was the first in the world to construct a lake from an arm of the ocean. Its main dam was one of the largest in the world at the time of its construction, disconnecting Plover Cove from the sea.



Figure 6. Plover Cove Reservoir in Hong Kong

The dam of the reservoir is 28m tall and approximately 2 km long, which was built by layers of sand and gravel. Besides rain from its catchment, it also stores water imported by pipes from Dongjiang. The Bride's Pool flows into the Plover Cove Reservoir. One main dam and three service dams were built to shut the cove off from the sea. The cove was then drained and was converted into a fresh-water lake.

The location was a former cove (bay, as the name suggests) and was a popular hiking site. Construction work commenced in 1960 and was completed in 1968, providing a capacity of 170 million m³. Work on raising the height of the dams began in 1970. Upon completion in 1973, the reservoir capacity was increased to 230 million m³ (see Figure 6).

3.4. Coastal reservoir in Singapore

Singapore is a tropical coastal city between the lines of longitude E103° 38' and 104°05', the latitude N 1°09' and 1°29' with population of 4 million and area of 680km². The mean annual rainfall is 2.4m. The total evapo-transpiration, infiltration, etc. loss is around 1.17m to 1.27m per year. At the end of 2000, total volume of water consumed in Singapore was 455.4 million m³/year. Half of Singapore's water supply is imported from Malaysia across Johor strait through a Causeway, and the other half of water demand comes from its own reservoirs.

Due to its rapid economic and population growth in the past decades, the demand for potable water in Singapore increases steadily, the former way of water supply can't satisfy the need of people's living and production. To augment water supply, Singapore has built the Marina Barrage to develop further its rainfall (see Figure 7).



Figure 7. Marina Barrage in Singapore (Across Marina Channel at Marina South)

The Marina Barrage is a dam built across the 350-metre wide Marina Channel to keep out seawater. Marina Reservoir, together with Punggol and Serangoon reservoirs, increased Singapore’s water catchment area from half to two-thirds of Singapore’s land area in 2011. It creates a fresh water reservoir behind it at the same time acts as a tidal barrier that prevents high tides from causing flooding of inland low-lying areas. The Project is unique in that it is designed to achieve three aims: to act as a tidal barrier for flood control, to create a new reservoir to augment the water supply and to maintain a new body of freshwater at constant level in the heart of the city as a major lifestyle attraction. The Project has been carefully designed to blend in well with the environment, with guidance from Urban Redevelopment Authority (URA)'s Design Advisory Panel. Figure 8 shows the model of the Marina Barrage design, and Figure 9 shows the working principal of the Marina Barrage.

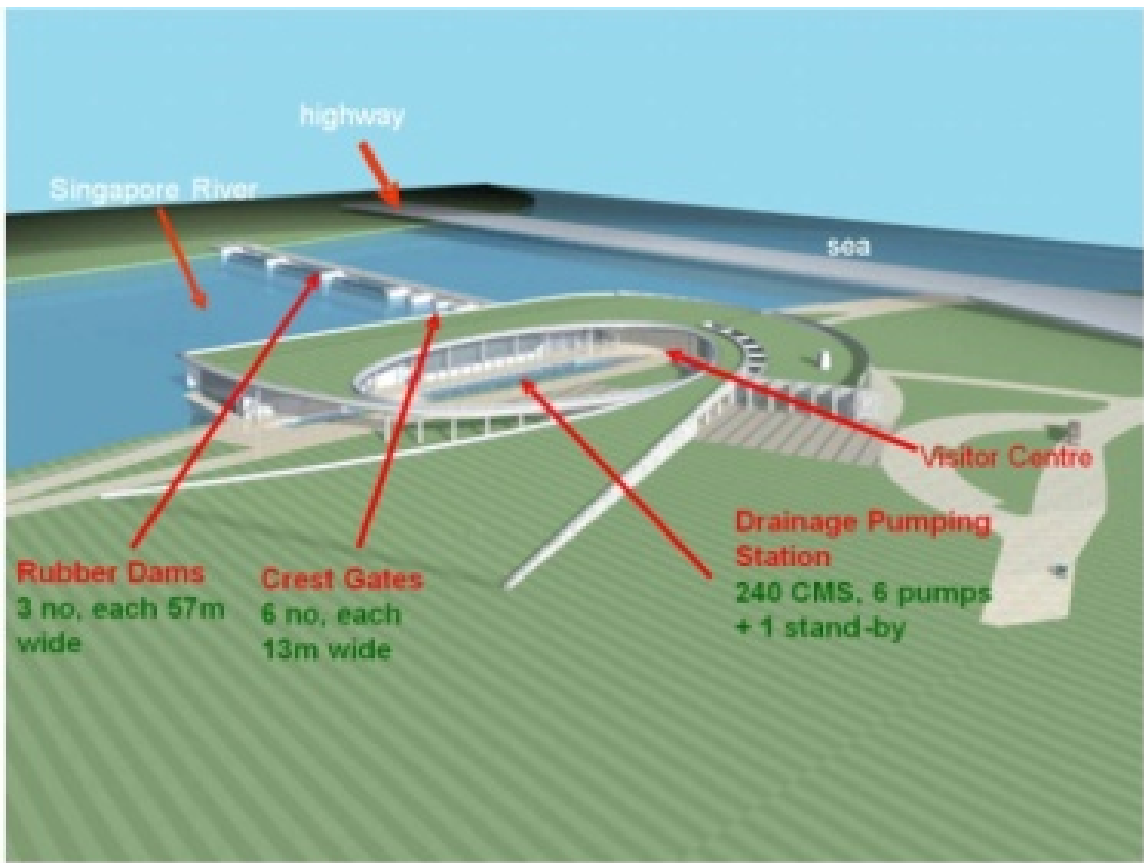


Figure 8. Model of the Marina Barrage Design

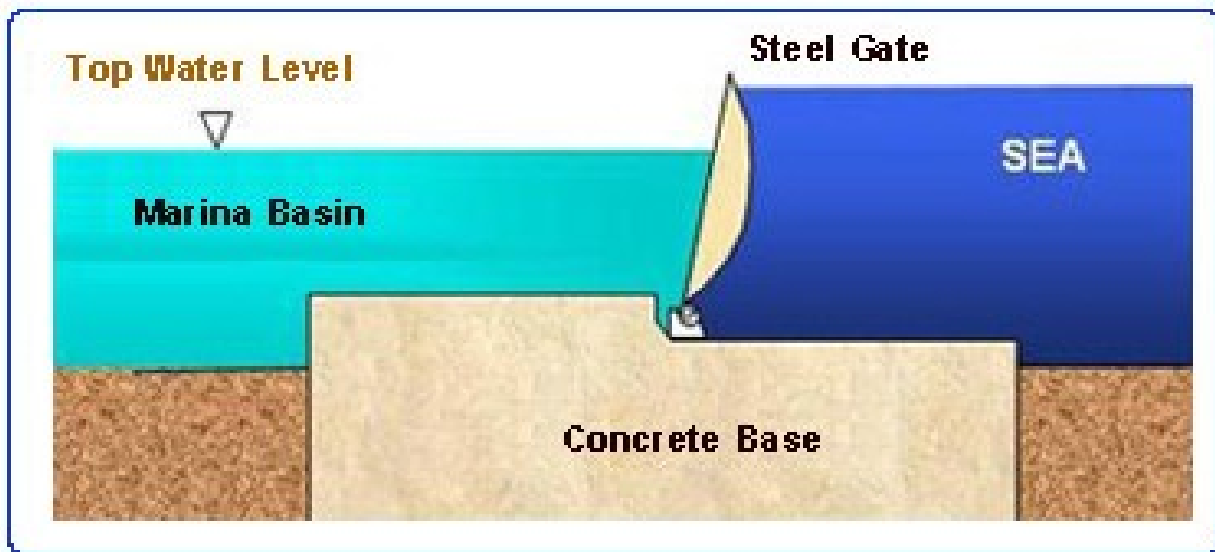


Figure 9. Working Principal of the Marina Barrage

The barrage, which comprises nine numbers of 26.8-metre-long hydraulically operated steel crest gates, will be built across the 350m wide Marina Channel to keep out sea water. Under normal conditions, the steel gates will remain closed to isolate the reservoir from the sea. During heavy rain, the steel gates will open as necessary to release excess stormwater to the sea when the tide is low. However, when it is not possible to do so during high tide, the Drainage Pumping Station capable of pumping up to 280 cubic metres per second will pump out the excess stormwater into the sea.

For water supply, the Marina Barrage have enhanced Singapore's water supply in line with Singapore's Four National Taps water supply strategy to diversify its water sources (The 4 National Taps are: local catchment, reclaimed water, desalted water and imported water). The Marina Reservoir will have the largest urban catchment of 10,000 ha among all the reservoirs. With this Project, about 60 per cent of Singapore will become catchment area.

For flood control, the Marina Barrage is part of a comprehensive flood control scheme to alleviate existing flooding in the low-lying areas of the city such as Chinatown, Boat Quay, Jalan Besar and Geylang. During heavy rain, the series of nine crest gates at the dam will be activated to release excess storm water into the sea when the tide is low. In the case of high tide, giant pumps which are capable of pumping an Olympics-size swimming pool per minute will drain excess storm water into the sea. With the Barrage and other flood-alleviation projects, flood-prone areas in Singapore will be further reduced from the current 150 ha to 85 ha, down from 3200 ha in the 1970s. Figure 9 shows the principal of how the barrage control the flood.

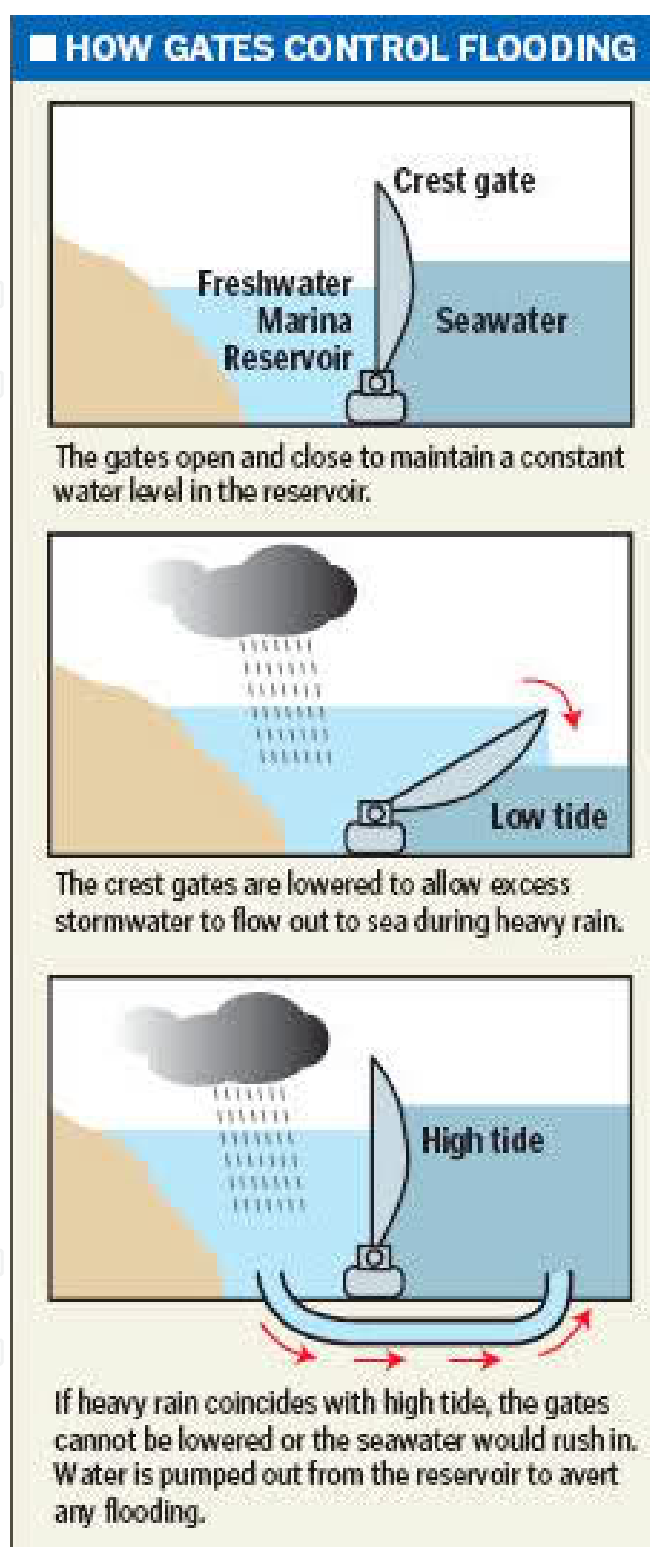


Figure 10. Principal of How the Barrage controls Flood

For lifestyle attraction, it is ideal for all kinds of recreational activities such as boating, wind-surfing, kayaking and dragon boating etc. As the water in the Marina Basin is unaffected by

the tides, its water level will be kept constant all year round. Marina Barrage is a showpiece of environmental sustainability, and won the Green Mark Platinum Infrastructure Award, the top award at the BCA Awards organised by the Building and Construction Authority in May 2009.

4. Environmental and social impact

The coastal reservoir at river mouth can capture every single drop of runoff, and also has the potential to collect all contaminants yielded from the catchment. For water quality, coastal reservoirs catch the stormwater runoff which is closer to drinking water in quality than the treated salt water is that is produced by desalination. Only high quality water that is free of contaminants will be allowed to enter the coastal reservoir for later use, all poor quality water will be drained into the ocean guaranteeing an acceptable level of water quality.

For environmental impact, as there is nearly no land requirements for building coastal reservoirs and water quality can be guaranteed, the damage to the local ecosystems and marine wildlife can be minimized greatly. The proposed method of harvesting will avoid any severe environmental impacts such as depriving local rivers of water. As the reservoirs construction at sea, no land is needed for construction purposes making them better for the environment than typical inland mountainous reservoirs. Only high quality water (free of contaminants) will be allowed to enter the reservoir, which will help to minimize the impact of the coastal reservoir on the local ecosystem and marine wildlife.

Due to the reservoirs ability to capture every single drop of runoff it will always be functional as long as rain continues to fall. This allows for a stormwater capturing technique that is highly sustainable, will last for many decades and does not pose any major risks to the population. Coastal reservoirs will not lead to flooding, as the water collected is in the ocean. When there is too much stormwater which may occur during long wet periods, the excess water will be drained into the ocean this preventing any form of flooding. For place making, coastal reservoirs are able to fit into any location at the mouth of a river (river estuary) entering into ocean. This is very convenient for coastal cities which have huge population and less space.

5. Comparison between coastal reservoir and other water solutions

Energy use: Energy use on coastal reservoir is mainly on the transfers of potable water to areas above sea level from a water treatment plant like desalination plant that also needs to transfer potable water to users above sea level. Water Recycling from a wastewater treatment plant needs more energy as it needs to be transported to inland reservoirs for mixing before it is distributed to users, this incurs high energy cost of mass water transport.

Emigrant cost: as coastal reservoirs are usually built near to the estuary in the sea, there is almost no emigrant cost. But inland reservoirs can affect large amounts of people especially when damming major valleys. For desalination, water recycling and mass water transport, there is no need to emigrate too many people while some infrastructure may still require property acquisition.

Waste output: coastal reservoirs and inland reservoirs have no waste output with comparison of desalination, which has high wastage from desalination (as little as 30% freshwater yields from seawater intake). Waste output of water recycling is mainly from water treatment waste.

Usable lifespan: coastal reservoirs are affected by siltation and rainfall variability, the same as inland reservoirs. As seawater will always be available, desalination mainly depends on sustainable energy supply. Water recycling which is similar to desalination, as waste water will always be available, depends on sustainable energy supply, which is similar to desalination. For mass water transport, it depends on both reliability of source and sustainable energy supply.

Maintenance cost: The maintenance cost on coastal reservoirs and inland reservoirs is low as it is mainly used for general dam maintenance, besides extra cost on coastal reservoirs includes coastal erosion / salt affects' protection. For desalination, except coastal erosion / salt affects protection, the maintenance also includes treatment systems, servicing and parts replacement. So do the maintenance of water recycling. High maintenance of mass water transport cost on transport device, water transfer systems and management plans / agreements.

Potential for further capability change: coastal reservoirs' potential is high for the storage volume can be expanded at most sites, while inland reservoirs can't be changed very much as initial design is usually for maximum possible yield. It is also not difficult for desalination to enlarge or to reduce water yield, which only need more desalination plants can be built at the coast if energy is available. Waste water recycling is similar to desalination, which need more waste water treatment built. But potable reuse is still a distant possibility and may never be implemented except under extreme conditions [32]. For mass water transport, it depends on availability of remote sources and availability of energy.

Table 3 shows the comparison of construction cost and cost per kilolitre of water between coastal reservoir and other water solutions

	Coastal Reservoirs	Inland Reservoirs	Desalination	Water Recycling	Mass water transport
Construction cost per kilolitre of water(US\$)	2.67-6.01	5.83-7.5	6.41-10.08	5.57-8.30	2.75-6.37
Cost per kilolitre of water(US\$)	0.15-0.25	0.34-0.4	0.43-1.13	1.44-1.53	0.39-6.1

Table 3. Relative comparison of Coastal Reservoirs to other Australia Water Resources

The data of the table is based on the conditions in Australia. The construction cost per kilolitre of water and cost per kilolitre of water of coastal reservoirs are calculated based on the existing coastal reservoirs in the world [33-37]. For inland reservoir, the data is based on statistical data of the United Nations [38]. For desalination, the construction cost per kilolitre of water and cost per kilolitre is from comprehensive evaluation of Israel [39], Singapore [40], and Australia [41], America [42-43], India [44-45] and so on, which in the world mainly have robust desalination technology. For water recycling, the data is on account of Remco Engineering on Water Systems and Controls in USA [46] and National Snapshot of Current and Planned Water Recycling and Reuse Rates in Australia [47]. The data resource about mass water transport is in view of water transport project in Australia [48], the USA [49-50], China [51] and Africa, which of the countries in the world are famous for water transporting. From the above, coastal reservoirs are low-cost compared with other water solutions.

6. Conclusions

"Water is everybody's business".

One of the Key Messages in the 2nd World Water Forum

Different from the proposals of desalination and wastewater recycling, the proposal of coastal reservoir will use the natural catchment runoff and there will be no need to separate the freshwater and salt or wastes, thus the energy cost associated with the treatment will be zero, there will be no carbon dioxide emission either. The pumping costs for proposals of desalination, wastewater recycling and coastal reservoir will be almost same and negligible relative to their treatment cost, thus no comparison will be given in this study. When compared with the proposal of on-land reservoirs, the method of coastal reservoirs has no cost to cover the inundation of land and people's relocation, normally this is very expensive and could be more than half of dam's construction cost. The existing coastal reservoirs in Hong Kong that have existed over 50 years, have no significant impacts on the ecosystem, and also no evidence from other coastal reservoirs in China, Korea and Singapore etc, shows that coastal reservoirs have significant environmental impacts. This conclusion could be valid for the proposed coastal reservoir in this study as fish will still have the passage to go to upstream; every year only the excessive floodwater will be diverted and the time and amount of water diversion could be adjusted to reach the win-win solution for water resources development and ecosystem like fish breeding and stocks alike. It should be stressed that experts from different disciplines should be invited to clarify the environmental impacts of coastal reservoir.

The main advantage of coastal reservoir is storing excess fresh water in the rainy season, and then the fresh water can be transferred to near watersheds through artificial channels or pipelines. Last, the fresh water can be supplied people to drink and meet the needs of agriculture [31]. These do not require mountainous areas for dam construction. The highest

growth in population and therefore water demand is usually expected to be close to the coast. Coastal reservoir can be located close to the high demand area.

Water demand is related to population growth, in theory population increases in coastal areas are much higher relative to the inland regions, and hence the water demand in coastal regions is likely to continue to be higher than inland regions. The future water demand in coastal regions is difficult to meet by developing more on-land reservoirs as it needs an ideal combination of suitable hydrological, geological and topographic conditions. Therefore, coastal reservoir will play a more and more important role in the freshwater resources development in the near future.

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