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Assessment of social and environmental impacts of coastal reservoirs

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Abstract

Water is essential for the global population's domestic, agricultural and industrial purposes. Water shortage and its associated issues are projected to worsen with the population growth. Among many innovative solutions, coastal reservoir (CR) may be one of the feasible solutions. Many CRs have been constructed around the world. It is necessary to systematically analyze the environmental/social impacts of these coastal reservoirs, and the results should be compared with other solutions like desalination plants, wastewater treatment and reuse, dams, reservoirs, inter-basin water diversion and rainwater tanks etc. The world largest scientific database "Web of Science" and "google imagine" have been used as a tool for comparison. The results show that coastal reservoirs can be socially beneficial and have the potential to increase tourism within a region and thus hold economic value for communities. Good practice, policy and care can ensure the feasibility of coastal reservoirs as a future fresh water resource.

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RESEARCH ARTICLE

Assessment of social and environmental impacts of coastal reservoirs

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Abstract: Water is essential for the global population's domestic, agricultural and industrial purposes. Water shortage and its associated issues are projected to worsen with the population growth. Among many innovative solutions, coastal reservoir (CR) may be one of the feasible solutions. Many CRs have been constructed around the world. It is necessary to systematically analyze the environmental/social impacts of these coastal reservoirs, and the results should be compared with other solutions like desalination plants, wastewater treatment and reuse, dams, reservoirs, inter-basin water diversion and rainwater tanks etc. The world largest scientific database "Web of Science" and "google imagine" have been used as a tool for comparison. The results show that coastal reservoirs can be socially beneficial and have the potential to increase tourism within a region and thus hold economic value for communities. Good practice, policy and care can ensure the feasibility of coastal reservoirs as a future fresh water resource.
Keywords: coastal reservoir, environmental impacts, social impacts, water quality, water supply

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1 Introduction

Water has always been a necessity for civilization. Water is critical for the survival of plants and animals alike, yet 1.1 billion people worldwide do not have access to safe drinking water. As populations increase and migrate to coastal regions, it is reasonable to meet this growing demand by augmenting its storage in the 21st century using innovation and alternative solutions, otherwise "The wars of the 21st century will be fought over water unless we change the way we manage it." The use of coastal reservoirs may facilitate the availability, and sustainable management, it is necessary to answer CR's sustainability and environmental/social impacts of a coastal reservoir as a freshwater source.

Coastal reservoir is a freshwater reservoir situated at the end of a river mouth, which has the potential to capture every single drop of runoff from rainfall. It is fed by the river directly from rainfall[1]. A wetland may be useful to pretreat the runoff if it is polluted by domestic, agricultural and/or industrial sources.

For future water supply, other water supply solutions include:

- Inland damming
- Wastewater recycling and reuse
- Desalination plants

This paper investigates the environmental/social impacts of coastal reservoirs by comparing with these existing solutions.

Table 1. List of coastal reservoirs in the world.

Name	Catchment (km^2)	Dam length (m)	Capacity ($10^6 m^3$)	Year completed	Country/Location
Qingcaosha	66.26	48,786	435.00	2011	China/Yangtze
Saemanguem	332.00	33,900	530.00	2010	South Korea
Sihwa	56.50	12,400	323.00	1994	South Korea
Marina Barrage	113.00	350	42.50	2008	Singapore
Chenhang	1.40	2,100	9.14	1992	China/Shanghai
Yuhuan	166.00	1,080	64.10	1998	China/Zhejiang
Baogang	1.80	3,000	12.00	1985	China/Shanghai
Plover Cove	45.90	2,000	230.00	1968	Hong Kong
Lake Alexandrina	1061.00	Natural	1,610.00	1930s	Australia

2 Existing Coastal Reservoirs

The coastal reservoir differs from inland reservoirs as it has the advantage of collecting the total catchment runoff; however, this is accompanied with high pollution risks. The coastal reservoir has additional advantages in comparison to previous water resource storage facilities. There have not been extensive long-term studies into the sustainability and efficacy of coastal reservoirs for use in water resourcing. Although coastal reservoirs have been recognised for some time, their acceptance socially has not been widely established. This applies considerably to the public and government. There is some understanding of the current water scarcity issues, however, clear solutions to ensure that water resources are sustainable for human and economic growth are not understood and have not been developed. There is no strategy for the management of water resources that will provide for sustainable and economic population growth and movement. To ensure the holistic feasibility of coastal reservoirs as a supply of fresh water, a study of the social, environmental and financial impacts, benefits and differences from alternative water sources (dams and inland reservoirs) is conducted.

The first coastal reservoir was built in 1932 in Zuider Zee, Netherlands. A large inlet was closed off from the sea capturing 1,240 km^2 of water. This salt water inlet became predominately fresh water over time with the aid of a pumping process to remove saltwater[2], the desalination process took approximately 5 years to achieve water that was less than 3.5 grams per litre[3]. Almost at the same, Australia Engineers enclosed the mouth of Murray-Darling River, the largest river in Australia, it was expected to change the Alexandra Lake into a freshwater lake for the purpose of irrigation and drinking in South Australia, the driest state in Australia. In 1968, Hong Kong constructed the Plover Cove as the drinking water reservoir for a mega city, probably this is the first successful example for urbans drinking water supply. In the 21st Century, many coastal reservoirs have been constructed as shown in Table 1, Qingcaosha in Shanghai is the largest one for Shanghai's water supply.

As the field of knowledge currently surrounding coastal reservoirs is limited, further evidence in the form of research will assist academics and the general public in identifying and developing solutions to the current water shortage problem.

3 Other Water Solutions

Current freshwater supplies predominately derive from inland damming, desalination, storm-water harvesting, groundwater and waste water treatment.

Inland dams Damming has been the most widely used method for water supply in society for decades. Concrete dams have a lifespan of approximately 100 to 200 years, which can vary depending on the sedimentation rate in the dam. Algal blooms in Australia, caused by nutrients caught up in sedimentation, costs between 180-240 million dollars yearly. These siltation issues are an ongoing problem for inland damming. The sedimentation is a result of 75% of total sediment yield being retained in lakes, reservoirs and river systems. The total sediment yield in the world was estimated at 13.5 $\times 10^9$ tons/year. The by-product of this is a reduction in storage capacity of 1% per year[4].

Relevant shortcomings to the sustainability of inland damming include: limited topography of sites, high pressure on walls which require expensive materials and construction, water distribution costs as catchments are often placed away from settlements and the fact that inland damming cuts off the hydrological cycle by not utilizing the entire potential from runoff as the river travels further.

Groundwater Groundwater resources are considered almost fully developed. Groundwater features higher quality water than surface runoff in regards to chemical, physical and biological and as such, requires less treatment to water. However, groundwater requires complex measures to extract the water[4].

Desalination Desalination treatment of water has the major drawback of being economically disadvantaged, as it requires large amounts of power to run the process. Desalination additionally has chemical and concentrate discharges to consider for ecological grounds as the runoff can impact fish and humans.

Water diversion It has significant construction and maintenance drawbacks relating to costs. There are additional concerns with social, environmental and interstate issues regarding land use and crossing of borders.

Reuse of wastewater Substantial social issues arise with reuse of wastewater as the public does not trust the idea of drinking water sourced from harmful wastewater. Treatment requirements are high due to contaminated waters which result in higher costs to operate treatment plants.

Rainwater harvesting It has the potential to be scaled into large schemes. However, currently, it is generally socially accepted only in smaller household scales. It has its own set of disadvantages including storage limits, unreliable rainfall, initial costs, regular maintenance and contamination. Stormwater is similar to rainwater harvesting with the difference being stormwater is rain that has been drained from the land rather than rainwater that falls directly from roofs into tanks. Therefore, this water has recycled water purposes as the contamination is higher and requires higher levels of treatment in comparison to rainwater harvesting.

4 Existing Coastal Reservoirs' Environmental Impacts

Water quality and environmental issues are important for the feasibility of coastal reservoirs in freshwater supply. The water in coastal reservoirs catchment requires treatment before further freshwater use. The lower the contamination in the water will result in less treatment required. This is a desirable outcome in terms of coastal reservoirs being accepted into society due to cost reduction and social acceptance. Relevant environmental and ecological impacts can be seen from Table 2.

For all stagnant water bodies including dam water and coastal reservoirs, the most significant threat is the occurrence of algal blooms. Algal blooms may be described as a sharp growth of particular algae or cyanobacteria. Coastal Reservoirs can select the best quality for storage and use wetland to pretreat the river water, thus it is not a big issue relative to inland dams. Even so, the detail investigation is needed.

Qingcaosha Qingcaosha coastal reservoir is a freshwater reservoir located in Shanghai, China which receives raw water from the Yangtze River. The reservoir was completed and running in 2010 and is a drinking water source for over 15 million people now, it was designed to supply a water volume of 7.2×10^9 GL per day. An extensive study on the water quality characteristics in the Qingcaosha Reservoir and of the influent water was completed in 2013. The impurities of the water inside the Qingcaosha Reservoir and in the influent in the

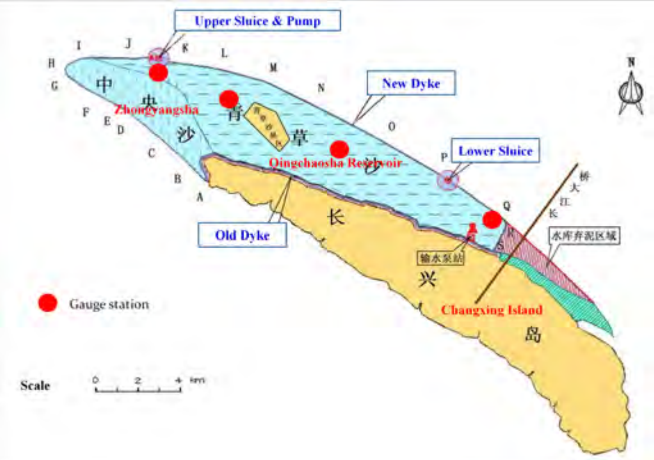

Figure 1. Locations of sampling sites [5].

Table 2. Environmental and ecological impacts.

Environmental and ecological impacts	Description
Ecology	Plant, fish and bacteria species population and distribution is taking into account for the impacts of coastal reservoirs.
Siltation	Sediment build up impacting water quality
Sediment quality	Sediment releasing nutrients impacting water quality
Pollution	Pollution created from industrial discharge, sewage leaks, agricultural dischargeand commercial and domestic pollution.
Chemicals present	Human indicating chemicals including caffeine and pharmaceuticals.

Yangtze River were also examined. This addresses the issue of influent water quality, a relevant threat to coastal reservoirs. Figure 1 shows where the testing samples were taken from inside Qingcaosha reservoir and in the Yangtze River. The low flow rate of the river releases of nitrogen and phosphorous from sediments resulting in eutrophication and algal blooms. The study showed TN in the range of 2-4 mg/L and TP in the range of 0.05-0.2 mg/L inside the reservoir. Both TN and TP sit within the limits as given by the Chinese water quality standards.

Figure 2. Sampling map for Marina Reservoir [6].

The recorded concentrations of nitrates and phosphorous inside the Qingcaosha Reservoir were slightly higher compared to the outside reservoir concentrations in the water, the highest concentrations were recorded in the middle of the reservoir. The Qingcaosha Reservoir has a depth in the range of 1.5-7.1 m and has a hydraulic retention time of 15-35 days which is a relatively long hydraulic retention time. The water flows through the reservoir from inlet sluice to pump station and is pumped and distributed to 8 drinking water treatment plants in Shanghai. There is a closed outlet sluice set up to discharge excess water if needed, cyanobacteria are sensitive to prolonged periods of intense light and high light intensities above 17,777 Lux as discussed, the cyanobacteria were dominant in late summer to autumn. And chlorophyte and diatoms were dominant in winter to early spring. The cyanobacteria experienced a sharp increase in summer 2011.

Marina Barrage It is a coastal reservoir in Singapore, built in 2008. In 2011, a study was published where the occurrence of emerging organic contaminants was measured in the reservoir. The location of sampling sites consisted of tributaries of the Marina Bay and two locations in the reservoir. These locations can be seen from Figure 2.

The emerging organic contaminants (EOCs) were targeted throughout the study to determine the levels to which these contaminants are having an effect on the water quality in the catchment. The presence of the wide array of emerging organic contaminants indicates wastewater inputs possibly from subsurface leaks or sewage leaks. Stormwater runoff contributes to the octylphenol, nonylphenol ethoxylates and their degradation products presence.

Plover Cove Reservoir It is a coastal reservoir in Hong Kong completed in 1968. The reservoir has a capacity of 230 million m^3 and the dam closing off the cove is approximately 2 km long. The enclosed reservoir can be seen from Figure 3. The algal concentrations declined significantly after the construction of the Plover Cove Reservoir [7], this is a good example to show that once clean water is stored, the algal blooms problem can be avoid completely.

Lake Sihwa It is a coastal reservoir in South Korea constructed in 1996 (Figure 4). The reservoir was created to supply agricultural water and expand agricultural land. However, the coastal reservoir turned into a failure during desalination. The water quality in the reservoir failing to desalinate was a result of stratification, the inflow of polluted water and anoxia. The water in Lake Sihwa is stratified with polluted water at the surface and entrapped, saline water at deeper ranges in the lake. This failed coastal reservoir is a clear evidence for those coastal reservoirs without bypass channel to divert the unwanted water. The pollution sources include high population den-

Figure 3. Location of Plover Cove.

sity, many factories, wastewater, lot areas, point or nonpoint sources etc.. Many measures were taken to improve the water quality in the reservoir, and are chronologically detailed in Table 3. It can be seen that without bypass channel, none of them are effective for the existing management methods.

Lake Alexandrina It is the first coastal reservoir in Australia. A study tested samples at 5 sites during an extreme low flow period in Lake Alexandrina. The location of the reservoir and sampling sites can be seen from Figure 5. The flow was at an extreme low period between 2007 and 2010, during which the total dissolved solids (TDS), turbidity, total nitrogen (TN) and total phosphorous (TP) increased dramatically as shown in Figure 6.

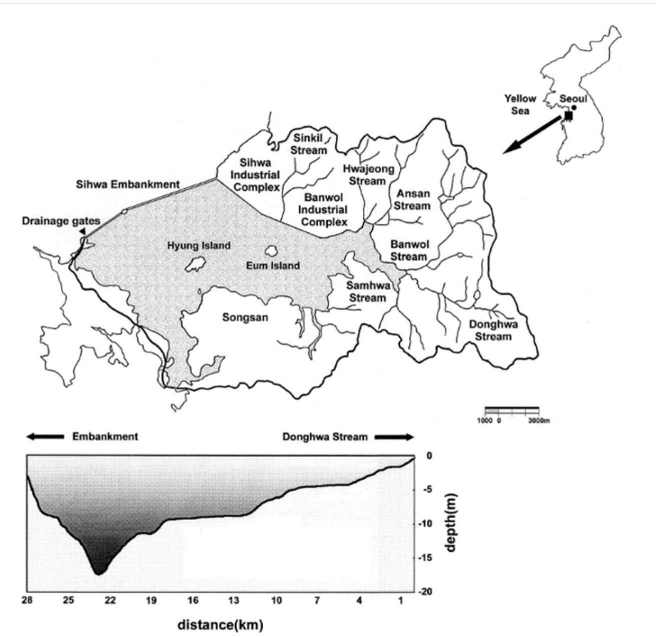

Figure 4. Location of Sihwa Reservoir.

4.1 Environmental Impacts

Singapore A study published in 2010 determined the fish population in the Marina Basin before the construction of the Marina Barrage. The study shows that a list of fish would survive based on the current fish inhabitants in the basin without access to the sea. This list consists of 31 out of the total 138 fish from 57 families[8]. This study is vital to predict the ecological impacts caused by constructing a coastal reservoir from the Marina Basin into the Marina Barrage. The fish species are clearly impacted and many will not survive going from saltwater to freshwater. This is a serious consideration for coastal reservoirs construction worldwide.

To discover possible environmental impacts of coastal reservoirs, the writer keyed in "environmental impacts of Zuider Zee" in Web of Science, one of the largest research databases: only one paper by Lammens *et al.*[9] appeared on 18 February 2017. Their research reveals that the impacts of Zuider Zee Reservoir include "damming and fixing the water table prevented the development of emergent vegetation and caused steep water-land gradients", other impacts are "high nutrient loads, which cause phytoplankton blooms, the disappearance of aquatic macrophytes and intensive fishery". However, when "environmental impacts of Three Gorges Dam"- the largest inland dam in the world completed in 2007, was keyed into the same database, 769 journal papers appeared. When "environmental impacts of desalination" was keyed in the same database, 3,697 journal papers appeared. Eighty-five-year Zuider Zee's existence is long enough for researchers to infer coastal reservoir's environmental impacts. Certainly, they attract far less concern than inland dams and desalination plants. To compare the environmental impacts of coastal reservoir with others, the author keyed in "environmental impacts of xxx" in Web of Science, the results are shown in Table 4.

4.2 Financial Comparison

The proposed A$1.6 billion Traveston Crossing dam in Southeast Queensland, Australia would store 161 GL of water and could supply 70 GL/year, and 76 km^2 of land to be flooded permanently as the reservoir[11]. The design life span of concrete dam and its steel structures is about 100 years, during which span the total water supply is 7,000 GL, thus the capital cost is 0.23 A$/kL (= A$ 1.6B /7B m^3). Its running cost is much cheaper compared with desalination or wastewater reuse.

Sydney Desalination Plant invested A$1.8 billion for its output of 90 GL/year. Its design life span is about 20 years, the total water supply in this period is 1,800 GL. Hence, its capital cost is 1.0 A$/kL. This plant has been in "standby mode" since its birth in 2010. The taxpayers need to pay 535 m A$/year for its state of hibernation, or 5.9 A$/kL (= A$ 535 m /90 GL) of manpower cost. This desalination plant needs the power of 4 kWh/kL[12], thus the energy cost is about 1.2 A$/kL, so the total running cost is 7.1 A$/kL.

The Western Corridor Project invested A$2.6 billion for water supply capacity of 130 GL/year, thus its capital cost is 1.0 A$/kL for 20-year design life span. Its manpower cost is simi-

Table 3. Water quality management of Sihwa Coastal Reservoir (SCR) [10].

Objectives	Year	Major management measures	Expenditure (million US$)
Increase tidal mixing	1997	Test sluice operation to increase seawater circulation	
	1998	Normal sluice operation (0.8×10^3/d tidal flushing)	
	1999	Feasibility study of Sihwa Tidal Power Plant (STPP)	3.0
	2004	Onset of STPP construction	426.9
	2011	Test operation of STPP ($32\text{-}160 \times 10^6$ m^3/d tidal flushing)	
	2012	Full STPP operation (160×10^6 m^3/d tidal flushing)	
		Subtotal	429.9
Strengthen pollution control	1987	Operation of 1st Ansan STP (cap. 121,000 m^3/d, primary treatment)	248.4
	1993	Upgrading of 1st Ansan STP (secondary treatment)	
	1995	Operation of Sihwa STP (cap. 176,000 m^3/d, secondary)	168.2
	1996	Diversion of Sihwa and Ansan STP effluents to outside of SCR	
		Construction of oxidation ponds (capacity 128,000 m^3/d)	15.8
		In-lake WQ management (Allum, Aeration)	4.4
	1997	Construction of wastewater collecting channel (11 km)	5.6
	2001	Expansion of 1st Ansan STP (cap. 385,000 m^3/d, secondary)	508.7
	2004	Expansion of Sihwa STP (cap. 103,000 m^3/d, advanced)	
	2005	Operation of 2nd Ansan STP (cap. 149,000 m^3/d, advanced)	
	2009	Upgrading of 1st Ansan STP (advanced treatment)	
	2006	Operation of Bongdam STP (cap. 8,000 m^3/d, advanced)	20.4
	2010	Operation of Daeyami STP (cap. 5,000 m^3/d, advanced)	27.5
	2007	Stream sediment dredging and marine debris cleanup	11.7
	2008	Stream maintenance and Tando-ho WQ management	17.3
	2009	Livestock wastewater treatment facilities	24.5
	2010	Nonpoint source treatment and monitoring	24.3
		Groundwater quality monitoring and management	3.7
	2012	Constructed wetland to reduce nonpoint pollution (0.75 km^2)	34.1
		Subtotal	1114.6
Adaptive management	1988	Finalized environmental impact assessment	
	1996	Establishment of special WQ management measures (MOE)	
	1998	Renunciations of taking irrigation water from SCR (MOMAF)	
	2000	Renunciations of keeping SCR as a freshwater reservoir	
		Designation of SCR as a SCMA (MOMAF)	
	2001	Implementation of 1st phase of SCR EMMP (2001-2006)	0.5
		Establishment of SCR WMC (MOMAF)	0.1
	2004	Establishment of SCR SDC (MOLT)	0.1
	2007	Implementation of 2rd phase of SCR EMMP (2007-2011)	0.5
	2011	Implementation of TPLMS (MLTM)	0.3
		Subtotal	1.5
		Total	1546.0

lar to the desalination plant, but its required energy is less, and 0.6 A$/kL is assumed. This gives that wastewater recycling methods running cost is 5.9 A$/kL + 0.6 A$/kL = 6.5 A$/kL.

The Qingcaosha Coastal Reservoir in Shanghai spent A$3.7 billion for the construction cost including a 45 km long dam, a pumping system with the capacity of 200 m^3/s or 2,600 GL/year, a 114 km long pipeline system and a 7.2 km underground tunnel (about 6 m in diameter), two sluice gates with widths are 70 m and 20 m (http://news.hexun.com/2011-06-09/130379841.html), the design life span of coastal reservoirs is also 100 years, thus its capital cost is 0.01 A$/kL. Its running cost is very low as the government charges the residence's tap water at 0.4 A$/kL only.

In this study, inland dams' running cost is assumed to be 0.4 A$/kL as same as the coastal reservoir. Table 3 provides the comparison of costs among different methods, where the second row shows the projects. The total capital cost in row 4 means the cost at its beginning. Row 5 is its design capacity. Row 6, the capital cost per kL, is obtained by dividing the total capital cost in row 4 with the total water supply in its life span (i.e., the product of data in row 3 and 5). The running cost includes the manpower cost and energy cost. It can be seen that for one kL of water, the capital cost of desalination and wastewater recycling is about 100 times higher than the cost of coastal reservoir, the running cost is about 17 times higher.

Table 4. Comparison of publications in environmental impacts between CR and others.

	No. of papers		No. of papers		No. of papers
Marina Barrage	1	Plover Cove	0	Three-Gorge Dam	769
Qingcaosha	0	Zuider Zee	1	Desalination	3,697

4.3 Social Impact

The offshore nature of coastal reservoirs limits the involuntary resettlement of communities as is required with dams and inland reservoirs. This has both social and financial benefits as high costs are associated with the resettlement of people. The complexity of resettlement and the restoration of livelihoods should not be underestimated. The development of the Three Gorges Dam, China required the public resettlement of 1.3 million people. Studies indicate that those direct effects were negatively impacted both socially and economically. In some circumstances, villages are resettled together. And in other circumstances, individuals are required to resettle alone as the government or private body may refrain from orchestrating a majority resettlement. This has the potential to cause conflict in villages where dispossessed people resettle and express opposing views to the community in which they resettle in. Enclaves of people with dissimilar background settle together can become a higher risk factor in multicultural countries.

Local communities near coastal reservoirs would benefit from access to a potable water source, being uplifted from the poverty line in particular circumstances, decreased the threat of flood and secured livelihood for farmers. There would be limited or no relocation of households and more jobs would be created in the area during the development of the coastal reservoirs. Post completion of the coastal reservoirs, there is hope of increased health and wellbeing with increased recreational activities and a greater respect and appreciation for waterways. Business owners would benefit from increased tourism and economic standards in surrounding area.

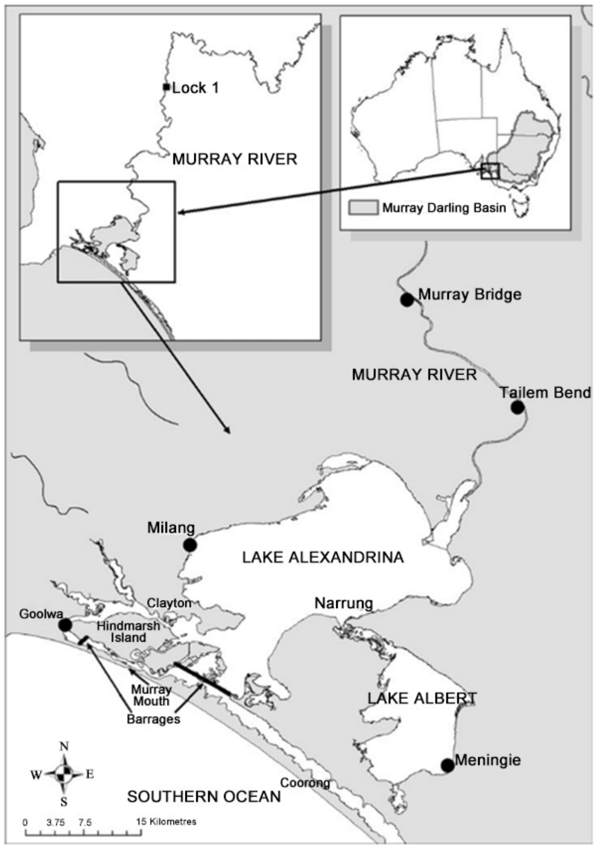

Figure 5. Sampling site locations for Lake Alexandrina [13].

The Government should be required to create a sustainable approach and regulations regarding recreational and non-recreational activities on the coastal reservoirs. Additionally, they would benefit from a reduced flood water management scheme and funds supporting those impacted in the event that a flood does occur. Coastal reservoirs can be socially beneficial and have the potential to increase tourism within a region and thus hold economic value for communities. Designs with a high aesthetic value such as Marina Barrage are inviting for not only local community members but tourists who visit the region. PUB Singapore's National Water Agency has encouraged ownership of the waterways and encouraged community involvement by allowing locals to use the space leisurely through water sports or surrounding walks. An easy and simple way to compare social impacts of different solutions is to search google imagine. When "Marina Barrage" is keyed in, almost all pictures are happy, but other solutions have many negative imagines.

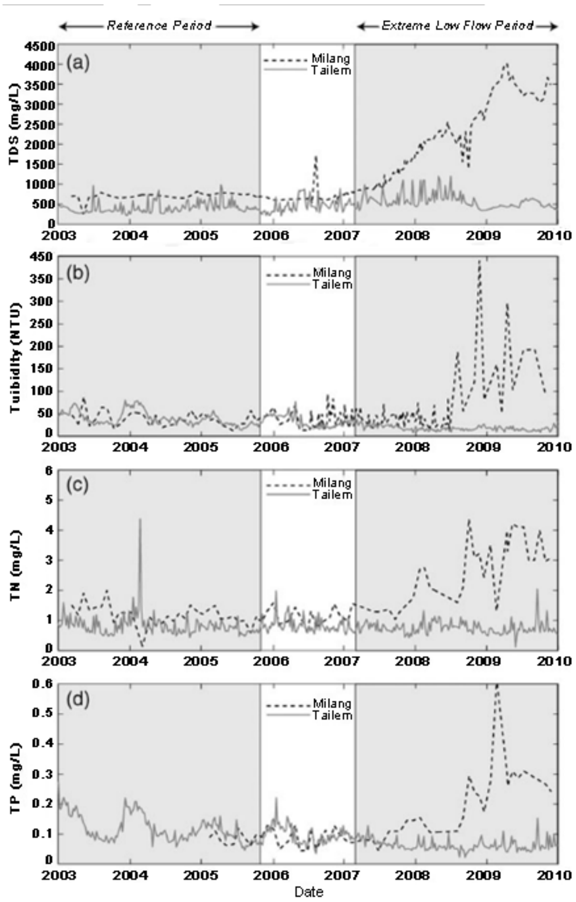

Figure 6. TDS (salinity), TP, TN and turbidity vs flow [13].

5 Conclusions

The feasibility of coastal reservoirs as a dominant fresh water supply is dependent on their implications on the social and ecological environments. Studies of cases in which coastal reservoirs have been developed and in some cases failed have highlighted the primary importance of ensuring minimal environmental damage and minimal impact to society.

If a low environmental impact can be obtained and the closure and retention of water is able to occur with minimal nutrient loading, biodiversity can be preserved within the reservoir thus limiting social impacts. Social impacts related to nutrient loading and a lack of biodiversity include decreased social interaction for social fisherman and an impacted livelihood of fisherman and furthermore subsequently increasing fish prices in the local market due to a case of supply and demand.

Eutrophication has proven to be a main factor in the functionality of coastal reservoirs as evident through the failed reservoirs of Sihwa and Saemangeum, thus bypass channels are critical. By comparing with other water solutions, it is found that coastal reservoirs are technically feasible, cost-effective, social acceptable, environment-friendly and sustainable.

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