Editorial Board

Printed in Beijing.

Volume 2 Issue 2 • September 2017 • ISSN 2424-8053 (print)
ISSN 2424-9882 (online)

JOURNAL OF SUSTAINABLE URBANIZATION, PLANNING AND PROGRESS

Guest Editor: **Shu-Qing Yang**
University of Wollongong, Australia

Editor-in-Chief: **T.G. Sitharam**
Indian Institute of Science, India

URBAN DEVELOPMENT SCIENTIFIC PUBLISHING PTE. LTD.

September 2017 | Volume 2 | Issue 2 | Page 1 – 58 |

Journal of Sustainable Urbanization, Planning and Progress

http://ojs.udspub.com/index.php/jsupp

Contents

EDITORIAL

Can floodwater in estuaries be developed as drinkable water without desalination?

Guest Editor: Shu-Qing Yang
Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia

http://doi.org/10.26789/JSUPP.2017.02.009

In 2015, members of the United Nations (UN) assessed the crisis that human has now and developed 17 Sustainable Development Goals (SDGs) which have been collectively endorsed by UN's 193 members, and the deadline is 2030 to achieve these goals. Amongst them, SDG6 relating to water is the most challenging to achieve given the water stress that most countries globally face along with lack of revolutionary new methods to provide safe and affordable drinking water for all. Currently more than 40% of the global population is affected by water scarcity, and this percentage is only going to rise. In other words, if no new technologies are developed or adopted by the 193 members, the promise will be far from fulfilled. Under these conditions, the "coastal reservoir" system is a paradigm shift in water resources development, which could be a timely solution for countries, proving "The true test of commitment will be implementation".

In 2017, the International Association for Coastal Reservoir Research (IACRR) was established to provide an option towards accomplishing SDG6 using a new technology. The coastal reservoir (CR) is a system whereby the dam is situated in the seawater environment to develop floodwater. IACRR's vision is to provide sufficient, clean and affordable water with minimum environmental and social impacts. IACRR is already receiving tremendous support from several entities including decision-makers, researchers, engineers and journalists. In fact, the papers listed in this issue provide an in-depth view into CR, its use, technology underpinnings, and its applicability in the south-Asian context. On behalf of the authors and readers, I thank JSUPP for its generous support for publishing these papers. I believe this issue will be the first of its kind documentation on CR as it clearly answers the following questions:

Is CR technology applicable to developed countries like Australia? First paper[1].

A quick look at the CR map of the world shows that almost all CRs have emerged in developing countries, except in Singapore and Hong Kong, with very few in developed countries like USA, and Australia (only one in the 1930s). Many possible reasons may exist for this like less population and small water gap between supply capacity and demand, high environmental and water quality standards, etc. This paper clearly shows that Australia uses only 5% of its annual runoff, and desalination and wastewater reuse are not its water solution priorities. Coastal Reservoirs, if design properly, have minimum environmental impacts relative to other solutions, also the water quality is comparable with the existing dam water, if not better. This paper presents preliminary CR designs for each capital city and an interesting conclusion is that CRs can also solve inland regions' water crisis. A criteria has been proposed to justify the feasibility of water diversion projects.

How to enhance water quality in a large river's coastal reservoir? Second Paper[2].

The worst enemy of CR is not seawater pollution, but land based pollution. There exists a high risk for any CRs to develop water from a large river. Qingcaosha Reservoir (QR) is a typical example, where the quality of incoming water is not very good. This paper discusses purification of water using natural systems such as wetlands. The research outcome shows that after the continuous purification through wetlands, the quality of raw water has improved. The average value of $NH_4{}^+$-N, NO_3-N, TN, TP in the outlet are 81%, 65%, 77% and 66% of the inlet respectively, after flowing through the natural wetland in the reservoir. The wetlands can solve two major problems facing the coastal zone reservoirs which are enhance intake water quality and stabilize water quality. In the design of coastal reservoirs, the authors suggest that we should make full use of existing wetlands, enhance the function of wetland water purification through ecological engineering methods, and construct artificial wetlands as a supplement.

Is CR technology environment-friendly and socially acceptable? Third Paper[3].

It is well known that for infrastructural development in almost every country, environmental impacts assessment (EIA) is a must. While the authors did not conduct any detailed EIA research to address this paramount question, they used a simple and convincing method to answer it, i.e., using secondary sources to examine papers in the largest database of research community, i.e., the web of science. The result of this literature search is astonishing as the existing CRs show almost no negative impacts. By examining images in google, the authors compared the social impacts of different projects. The research method used in this paper is interesting and novel and the conclusion is convincing, i.e., the existing CRs have minimum environmental/social impacts relative to other methods.

Is CR technology applicable to China? Fourth paper [4].

China is the most populous country in the world with a substantial chunk of its population highly concentrated along its eastern coastline. Globally, Hong Kong is the first city whose drinking water comes from its CRs. In the 1990s, the UN predicted that Shanghai would be one of the largest cities with severer water shortage induced by pollution. This crisis has been avoided by Shanghai CR, which is the largest CR in the world. Given this, it is important to discuss whether the successful applications can be extended to other coastal cities, and whether China's historical problem which is, 50 km^3/year water gap between its demand and supply capacity can be solved. This paper clearly answers these questions and goes further to provide the preliminary CR layout for each city. The interesting finding is that the huge water gap is only 2.7% of its runoff lost to the sea. The data clearly reveals that China is not running out of water, but water is running out of China.

Is CR technology applicable to lagoons or coastal lakes? Fifth paper [5].

It is often that water is available in abundance but not a drop is drinkable. Can a brackish lake be developed as a coastal reservoir for high quality freshwater storage? Australia attempted this in 1930s for its Alexandrina Lake, but failed. This paper presents an innovative CR design where the mistake in Australia's early attempt is avoided. The feasibility study is positive for the formation of fresh water reservoir in a typical brackish water lake. Ashtamudi Lake in southern India was taken as a case example to test this. The result shows that the water is good enough for urban water usage in the coastal town of Kollam, India.

Is there any option to Inter-link Indian rivers? The case study of Netravathi River. Sixth paper [6].

For a long time now, India has had a heated debate on its ambitious river inter-linking project. This very costly (about US$168 billion) project tries to divert water from the Himalayas to its southern tip. Given its contentious nature, it is important to assess alternatives to this project. This paper presents a vivid case similar to China or most other places of the world, showing that India is not running out of water, but possibly water is running out of India. The southern part of India in particular is in fact not short of water, but is lacking in ways and means to store it. Its CR feasibility study clearly shows that a large amount of flood waters exist. From the detailed hydrological analysis of Netravati and Gurupura rivers, this paper estimates the runoff into the sea, at 388 TMC from Netravati River and shows that just 2.5% of this amount would be sufficient to meet the present water shortfall of Bengaluru, the largest city in the Southern Indian Peninsula. It is postulated that India's water thirst can be completely quenched using coastal reservoir technology, even without the Rivers interlink project.

How wetland pre-treatment enhances performance? Seventh paper [7].

This paper highly recommends productive/agricultural wetland to pre-treat river water for CR's storage. Different from Qingcaosha CR, the Caofeidian CR is small and its catchment is also very small, even then, the water quality becomes a big issue caused by serious agricultural non-point source pollution. In this paper, agricultural/productive wetlands are introduced to purify water. The productive wetland by floodplain could reduce 450 tons of COD, 18 tons of total nitrogen, 3.6 tons of total phosphorus annually, and reduce the water evaporation by 14,000 m^3 annually. Agricultural wetland (Paddy field ecological ditch) can effectively remove the storage of pollutants with 4 tons of total nitrogen, 0.8 tons of total phosphorus annually, and conserve 1,000 m^3 water nearly. Their results show that Caofeidian CR's water quality has been significantly improved after wetland purification. Thus, it is certain that, if designed properly, CRs can provide very high quality water to the users without incurring high cost.

Meeting India's SDG6 through Coastal Reservoirs? Eighth paper [8].

What is India's Sarovarmala? Why is it important for the Indian government to keep its promise, of providing sufficient, clean and affordable water to its 320 million people who live in water-starved conditions and ensure provision for 840 million by the year 2050? This paper first analyses India's recorded rainfall pattern and finds that no significant changes can be observed. The author then makes the case that "Increase in population" and "inefficient management of precipitation" are the main reasons for water scarcity. The most sustainable solution for India's water problem is to make provisions to store rainwater during the monsoons and wetter seasons in coastal reservoirs, and use it in drier seasons when needed. This paper estimates that potential runoff to the sea from India is about 4,400 thousand million cubic feet. This paper suggests constructing coastal reservoirs along the Indian coastline along the west and east to form a necklace (mala) which can then help alleviate India's water crisis. Further, doing so can make SDG6 achievable in India.

References

[1] Yang S Q, 2017, Will coastal reservoirs dominate future Australian water supplies? *Journal of Sustainable Urbanization,*

Planning and Progress, vol.2(2): 4-15.
http://doi.org/10.26789/JSUPP.2017.02.003

[2] Wang Q, Wang F Y and Xiong L H, 2017, The role of wetland in water quality purification and maintenance of coastal reservoirs: a case of Qingcaosha Reservoir. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 16-18.
http://doi.org/10.18063/JSUPP.2017.02.005

[3] Yang S Q, Smith L and Sivakumar M, 2017, Assessment of social and environmental impacts of coastal reservoirs. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 19-26.
http://doi.org/10.26789/JSUPP.2017.02.001

[4] Yang S Q, 2017, Application of coastal reservoirs in China and its feasibility. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 27-33.
http://doi.org/10.26789/JSUPP.2017.02.010

[5] Sitharam T G, Kolathayar S, Samuel M P, *et al*., 2017, Feasibility study on formation of fresh water reservoir and impounding the surface runoff for urban water survival in a coastal brackish water region of Kollam, India. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 34-37.
http://doi.org/10.26789/JSUPP.2017.02.004

[6] Kolathayar S, Sitharam T G, Ramkrishnan R, *et al*., 2017, Feasibility of creating a fresh water reservoir in the Arabian Sea impounding the flood waters of Netravathi River. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 38-42.
http://doi.org/10.26789/JSUPP.2017.02.006

[7] Chen X Y, Lu J J, Wang Q, *et al.*, 2017, Characteristics of water purification pattern of Caofeidian freshwater reservoir. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 43-48.
http://doi.org/10.26789/JSUPP.2017.02.007

[8] Sitharam T G, 2017, Efficacy of coastal reservoirs to address India's water shortage by impounding excess river flood waters near the coast. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 49-54.
http://doi.org/10.26789/JSUPP.2017.02.008

REVIEW ARTICLE

Will coastal reservoirs dominate future Australian water supplies?

Shu-Qing Yang
Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia

Abstract: Next to air, fresh water has been always considered as the most important resource, central to economic development as well as to human physiological needs. Currently the total world population is about 7 billion, and by 2050, it is projected to be 9 billion. By that time, an additional 40 Nile Rivers will be needed. Historically, inland dams have successfully solved the water deficit problems in many places, but more and more countries are resorting to emerging technologies like desalination, wastewater recycling and rainwater tanks which are needed to replace inland dams for a number of geomorphological, environmental and social reasons. These new technologies require a paradigm shift in the water supply industry: global water consumption is only 5-6% of annual runoff – as it is in Australia – so the coming shortage is not of water, but of storage.

A coastal reservoir is a reservoir designed to store floodwaters in a seawater environment. The first generation of this technology has been successfully applied in China, Singapore, Hong Kong and Korea, but the water quality is generally not as good as that from inland reservoirs. The second generation of coastal reservoirs has been developed and its water quality is comparable with the water available from conventional urban water supply reservoirs, if not better. The conceptual design of coastal reservoirs for Australia's capital cities is outlined.
Keywords: urban water supply, coastal reservoir, inter-basin water diversion, inland dams, water quality

Correspondence to: Shu-Qing Yang, Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia; Email: shuqing@uow.edu.au

Received: July 2, 2017; **Accepted:** August 10, 2017; **Published Online:** September 30, 2017
Citation: Yang S Q, 2017, Will coastal reservoirs dominate future Australian water supplies? *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 4-15. http://doi.org/10.26789/JSUPP.2017.02.003

1 Introduction

According to Kummu *et al.*[1], the population under water scarcity since the 1900s has increased by nearly 16-time, but total population has increased only 4-fold over the same period. Alavian *et al.*[2] show that 80 countries now have water shortages, and 2 billion people do not have sufficient clean water, with at least 1 billion people not having their basic water needs. The current world population of 7.2 billion is estimated to be increasing by 1 billion every 12 years, about 50% of the total population will soon be affected by severe water shortages. Most of them will live in coastal cities due to urbanization. An example of global water crisis can be seen in Australia, the driest inhabited continent in the world with 24 million people in 2016 spread over 7.7 million km^2, where desert makes up about 18% of the mainland. Not only is the continent dry, but its rivers generally flow with less regularity and predictability than those of other continents[3,4]. The largest river system (the Murray-Darling river basin) is similar in area to that of the Ganges River in India (about 1 million km^2), but during Australia's Millennium Drought (2000-2009), the Ganges River flow was 200 times higher than that in the Murray-Darling system.

In 2013-2014, Australia used 24×10^3 GL/a of industrial and household water[5]. Compared with the annual runoff to the sea which is about 400×10^3 GL/a, the consumed water was only 6% of total runoff, similar to the rest areas in the world. In the next 100 years, only $1-2\%$ of additional runoff is needed to sustain Australia's growth in water demand. More and more countries are realising that on-stream dams are not the future for water development, so new technologies are required. These ideas and solutions have been tested in Australia to ensure security of supply:

1) Inland dams. In the 20th century, the dam industry played a leading role in securing water supply such that Australia has the highest storage per capita in the world. In the 21st century, it is now hard to find dam sites which are economically suitable for development. Further, there is much more technical and public recognition of the negative impacts on riverine ecosystems. Consequently, governments, research communities and the public are shifting to other alternatives to locating water storages on significant watercourses.

2) Wastewater reuse. This technology was first highlighted by its success in low-rainfall Windhoek, Namibia and has been applied in Singapore and Brisbane[6]. The Western Corridor Project in Brisbane cost $ 2.7 billion in 2008, but in September 2013, then Premier Peter Beattie admitted that the scheme was a "tragic error of judgment" because the public rejected drinking recycled sewage because of its "yuk factor".

3) Desalination plants. This has been seen as a promising way to supplement climate/weather-dependent water supplies during droughts, especially for island countries like Singapore and Australia. There are 92 desalination plants in Australia but experience from Melbourne and Sydney plants indicates they are economic "white elephants", whatever their technologic and political benefits.

4) Demand management. In the late 20th century, Australia started the swing from supply management – governments delivering the water wanted by society and industry – to demand management – customers reducing water wastage and unnecessary consumption. This move has reduced the immediate demand for more storages to be built but increasing demand by more population will eventually reignite the need for greater water supply and storage.

5) "Operation Plowshare" was an American program to use nuclear explosions for peaceful purposes, a section of the Australian water industry toyed with the idea of blasting several subterranean, sealed-by-molten-rock vessels into which flood flows in Queensland Channel Country would be directed by surface windrows into the vessels via large diameter bores. A central vessel would then be heated by a later nuclear explosion to generate steam for a surface power plant to supply electricity to raise water from surrounding vessels by pumps. It was understood that the nuclear devices would have been supplied free of cost.

6) Adelaide and Perth have considered towing Antarctic icebergs north to have them melt into impervious liners, perhaps aided with a covering of carbon black or similar[7].

2 Problems with Dams

The problem of all dams is that the dam sites with suitable location with near demand centres have been developed in the post-WW2 40-year era of dam building. The remaining dam sites are generally not suitable for development. Consequently, there is no much new dams after 2000 as shown in Figure 1[8].

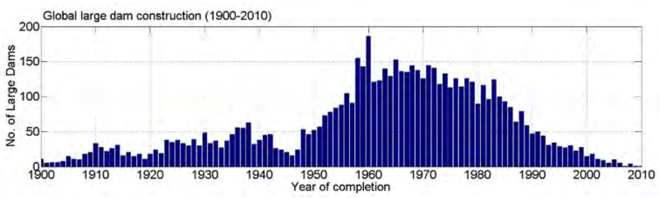

Figure 1. Number of large dams constructed in the world by year.

Another problem with dams is sedimentation[9]. The total sediment yield in the world is estimated to be 13.5×10^9 t/a or 150 t/km^2/year and about 25% of this is transported into the seas and oceans and 75% is trapped in the lakes, reservoirs and river systems[10]. UN experts warn that a fifth of the current storage capacity of reservoirs worldwide will be gradually lost over the coming decades as a result of sedimentation[11]. Further, global warming may increase the severity of storms and rains which would accelerate the natural erosion rates that feed reservoirs. The life span of world reservoirs depends on the sedimentation rate which is reducing their storage capacities by more than $1-1.5\%$ per year[12]. A concrete dam's design life span is about 100-200 years, so assuming an average life span of to be 150 years, the future operating dam numbers and total storage can be calculated. The results are shown in Figure 2, which clearly indicates that by 2150, all reservoirs will have been abandoned as effective water storages. Figure 2 clearly shows that our water crisis is being intensified by sedimentation quite separately from demand.

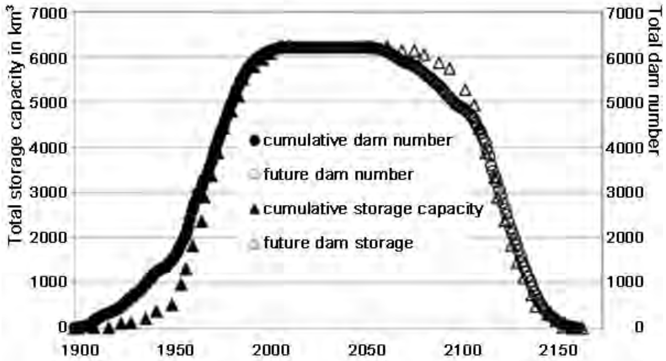

Figure 2. Number of operating large dams in the world and their total water storage in km^3 based on the assumption of 150-year dam life spans. Filled symbols are historical and open symbols are future estimates assuming average sedimentation occurs.

3 How Those Problems Affect Australia

Australia's dam construction is shown in Figure 3a which is based on the data available in The Australian National Committee on Large Dams' (ANCOLD) website. It has the same post-WW2 boom as in Figure 1, the six-fold peak rate of building over the pre-WW2 average but a 10-year later peak and return to pre-WW2 numbers. More than a half of the dams were designed for purposes other than water supply like irrigation, flood control and hydro-power. A problem for siting Australian dams is that we don't have the high mountains and deep valleys common on other continents to provide narrow dam sites with extensive upstream storage topography. Our flat land not only deprives us water storage in winter snowpacks but makes our reservoirs comparatively shallow with a large water surface, so they are prone to evaporation losses and greater sediment deposition. This is why the benefit of dam construction in Australia often cannot cover its cost. For example, the Ord River Scheme in Western Australia cost A$ 613 million between 1958 and 1991, but the benefits were just A$ 102 million in the same period[8]. The benefit-cost ratio of 0.17 is far below the 1.3 or so needed for governments to recover their outlays through taxes and charges.

Australia has the highest population growth among the major developed countries[13] as shown in Figure 3b. White estimates the mean annual sedimentation rate for Australia is about 0.27% of reservoir's storage, about 1/4 of the world's average[12]. In other words, dam operators in 185 years' time

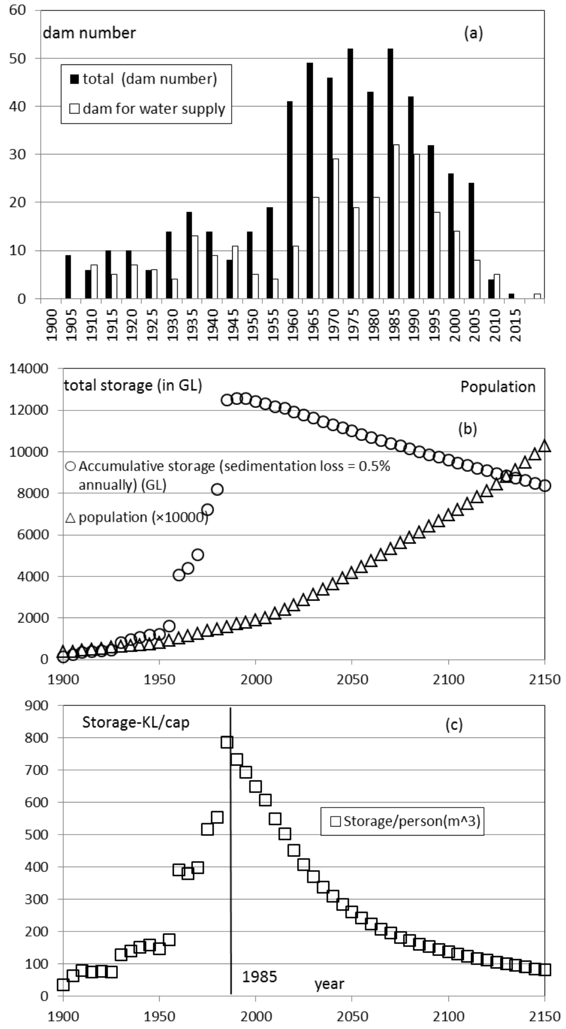

Figure 3. The effect of not increasing Australia's water storage. (a) Number of dams constructed and number for water supplies. (b) Population growth and total storage capacity. (c) Storage capacity per capita from 1900-2150.

can expect to be working with perhaps only 50% of their original storage. This means that, if no new dams are constructed, the storage volume per capita will be decreased significantly as shown in Figure 3c.

Australia's 500 large dams yield the highest per capita surface water storage in the world at 800 kL/capital in 1985. Such storage is needed because Australian rivers are characterised by low discharges and the highest variability of all the continents[3,4]. However, this storage has been effectively waning since 1985 due to increasing demand from a growing population and to sedimentation. Figure 3c reveals that we have already lost 1/3 of our storage capacity, and by 2050, our storage capacity per capita is projected to shrink to WW2 levels. Obviously, we need more storage for an increased population to survive during droughts like the Millennium Drought of 2000−2009.

For the above two reasons, it is clear that dam-building era from the 1950s to the 1980s is over, never to return. But perhaps dam-building only needs to change the way it does business.

4 Coastal Reservoirs

Coastal reservoirs are the result of siting dams inside seawater. They are similar to inland dams in that they are constructed to high standards of strength and impermeability and for the shortest practical length to minimise costs. They have an advantage over inland dams because they have the potential to collect every single drop of runoff from their catchment. That advantage is also a disadvantage because they have the potential to collect every micro-pollutant from their catchment. As a result, some coastal reservoirs in Table 1 have become wastewater reservoirs, such as the Sihwa Lake in South Korea[14]. Because the volume of wastewater maintains the same growth rate as population (as does the usage of fertilizer and pesticides), it can be predicted that the raw water quality in these coastal reservoirs will never meet drinking water standards unless new technology solves the problem of non-point source pollution.

These first generation barrages are normal to the flow direction, which cuts off ships' navigation and fish migration, and causes significant environmental impacts. An in-stream coastal reservoir has a fixed storage capacity, which may not be able to match the designed water demands; the accumulative contamination in the reservoir may deteriorate its water quality. Another problem of the first generation coastal reservoir is caused by a high evaporation loss, the example can be seen from Australia's first coastal reservoir formed by five barrages at Lake Alexandrina outlets, it was intended to change its brackish water into a freshwater lake using Murray River water. The high evaporation over very large surface areas, coupled with low river flow in the Millennium Drought, led to its salinity becoming an undrinkable 6,000 mg/L in mid-2010.

The first coastal reservoir in the world was built in the Netherlands in 1932 and it took five years for its originally saline water to be replaced with freshwater. In 1968, Plover Cove in Hong Kong became the first coastal reservoir in the world for drinking water purposes. Most reservoirs in Singapore are coastal reservoirs: Pandan, Kranji and Marina Bay. In China, Shanghai constructed the Baogang coastal reservoir in 1985 and Chen Hang coastal reservoir in 1992. Currently, its water supply mainly comes from the 527 GL Qingchaosha coastal reservoir, which is by far the largest coastal reservoir in the world for drinking water purposes. Its construction cost in 2011 was US$ 2.8 billion to supply 2,600 GL/a for 24 million people.

In Table 1, except for Shanghai coastal reservoirs, all existing reservoir barrage alignments are normal to the river flow direction. This alignment is the same as inland dams and significantly changes the river flow regime, causing many environmental and ecological problems for navigation, passage of migratory fish etc. Sihwa coastal reservoir in South Korea, for

Table 1. World's existing coastal reservoirs.

Name	Catchment (km^2)	Dam length (km)	Capacity (GL)	Year completed	Construction cost (US$ B)	Country – River
Zuider Zee	170,000	33.00	5,600	1932	N.A.	Netherlands
Lakes Alexandrina & Albert	1.1×10^6	7.60	1,600	1940	N.A.	Australia – Murray
Plover Cove	46	2.00	230	1968	0.07	Hong Kong
Baogang/Shanghai	1.8×10^6	3.70	12	1985	N.A.	China – Yangtze
West Sea Barrage	20,000	7.80	2,700	1986	1.80	N. Korea – Taedong
Chen Hang/Shanghai	1.8×10^6	4.70	8	1992	N.A.	China – Yangtze
Sihwa	476	12.40	323	1994	0.30	South Korea
Yu Huan	170	1.00	64	1998	0.10	China – Zhejiang
Marina Barrage	110	0.35		2008	0.20	Singapore
Qingcaosha/Shanghai	1.8×10^6	43.00	550	2011	2.80	China – Yangtze
Saemanguem	330	33.00	530	2011	2.10	South Korea

note: N.A. = not available

instance, was abandoned for water supply because of accumulative non-point-source contamination[15].

It is predicted that coastal reservoirs that totally cut off the river flow from the sea would not be approved by any government in the future. It would have been necessary to develop the second generation of coastal reservoirs which should avoid the mentioned disadvantages, thus its water development is technically feasible, economically viable, environmentally sustainable and socially acceptable.

5 Second Generation Coastal Reservoirs

These coastal reservoirs (Figure 4) aim to solve the problems with first generation coastal reservoirs by:

1) Potentially reducing construction costs.

2) Reducing operating costs especially in terms of maintaining quality standards.

3) Reducing the adverse impacts of coastal reservoirs on ecosystems to levels acceptable to the public and to governments.

4) Bypassing polluted water or opening rivers to navigation and fish passage without interruption, so quality of the stored water is enhanced to levels acceptable to the public and water authorities. The most important feature of the second generation coastal reservoir is its capability to select high quality water for storage.

5) Eliminating dislocation of people caused by land inundation, cessation of agricultural activities, disruption of transport corridors etc.

6) More flexibility in design, construction and operation of barrages for existing conditions as well as future changes in demand, quality standards, environmental expectations etc.

5.1 Solid Barrier

As the sea is the biggest reservoir on the planet, the coastal reservoir can be constructed in any place in the sea, even to-

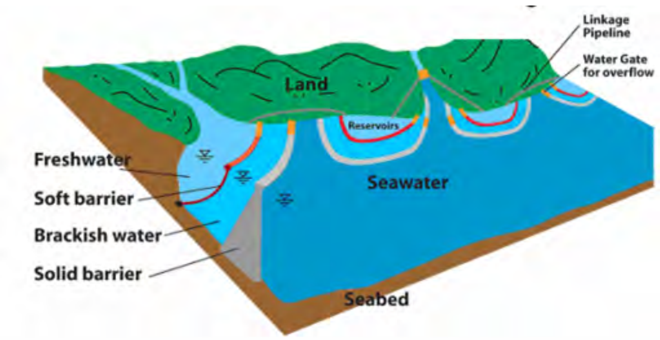

Figure 4. Scenarios for second generation coastal reservoirs[20], the intake system is shown as an orange square, which can divert good quality river water to the reservoir for storage in flood seasons.

tally offshore if the coast must remain undisturbed. The primary barrier is located, at least in part, in a body of seawater (see Figure 4). It goes without saying that coastal reservoirs are designed to have the shortest practical barrage length for minimum construction cost, commensurate with providing the required storage volume, seafloor shape, geology etc.. The primary, solid barrier of a coastal reservoir must be of sufficient height to withstand tidal surges and wave action, but it needs not to be as sturdy as the walls of inland dams because the water pressure differential across the wall is usually less than 10 m whereas that across a conventional dam may be in excess of 100 m. It may be constructed as a concrete wall, stone breakwater, a row of caissons, earth/rock dike or a pile of huge sandbags. For example, a 170 km long dike was constructed in 2002 to protect the navigation channel in the Yangtze estuary using prefabricated caissons and sandbags/geosynthetic tubes[16], where the water depth ranges from 5.0 to 8.5 m, wave height is 3.3 to 5.9 m[17]. The total cost including dredging of 0.3×10^9 m^3 soil was US$ 2.5 billion; that is, 15 million US$/km. Huge sandbags are used in the construction of dike in Qingcaosha coastal reservoir, Shanghai.

5.2 Soft Barrier

Seepage for an inland dam can be a big problem, but for a coastal reservoir this is insignificant because the water pressure differences are small, and most of the time the reservoir's water level is slightly higher than the sea level. The sea water intrusion can be further prevented by introducing a soft barrier as shown in Figure 4. The soft barrier is an impermeable curtain suspended from a boom on the water surface[18]. It extends to the sea bed to separate fresh from brackish water contaminated by seawater from either wave action at the surface or any seepage of groundwater of seawater. The soft barrier can effectively prevent pollution of seawater from seepage in the seabed or overtopping by surging waves in extreme weather conditions. It should be highlighted that a soft barrier is not a must for the second generation of coastal reservoirs.

5.3 Bypass Gates & Water Quality Management

The most important feature of the second generation coastal reservoir is its capability to select good quality for storage and to discharge polluted runoff out of the reservoir without mixing. The existing coastal reservoirs like Singapore Marina Barrage generally receive polluted water (i.e., first flush), but discharge clean water to the sea (after sedimentation). By using the SPP (Separation, Prevention and Protection) strategy[19], water quality could be improved by separating freshwater and seawater by a barrier, clean water from polluted river water using intake regulation, and only good quality water is allowed to enter the reservoir via the intake regulation as shown in Figure 4. The collected fresh water needs to be protected against external pollution from the river and the sea. Seawater intrusion into the stored fresh water should be prevented. The SPP strategy is effective in collecting good quality water, because the intake gates in Figure 4 will be closed when poor quality water or first flush flows appear, so the polluted water flows to the sea via a bypass channel without entering the reservoir. A wetland pretreatment is also suggested to purify the river flow prior to its storage.

Generally, good quality water appears during flood seasons except its first flush that should not be allowed to enter the coastal reservoir, as the first flush transports majority of contaminants like total nitrogen (TN) and total phosphorus (TP) and other nutrients and heavy metals. These pollutants generally come from non-point sources over a land surface, particularly after a long spell of dry weather. Normally, it is not necessary to collect all runoff, as globally only additional 1∼2% of runoff is enough for human's water demand. For very large river basins, it is suggested that multiple pre-treatment wetland is applied to reduce TN, TP and other nutrients to ensure the reservoir's water quality. The intake/tidal gates can be inflatable rubber dams as those used in Singapore Marina Barrage.

The second generation coastal reservoirs have the capacity to select water for storage and to bypass unwanted water based on its quality in a river. The first generation coastal reservoirs have no bypass channel to discharge polluted water, and poor quality water is stored in the reservoirs, consequently the water inside the reservoirs is deteriorated, like the Sihwa coastal reservoir in South Korea[15]. Obviously if the bypass channels are used in the reservoir, the Sihwa lake can restore its water quality and function as a water source again.

Like inland dams, all coastal reservoirs will eventually lose its capacity due to sedimentation, but the difference is that another new coastal reservoir can be constructed in the sea near the silted coastal reservoir, whose land can be developed for industrial and resident purposes, even for agricultural activities without the problem of soil salinization. Therefore, one may conclude that the sites of coastal reservoirs are renewable, but the sites of inland dams are not renewable.

5.4 Environmental Impacts

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.*[21] 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.

The differences between coastal reservoirs and traditional inland reservoirs are summarized in Table 2. The first generation coastal reservoirs' shortcomings are also included for comparison, e.g., – poor water quality, high construction costs and inappropriate size. The second generation of coastal reservoir can be designed to overcome these problems so their application to Australia should be discussed.

5.5 Financial Comparison

The proposed A$1.6 billion Traveston Crossing Dam in Southeast Queensland would store 161 GL of water and could supply 70 GL/year, and 76 km^2 of land to be flooded permanently as the reservoir[22]. The design life span of concrete dam and its steel structures is about 100 years, during which span the total water supply is 7,000 GL, thus the capital cost is 0.23 A$/kL (= 1.6 B A$ / 7 B 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

Table 2. Difference between inland reservoirs and coastal reservoirs.

Aspect	Inland reservoirs	First generation coastal reservoirs	Second generation coastal reservoirs
Water quality	Good (from protected catchments)	Poor (collect and store all contaminants)	Good (only collect clean water, bypass polluted water)
Water level	Variable water level, above sea level	Variable water level near sea level	Almost constant water level near sea level
Dam alignment	90^o to flow direction	90^o to flow direction	Small angle to flow direction
Dam site	Limited (narrow dam sites with)	Limited (only inside a river mouth)	Unlimited (inside or outside river mouth)
Dam design	Concrete, earth/rock to withstand high water pressure	Concrete, earth/rock to withstand low water pressure but with wave/ tidal surges	Concrete, earth/rock to withstand low water pressure but with wave/tidal surge, with/without soft dam
Dam length	Short	Short	Long
Environmental impacts	High	Medium (obstruction to floodwater, fish, navigation)	Low
Seepage	By pressure difference	By density difference	By density difference
Pollutant	Land-based	Land-based + seawater	Land-based + seawater
Emigrant cost	High	None	None
Water extraction	By gravity	By pump	By pump
Water catchment	10~50%	100%	100%

its birth in 2010. The taxpayers need to pay 535 m A$/year for its state of hibernation, or 5.9 A$/kL (= 535 m A$ / 90 GL) of manpower cost. This water desalination plant needs the power of 4 kWh/kL[23], thus the energy cost is about A$1.2/kL, so the total running cost is 7.1 A$/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$/kL for 20 year design life span. Its manpower cost is similar to the desalination plant, but its required energy is less, and 0.6 A$/kL is assumed. This gives that wastewater recycling method's 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 45 km long dam, pumping system with the capacity of 200 m^3/s or 2,600 GL/year, 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[24], 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 6 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.

6 Coastal Reservoirs for Australian Capital Cities?

In the light of Australia's small water consumption compared with surface runoff, Yang[25–27] claims that our future water crisis will not be caused by water shortage, rather by storage shortage. As dams on rivers are becoming increasingly unattractive for economic, environmental, and social reasons, it may now be time to consider building dams at sea, creating coastal reservoirs to harvest floodwaters otherwise lost to the oceans.

To solve Australian coming urban water crisis, coastal reservoirs for the capital cities are proposed in Figure 5-14. Conceptual designs are indicated as follows: red lines represent solid dams or shoreline of fresh water reservoirs, artificial canals are represented by a thick orange line, intake/tidal gates are represented by short yellow lines. The flow path of high quality river water are represented by white lines with arrow heads, the flow path of poor quality water or by-passed water are represented by black lines with arrow heads.

In Australia, all capital cities except Hobart have faced water crisis, this can be seen from the emergence of desalination plants. Hence it is necessary to analyse whether the water crisis is caused by water shortage or storage shortage, and whether coastal reservoirs can quench Australian thirst.

Southeast Queensland This region has a population of 1.9 million people spread over the 240 km from the Gold Coast to the Sunshine Coast, west to the Great Dividing Range and includes cities of Gold Coast, Brisbane and Sunshine Coast. To reliably supply this region's 300 GL/a[28] demand, coastal reservoirs are suggested for the mouths of the Richmond River and the Brisbane River, as shown in Figure 5 and 6. The annual runoff of Richmond River is 3,300 GL/a and that of the Bris-

Table 3. Cost comparison among different methods of water supply for per kL of water.

	Inland dams	**Desalination plant**	**Wastewater reuse**	**Coastal reservoir**
Project discussed	Traveston Crossing Dam in QLD in 2007	Sydney desal. Plant in 2010	West Corridor Project in QLD in 2008	Qingcaosha in Shanghai in 2010
Design life span (year)	100.00	20.00	20.00	100.00
Total capital cost (A$ billion)	1.60	1.83	2.60	3.70
Water supply (GL/year)	70.00	90.00	130.00	2,600.00
Capital cost (A$/kL)	0.23	1.00	1.00	0.01
Running cost (A$/kL)	0.40	7.10	6.50	0.40

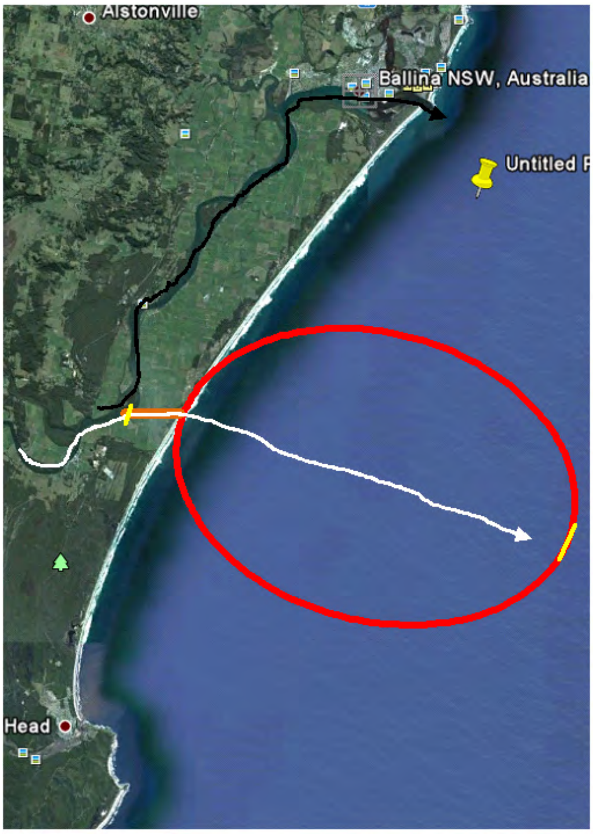

Figure 5. Potential coastal reservoir at Richmond River (100 km north to the Gold Coast).

Figure 6. Potential coastal reservoir at Brisbane River mouth.

bane River is about 2,500 GL/a[29]. The available water is 20 times more than the water demand. In Figure 6, the total length of dike is 16.3 km, the water surface area of coastal reservoir is 66 km^2.

NSW Its total population in 2015 was 7.7 million, with Sydney 4.9 million or 64%, and Newcastle Maitland 0.4 million or 5.6%. During the Millennium Drought (2000-2009), water in Warragamba Dam, the largest dam for Sydney's water supply, dropped to its lowest recorded level of 33.8% on 9-10 February 2007. Warragamba Dam's catchment is only 9,000 km^2, but the catchment areas of the Hunter River, Hawkesbury River and Shoalhaven River are 22,000 km^2, 21,600 km^2 and 7,000 km^2, respectively. If the coastal reservoirs proposed in Figures 7-9 are applied, the total catchment is as high as 44,300 km^2, which is 50 times larger than Warragamba Dam's catchment. It is certain that these regions' water supply can be secured. In Figure 7, the Fullerton Cove receives good quality water in flood seasons, and its shallow cove can be used as a wetland to pre-treat the river water that is stored in the coastal reservoir in the sea. Figure 8 shows that two barrages at the outlets of Hawkesbury River mouth can create a reservoir with 50 km^2. These barrages can be also used for road transport like freeway or high speed train rails. If average water depth is 10 m, then the storage is about 500 GL. Its annual flow rate is about 4,600 GL/a. As the catchment is covered by forest, thus the water quality should be good enough and the wastewater bypass channel may be unnecessary. Figure 9 shows the coastal reservoir of Shoalhaven River, whose flow is regulated by two hydraulic gates, these barrages can be also used for land transport. This reservoir can be a backup water source for Sydney, Wollongong, Nowra and Canberra in extreme dry years in future.

Melbourne Its annual rainfall is about 650 mm/a. Its largest dam, the Thomson River Dam is capable of holding around 60% of Melbourne's water capacity. The total storage capacity of the 10 reservoirs that supply Melbourne is 1,800 GL, and the water comes from 1,600 km^2 protected catchments in the Yarra Ranges. The annual flow from the catchment to these reservoirs is about 600 GL, but during 1997-2009, this dropped to 380 GL/a. On 1 July 2009, the storage was only

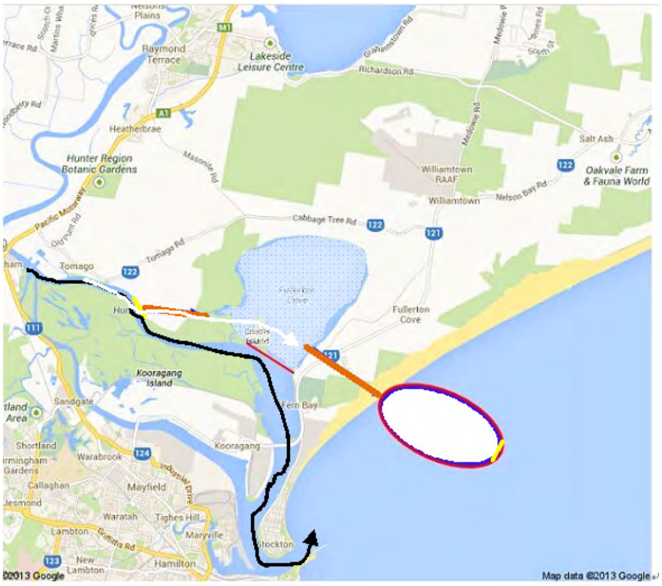

Figure 7. Potential coastal reservoir for Newcastle at Hunter River mouth.

Figure 8. Potential coastal reservoir at the Hawkesbury River mouth by 2.9 km barrage.

Figure 9. Potential coastal reservoir at the mouth of Shoalhaven River.

Figure 10. A potential coastal reservoir to develop the wetland pre-treated water from Yarra River using pipelines or underground tunnel.

26% of fully capacity. Water supply in 2014-2015 was 400 GL. If coastal reservoirs are constructed at the river mouths of the Yarra River (catchment area = 4,100 km^2), Bunyip River (4,100 km^2), Maribyrnong River (1,500 km^2) and Werribee River (2,000 km^2), the total catchment is about 11,600 km^2, and total runoff from these four catchment is 2,000 GL/a. An example of a coastal reservoir for Melbourne is shown in Figure 10 where the intake at the Yarra River is open only when the river flow has high quality water, the lake in the city can be used as a wetland to pre-treat the river water. The treated water is stored in the coastal reservoir.

Adelaide Its local inland reservoirs provided 32 GL/a water during the Millennium Drought (2000-2009), and the catchments of these inland dams are small relative to the coastal reservoirs' catchment like Torrens River and Onkaparinga River. Hence, if coastal reservoirs were constructed at the river mouths, the local reservoirs could provide more water to Adelaide, say 100-200 GL/a. In dry years, Adelaide's water supply depends heavily on water transfer from the Murray River, up to 90%. Lake Alexandrina is the first coastal reservoir in Australia as its barrages were constructed in the 1930s to develop its water resources. However, the design purpose is not successfully achieved as it was a saline water body in the Millennium Drought.

Similar to Las Vergas whose water supply comes from Hoover Dam by developing water from its nearby river – Colorado River, Adelaide's desalination plants may be unnecessary if a dam like Hoover Dam existed to develop water from its nearby large river: Murray-Darling River. Figure 11 clearly shows that Adelaide is not short of water, but its storage, as its annual inflow during the Millennium Drought was 5,700 GL/a, but the annual water demand was about 150 GL/a in the same period. Detailed research[18] shows that if a second generation coastal reservoir is applied inside the Alexandrina Lake, this Australian "Hoover Dam" can supply sufficient high quality water to the Adelaide and South Australia. Their results also show that the coastal reservoir would improve the lake's ecosystem, as the research shows if there was a coastal reservoir in Figure 12 in the Millennium Drought, the lake's water level would be higher and its hydraulic residence time would be shorter. This is understandable because the reservoir reduces the stagnant water volume and stores good quality water in flood seasons. The research also shows that it is safe for Adelaide to divert 500 GL/a in dry years like 2007-2009 from the coastal reservoir whose size is about 580 GL located inside the Lake Alexandrina. In flood seasons, the intake gate is open to store high quality water. After that, the intake gate is closed, and river flow by-passes the reservoir entering the lake and the poor quality water is used to improve ecosystem. This design does not use any shoreline of the lake, thus it has little impacts on human society.

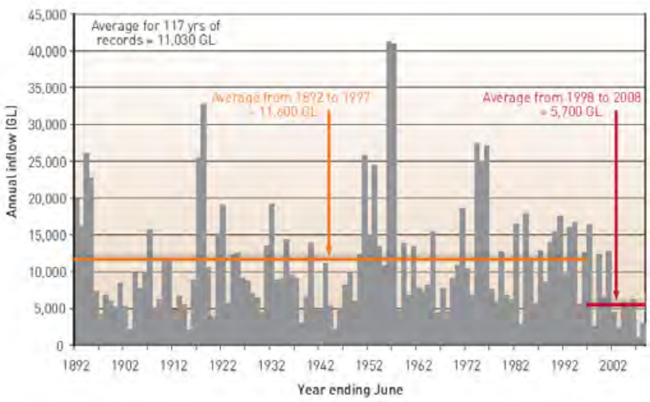

Figure 11. Murray-Darling River runoff into Lake Alexandrina from 1892 to 2008.

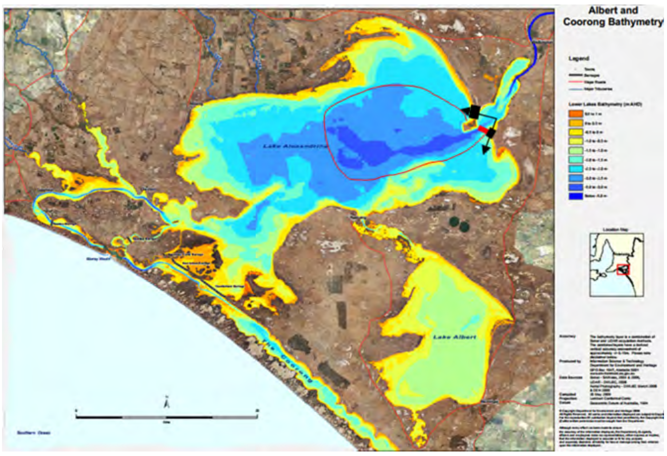

Figure 12. A coastal reservoir proposal in Lake Alexandrina to develop freshwater from the Murray River for Adelaide's water supply.

Perth Total population in West Australia in 2015 was 2.6 million, 82.7% lived in four coastal cities, i.e., Perth (2.0 million), Bunbury (0.075 million), Busselton (0.036 million), Geraldton (0.040 million). In 2005, Perth had a population of around 1.5 million people, and the city consumed 240 GL/a of water. It is estimated that the population in Perth in 2026 and 2056 will be 2.27 million and 3.36 million, the required water supply will be 350 GL/a and 520 GL/a, respectively[13]. Runoff from Swan River (570 GL/a), Murray River (720 GL/a, and 42 km from Perth) can be developed using coastal reservoirs for Perth's water supply. An example is shown in Figure 13, in which the bypass channel width is about 100 m on average, the estimated surface area of reservoir is about 19 km^2, and the estimated storage capacity is about 100 GL. Alternatively a barrage can be constructed near Point Walter Reserve and Chidley Reserve. As the polluted water is stored in the reservoir, a water treatment plant with RO technology may be needed to purify the reservoir water to drinking standard, similar to Singapore Marina Barrage.

Darwin The runoff from Adelaide River (1,700 GL/a) in Northern Territory can be developed for Darwin. The 180 km long river is 50 km away from Darwin CBD. Its catchment is about 7,640 km^2 and its tributaries include Margweret River, Manton River and Marrakai Creek. About 50% of the area was pastoral leasehold land, and 20% of it was Aboriginal land. The topography varies from low escarpment country in the upper reaches of Adelaide River to low lying flat floodplain areas near the coast. Figure 14 shows a conceptual design of coastal reservoir for Darwin's water supply.

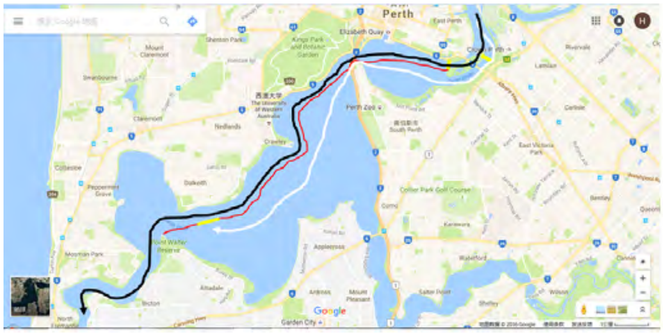

Figure 13. A coastal reservoir proposal at Swan River mouth for Perth's water supply.

Figure 14. Proposed coastal reservoir at the mouth of Adelaide River (45 km to Darwin).

7 Inter-basin Water Diversion for Inland Regions

Coastal reservoirs can supply sufficient water to coastal cities, and also can provide sufficient water to inland Australia to meet its vast water demand for irrigation and mining industry. This is achievable as the existing large dams for water supply could be used for this purpose, for example, if the capital cities' water supply comes from the coastal reservoirs, then the water in large dams like Warragamba Dam, Wivenhoe Dam and Thomson Dam can be diverted to inland regions across the Great Dividing Range, thus the Murray-Darling River Basin's water could be increased. As mentioned, Australian flat land is bad for inland dams' development, but good for water diversion. Water from some coastal reservoirs can be also diverted into the inland regions as shown in Figure 15, where the proposed coastal reservoirs for water diversion are those blue ovals. The existing inland dams are red solid dots. The existing pipelines in SA and WA are represented by red lines. The proposed water diversion pipeline from Kimberley to Perth is represented by a blue line, and the proposed pipelines are represented by red lines with arrows.

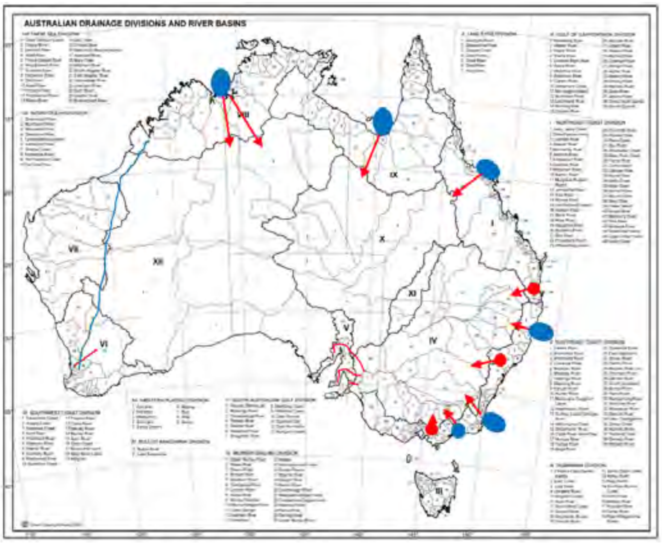

Figure 15. Proposed interbasin water diversion schemes from existing dams (red arrow with red cycles), and coastal reservoirs (red arrow with blue ovals).

To quantify the feasibility of these water diversion proposals, this study uses the energy required for water diversion to judge whether these water diversion routes are feasible and economic. Examining the pumping energy over long distance pipeline, this study proposed the following empirical equation to express the needed hydraulic head as the follows:

$$H(m) = 0.625X(km) + \Delta h(m) \tag{1}$$

where H is the hydraulic head in m, and X is the length of pipeline in km. Δh = elevation difference between the ending point and its source of route in m. Eq. 1 includes the energy loss by friction and the change of potential energy. In Table 4, the values of X (column 3) and elevations (column 6 and 7) are obtained from the google earth.

A feasible project can be seen from the existing water diversion pipelines in South Australia, the detail information is shown in Row 2 of Table 4. The Morgan- Whyalla pipeline is about 360 km long, Mount Lofty Ranges is about 460 m over sea level, and Δh = 60 m - 17 m = 43 m. Eq. 1 shows that H = 267 m, and the cost is about 0.24 A\$/m^3 [30]. The distance of water transfer from Wivenhoe dam across the Great Dividing Range is only X = 70 km lifting 384 m height, Eq. 1 gives H = 428 m. The calculated H using Eq. 1 is shown in the last column of Table 4.

Based on the H value, this study broadly divides the water division projects into four groups:

$H < 300$ m;	Class I;
$301 \text{ m} \leq H < 600$ m;	Class II;
$601 \text{ m} \leq H < 1200$ m	Class III;
$H \geq 1200$ m	Infeasible

Class I means that a project is simple and easy. A more difficult project is defined as Class II. A very difficult and costly project is defined as Class III. If H > 1,200 m, the project is infeasible. From this criteria, the Morgan-Whyalla pipeline in South Australia is Class I as its H < 300 m. The project of Mannum-Adelaide pipeline is Class II as its H is higher than 300 m, but less than 600 m. The Perth-Kalgoorlie pipeline is Class III (601 m < H ≤ 1,200 m). But the pipeline from Kimberley to Perth is infeasible as its H value is greater than 1,200 m.

Based on the value of calculated H, feasibility of a proposed route of water diversion can be justified. Table 4 shows that water diversion from the coastal reservoir at the Carpentaria to Georgia River has X = 250 km and Δh = 350 m, and Eq. 1 gives H = 506 m, less than 600 m, so the project is feasible with Class II. But Table 4 shows that it is infeasible to divert water from the coastal reservoirs at the river mouths of Bega where the distance X to the Great Division Range is only 50 km. Table 4 shows that the diversion routes are feasible but difficult (Class III) from Wellington Lake and Warragamba dam to the Murray-Darling river system. Most of rest diversion routes shown in Figure 15 are also feasible. However, more detail investigation needs to be conducted for the feasibility and environmental impacts of these conceptual proposals.

8 Conclusions

It is not that Australia is running out of water, it is that water is running out of Australia. This paper seeks to start the conversation into how coastal reservoirs may retain water for human use at reasonable cost. That conversation needs to start now because no any new dams have been constructed since the 1990s for Australia's capital cities. Substitutes for storage - desalination plants and wastewater reuse - have emerged in Australia but there are continuing debates as to these projects' economics and sustainability.

If an additional 1-2% of runoff is made available by means of coastal reservoirs, Australia should have sufficient water for its long-term sustainable development. It goes without saying that the coastal storages in this paper would need to be designed and cost to much greater detail before being imple-

Table 4. Basic information for proposed inter-basin water diversion schemes in Figure 15.

Water source	Annual flow (GL/year)	Distance to another river basin, X (km)	Highest elevation of diversion route	Elevation at source in m	Water destination/ elevation in m	Water lifting height H (m)
Morgan of Murray River	75	359	460	17	Whyalla/60	267 (Class I)
Mannum of Murray River	140	60	480	15	Millbrook dam, Adelaide/300	322 (Class II)
Mundaring Weir in Perth	8.4	530	450	130	Kalgoorlie/411.5	612 (Class III)
Kimberley in West Australia	200	1,900	670	30	Perth/300	1,457 (Infeasible)
Burdekin Dam in Burdekin River	7,200	180	400	158	Thomson River in Lake Eyre Division/400	354 (Class II)
Fairbairn Dam in Fitzroy River	3,000	110	590	200	Warrego Condamine-Culgod Rivers/590	458 (Class II)
Wivenhoe Dam in Brisbane River	300	70	484	100	Condamine-Culgoa river/484	428 (Class II)
Warragamba Dam in Hawkesbury River	600	50	800	141	Arthur River/800	690 (Class III)
Thomson Dam in Thomson River	400	25	1,000	435	Goulburn River/1,000	580 (Class II, tunnel)
Lake Argyle in Ord River	3,940	200	400	87	Mackay, Wiso/400	438 (Class II)
Coastal reservoir at Bega River	570	50	1,500	0	Murrumbidgee River /1,500	1,531 (Infeasible)
Coastal reservoir at Clarence River	4,920	80	1,000	0	Border River/1,000	1,050 (Class III)
Wellington Lake	3,600	100	1,000	0	Upper Murray River/1,000	1,062 (Class III)
Coastal Reservoir at Carpentaria	6,530 (Nicholson-Norman River)	250	350	0	Georgia River/350	506 (Class II)
Coastal Reservoir at Fitzroy, WA	6,000	180	186	0	Great Sandy desert/186	298 (Class I)

mented but their viability seems inevitable.

Acknowledgement

The author would like to express his sincere appreciation for the massive support from Centre for Coastal Reservoir Research, Faculty of Eng. and Information Science, University of Wollongong.

References

[1] Kummu M, Guillaume J H A, de Moel H, *et al.*, 2016, The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. *Scientific Reports*, 6: 38495. http://doi.org/10.1038/srep38495.

[2] Alavian V, Qaddumi H M, Dickson E, *et al.*, 2009, Water and climate change : understanding the risks and making climate-smart investment decisions. World Bank, Washington DC, 21-24. http://documents.worldbank.org/curated/en/362051468328208633/Water-and-climate-change-understanding-the-risks-and-making-climate-smart-investment-decisions

[3] Finlayson B L and Mcmahon T A, 1988, Australia v the world: a comparative analysis of streamflow characteristics, in *Fluvial Geomorphology of Australia*, Academic Press, Sydney, 17-40.

[4] Puckridge J T, Sheldon F, Walker K F, *et al.*, 1998, Flow variability and the ecology of large rivers. *Marine and Freshwater Research*, vol.49(1): 55-72. https://doi.org/10.1071/MF94161

[5] Australia Bureau of Meteorology, 2015, *Water in Australia 201314*, Bureau of Meteorology, Melbourne. http://www.bom.gov.au/water/waterinaustralia/files/Water-in-Australia-2013-14.pdf.

[6] Lahnsteiner J and Lempert G, 2007, Water management in Windhoek, Namibia. *Water Science & Technology*, vol.55(1-2):

441-448.
https://doi.org/10.2166/wst.2007.022

[7] Lawson J D and Russell-Head D S, 2016, Augmentation of urban water by Antarctic icebergs. Proceedings of 18th International Conference on Coastal Engineering, November 14-19, 1982, Cape Town, South Africa.
https://doi.org/10.1061/9780872623736.159

[8] Dam hard: water storage is a historic headache for Australia, n.d., *The Conversation*, viewed June 30, 2017.
http://theconversation.com/dam-hard-water-storage-is-a-historic-headache-for-australia-33397.

[9] United States Department of the Interior, Bureau of Reclamation, Technical Service Center, 2006, *Erosion and sedimentation manual* , Sedimentation and River Hydraulics Group, Denver.

[10] Batuca D G and Jordaan J M, 2000, *Silting and Desilting of Reservoirs*. A.A. Balkema, Rotterdam.

[11] Kondolf G M, Gao Y, Annandale G W, *et al.*, 2014, Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents. *Earth's Future*, vol.2(5): 256-280.
https://doi.org/10.1016/j.geotexmem.2011.01.008

[12] White R, 2001, *Evacuation of Sediments from Reservoirs*. Thomas Telford, London.

[13] Australian Bureau of Statistics, 2008, *Population Projections, Australia, 2006 to 2101*. ABS, Canberra.

[14] Liu J, Yang S Q and Jiang C, 2013, Coastal reservoirs strategy for water resource development: A review of future trend. *Journal of Water Resource and Protection*, vol.5(3A): 336-342.

[15] Bae Y H, Kim K O and Choi B H, 2010, Lake Sihwa tidal power plant project. *Ocean Engineering*, vol.37(5-6): 454-463.
https://doi.org/10.1016/j.geotexmem.2011.01.008

[16] Chu J, Yan S W, and Li W, 2012, Innovative methods for dike construction: An overview. *Geotextiles and Geomembranes*, vol.30: 35-42.
https://doi.org/10.1016/j.geotexmem.2011.01.008

[17] Yan S W and Chu J, 2010, Construction of an offshore dike using slurry filled geotextile mats. *Geotextiles and Geomembranes*, vol.28(5): 422-433.

[18] Yang S Q and Lin P Z, 2011, Coastal reservoir by soft-dam and its possible applications. *Recent Patents on Engineering*, vol.5(1): 45-56.

[19] Yang S Q and Liu P W, 2010, Strategy of water pollution prevention in Taihu Lake and its effects analysis. *Journal of Great Lakes Research*, vol.36(1): 150-158.
https://doi.org/10.1016/j.jglr.2009.12.010

[20] Yang S Q, Zhang Z, Ng B C, *et al.*, 2001, Coastal Reservoirs, Singapore Patent No. 200504653-7.

[21] Lammens E, van Luijn F, Wessels Y, *et al.*, 2008, Towards ecological goals for the heavily modified lakes in the IJsselmeer area, The Netherlands. *Hydrobiologia*, vol.599(1): 239-247.
https://doi.org/10.1007/s10750-007-9202-2

[22] Turner A J, Hausler G, Carrard N R, *et al.*, 2007, *Review of water supply-demand options for South East Queensland*. Institute for Sustainable Futures, UTS and Cardno (Brisbane), Sydney.

[23] Stamatov V and Stamatov A, 2010, Long-term impact of water desalination plants on the energy and carbon dioxide balance of Victoria, Australia: a case study from Wonthaggi. *Water and Environment Journal*, vol.24(3): 208-214.
https://doi.org/10.1111/j.1747-6593.2009.00179.x

[24] N.D., viewed on June 30, 2017.
http://news.hexun.com/ 2011-06-09/130379841.html

[25] Yang S Q, 2003, Potential Water Resources in Singapore. *Journal of Water Supply: Research and Technology - AQUA*, vol.52(6): 425-434.

[26] Yang S Q, 2004, *Global and China's Water Crisis and its Solutions in the 21st Century (in Chinese)*. Tianjin University Press, Tianjin.

[27] Yang S Q, 2016, Why may coastal reservoir dominate future water supply? *Proceedings of ANCOLD/NZCOLD Conference*, October 18-19, 2016, Adelaide.

[28] Seqwater, 2015, Connecting with customers. Annual Report 2014-2015, Seqwater, Brisbane.

[29] Yang S Q, 2015, A preliminary feasibility study for a backup water supply coastal reservoir in Southeast Queensland, Australia. *Journal of Water Supply: Research and Technology-AQUA*, vol.64(4): 470-485.
https://doi.org/10.2166/aqua.2015.103

[30] Marchi A, Dandy G and Maier H, 2014, Financial costs, energy consumption and greenhouse gas emissions for major supply water sources and demand management options for metropolitan Adelaide. Goyder Institute for Water Research, Technical Report Series No. 14/12, viewed on May 6, 2017.
http://www.goyderinstitute.org/_r111/media/system/attrib/file/102/EnergyCostsReport_Marchietal_Final_web.pdf

COMMENTARY

The role of wetland in water quality purification and maintenance of coastal reservoirs: a case of Qingcaosha Reservoir

Qiang Wang[1]*, Feng-Yi Wang[2] and Li-Hu Xiong[3]
[1] Shanghai Key Laboratory for Urban Ecological Processes and Eco-Restoration, School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China
[2] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China
[3] Zhejiang Institute of Marine Planning and Design, Hangzhou 310020, China

Abstract: Qingcaosha Reservoir (QR) is typical fresh water storage and salty water avoidance featured coastal reservoir, which is located in south branch of Yangtze River Estuary, China. Due to the location of QR, pollutants and short-term salt tides have threatened the clean fresh water intake of the reservoir. There are 289 km^2 shoal wetlands in upstream of QR. After the continuous purification of wetlands, water quality of raw water has been improved. Qingcaosha shoal, Zhongyangsha shoal, Beixiaohong shoal and Dongbeixiaohong shoal are on the circumference. From the water quality monitoring data after the reservoir operation, the average value of NH_4^+-N, NO_3^--N, TN, TP in the outlet are 81%, 65%, 77% and 66% of the inlet respectively after flowing through the natural wetland in the reservoir. The wetlands can solve two major problems facing the coastal zone reservoirs that enhance intake water quality and stabilize water quality. In the design of coastal reservoirs, we suggest that we should make the full use of existing wetlands, enhance the function of wetland water purification through ecological engineering methods, and construct artificial wetlands as a supplement.

Keywords: coastal reservoir, salt tide, wetland, water purification

*Correspondence to: Qiang Wang, Shanghai Key Laboratory for Urban Ecological Processes and Eco-Restoration, School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China; Email: wangqflora@163.com

Received: May 2, 2017; **Accepted:** August 3, 2017; **Published Online:** September 28, 2017
Citation: Wang Q, Wang F Y and Xiong L H, 2017, The role of wetland in water quality purification and maintenance of coastal reservoirs: a case of Qingcaosha Reservoir. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 16-18. http://doi.org/10.18063/JSUPP.2017.02.005

1 Introduction

Water is widely regarded as the most essential natural resources, yet freshwater systems are directly threatened by human activities [1]. Raw water, which includes rainwater, ground water, and water from bodies like lakes and rivers, is now severely contaminated due to the prosperous economy and industry in developing countries [2]. It is urgent to seek alternative water sources to full the increasing demand of good quality water. Therefore, many countries have built artificial reservoirs to support drinking water treatment plants. A Coastal Reservoir is a freshwater reservoir located in the sea at the mouth of a river with a sustainable annual river flow [3].

Coastal reservoirs are generally built in economically developed and densely populated areas. Pollution load poses a serious challenge to the water quality of the reservoir. As a kind of fresh water storage and salty water avoidance featured reservoir, coastal reservoir is open to intake water under context of fresh water, and closed to save water under context of salty tide. This is good to cut the peak and valley in time dimension. However, this leads to increased risk of pollution loads during water storage stage, and potential of algal bloom because of hydrodynamic reduction during reservoir close stage.

To take clean water and maintain good water quality during salty tide is the challenge facing the coastal reservoir, This paper would like to discuss that how Qingcaosha Reservoir (QR) which is a typical coastal reservoir to solve the problems.

2 Location of Qingcaosha Reservoir

Qingcaosha Reservoir is located in South Branch of Yangtse River Estuary, the north to Changxing Island, north east of Shanghai (31°27’N, 121°38’E). It is now the drinking water source for over 11 million people in Shanghai (designed water supply volume of 7.2×10^6 m^3/day). The QR has a surface area of 66 km^2, a volume of 4.35×10^8 m^3, and the depth ranges from 1.5-7.1 m. It receives a regular fresh water supply from the Changjiang River, and was designed to prevent the ocean tide from the East China Sea. The incoming fresh water flows through the reservoir from the west (inlet sluice) to the east (pump station), and is finally pumped and distributed to 8 drinking water treatment plants in Shanghai. The hydraulic retention time (HRT) is in the range of 15-35 days. A constant-closed outlet sluice was set to discharge excess water.

3 Water Quality Challenges to Qingcaosha Reservoir

The Yangtze River Delta area, as well as the Yangtze watershed is the most important industrial and agriculture center in China. Small enterprises in the Yangtze River Delta, such as textile companies, chemical plants, paint factories, and food production factories, make a significant contribution to the areas rapid economic growth. The consumption of water from these industries has led to increased water shortages in certain parts of the delta. Moreover, due to the lack of efficient waste treatment facilities and the scattered distribution of these small enterprises, water pollution has become a serious problem. In 2005, for example, the discharge of industrial wastewater and domestic sewage was over 63,109 tons, and only 40% of it was treated [4]. This does not include drainage water from agricultural fields and urban runoff, as well as imported pollution from upstream areas of the delta. Aquaculture itself is another significant source of pollution, with nitrogen (N) and phosphorus (P) from manure and feed as important pollutants [5].

Due to the location of QR, there are two major sources of salt tide that affect the concentration of chloride in their waters, one is the northern tide from north branch of Yangtze Estuary, and the other is the direct intrusion of saltwater from the East China Sea. When the chloride concentration is more than 250 mg/L the reservoir will stop taking water. According to the design of the reservoir, the maximum number of consecutive days without water is 68 days [6].

4 Wetlands in the Upstream of QR

The Yangtze River runs into the estuary area and flows through wetlands to the QR, and the wetlands include Baimomaosha shoal, Dongfengxisha Shoal, Shangbiandan Shoal, Xiabiandan Shoal *et al* [7]. (Figure 1 and Figure 2). The total area of the shoals is 289 km^2. The vegetation in the wetland is mainly composed of Phragmites australis community, Zizania latifolia community, Scripus triqueter community, Spartina alterniflora community and bare flat. Different vegetation types of wetland in the Yangtze Estuary have capacity on N and P removal in Table 1.

Table 1. Nitrogen (N) and phosphorus (P) removal capacity of different vegetation type of wetland in the Yangtze Estuary.

Vegetation types	N and P remove capacity (t/km^2/a)	
	N	P
Phragmites australis community	8.69 - 39.62	0.58 - 2.64
Spartina alterniflora community	14.99 - 36.68	1.54 - 3.93
Scripus triqueter community	1.47 - 12.34	0.21 - 1.75
Bare flat	0.04	0.004

After the continuous purification of wetlands, water quality in the QR water intake has been improved. (Figure 3 compares the water quality monitoring data of the Xuliujing water quality monitoring section and the reservoir water intake, and the contents of the main nutrient indicators (TN and TP) are significantly reduced [9].

Figure 1. The location of Qingcaosha Reservoir.

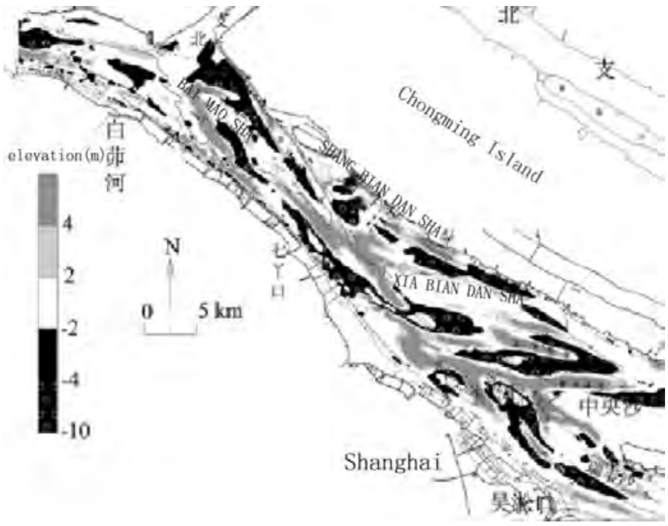

Figure 2. Shaols distributed upstream of QR.

5 Wetlands in QR

In QR, Qingcaosha shoal, Zhongyangsha shoal, Beixiaohong shoal and Dongbeixiaohong shoal are from the circumference (Figure 4). The design capacity of the reservoir is 438 million m^3, and the area is about 66.26 km^2, which includes 11.3 km^2 vegetation covered wetland nearby water intakes and upper reaches of the reservoir. The middle reach and downstream of the reservoir is without vegetation covered wetland.

From the water quality monitoring data after the reservoir operation, the average value of NH_4^+-N, NO_3^--N, TN, TP in the outlet are 81%, 65%, 77% and 66% of the inlet respectively after flowing through the natural wetland in the reservoir (Figure 5). The water quality of the upper reaches of the reservoir is obviously improved, and the water quality in the middle and lower reaches is not obvious. Hydrodynamic would decline after the reservoir stopped taking water due to the salt tide oc-

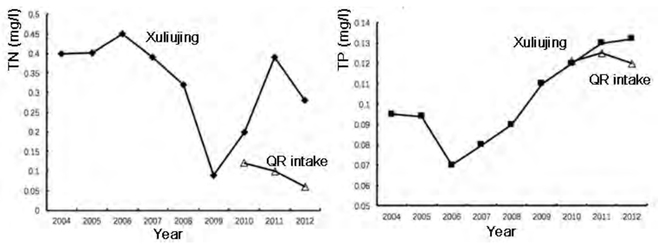

Figure 3. Comparison of the water quality monitoring data (TN and TP) between Xuliujing section and the reservoir water intake section in Yangtze River.

curred. When the salt tide occurred, the reservoir stopped taking water. The eutrophication level of the water body did not increase, but due to the growth of wetland purification time, further reducing the nutrient content of the water, thereby reducing the risk of water bloom.

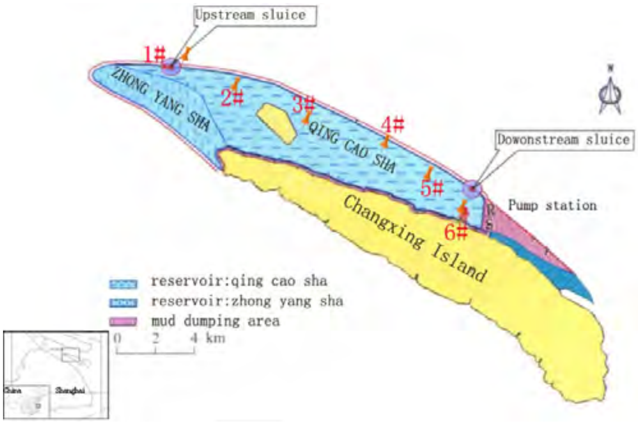

Figure 4. Monitoring points of water quality in QR.

6 Conclusion

Along the coast, Phragmites australis, Scirpus mariqueter and Spartina alterniflora are the dominant plant species that stabilize the shoreline and provide habitat for wild animals. These natural communities, together with the sediments on tidal flats, contribute to the sequestration of nutrients from rivers and shallow water.

A series of wetlands upstream of the reservoir purify the raw water. The wetlands play an important role in taking clean water for the QR. At the same time, the wetlands in the reservoir area also play an important role in maintaining good water quality during salty tide.

In order to play the wetland for the reservoir water quality protection better, we propose to protect these upstream wetlands better, make the full use of existing wetlands, enhance the function of wetland water purification through ecological engineering methods, and construct artificial wetlands as a supplement.

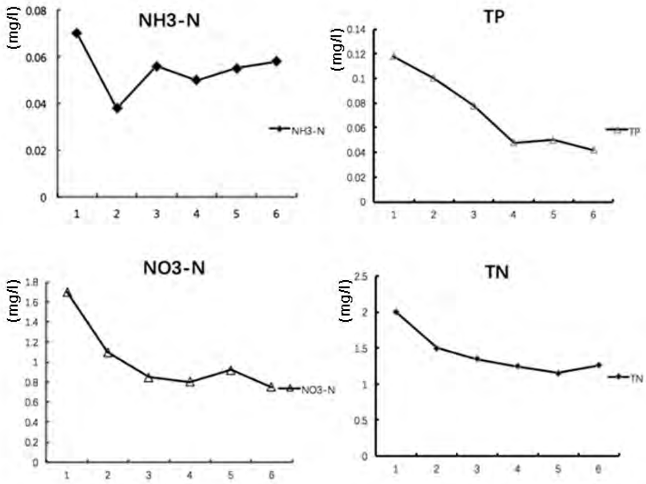

Figure 5. Average value of NH_4^+-N, NO_3^--N, TN, TP in six monitoring points in QR in 2011.

References

[1] Vörösmarty C J, McIntyre P B, Gessner M O, *et al.*, 2010, Global threats to human water security and river biodiversity. *Nature*, vol.467(7315): 555-561.
http://doi.org/10.1038/nature09440

[2] Ou H S, Wei C H, Deng Y, *et al.*, 2013, Principal component analysis to assess the composition and fate of impurities in a large river-embedded reservoir: Qingcaosha Reservoir. *Environmental Science: Processes & Impacts*, vol.15(8): 1613-1621.
http://doi.org/10.1039/C3EM00154G

[3] Yang S Q, 2004, Coastal reservoir construction.

[4] Shanghai Society of Hydraulic Engineering, n.d., viewed on November 2, 2008.
http://www.shhes.org.cn

[5] Li X, Mander Ü, Ma Z, *et al.*, 2009, Water quality problems and potential for wetlands as treatment systems in the Yangtze River Delta, China. *Wetlands*, vol.29(4): 1125-1132.
https://doi.org/10.1672/08-205.1

[6] Liu X M, Wang X P, Guan X W, *et al.*, 2009, Study on storage capacity and characteristic water level for Qingcaosha Reservoir. *Water Resources and Hydropower Engineering*, vol.40(7): 5-8, 48.

[7] Liu J, Zhao D Z and Cheng H F, 2011, Recent erosion-accretion evolution mechanism of South Branch in the Yangtze Estuary. *Port and Waterway Engineering*, 7: 113-118.

[8] Ren L J, Guo W Y, Li X Z, *et al.*, 2014, Impacts of changes in landscape of tidal wetlands on potential of the wetlands purifying nitrogen and phosphorus in water at the Yangtze Estuarine. *Journal of Ecology and Rural Environment*, vol.30(2): 220-227.

[9] Shanghai Investigation, Design and Research Institute, 2015, *Environmental impact statement of Qingcaosha Reservoir construction project*. Shanghai: SIDRI.

RESEARCH ARTICLE

Assessment of social and environmental impacts of coastal reservoirs

Shu-Qing Yang[1]*, Lewis Smith[2] and Muttucumaru Sivakumar[2]
[1]Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia
[2]School of Civil, Mining and Environmental Engineering, University of Wollongong, New South Wales 2522, Australia

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

*Correspondence to: Shu-Qing Yang, Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia; Email: shuqing@uow.edu.au

Received: July 7, 2017; **Accepted:** August 10, 2017; **Published Online:** September 25, 2017
Citation: Yang S Q, Smith L and Sivakumar M, 2017, Assessment of social and environmental impacts of coastal reservoirs. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 19-26. http://doi.org/10.26789/JSUPP.2017.02.001

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.

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.

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

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 13.5×10^9 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

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.

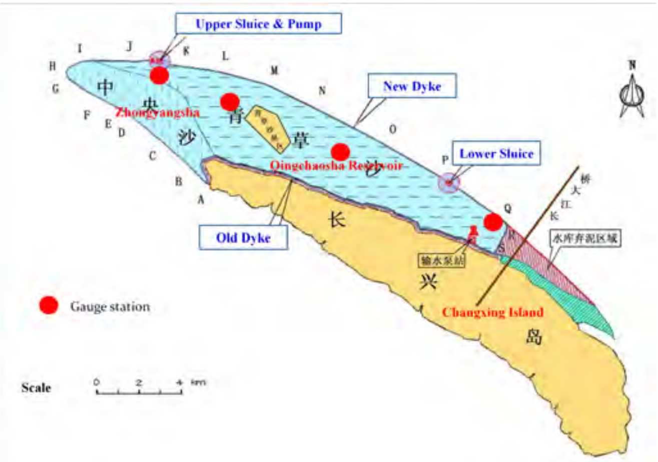

Figure 1. Locations of sampling sites [5].

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.

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

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

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

unwanted water. The pollution sources include high population density, many factories, wastewater, lot areas, point or non-point 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.

Figure 3. Location of Plover Cove.

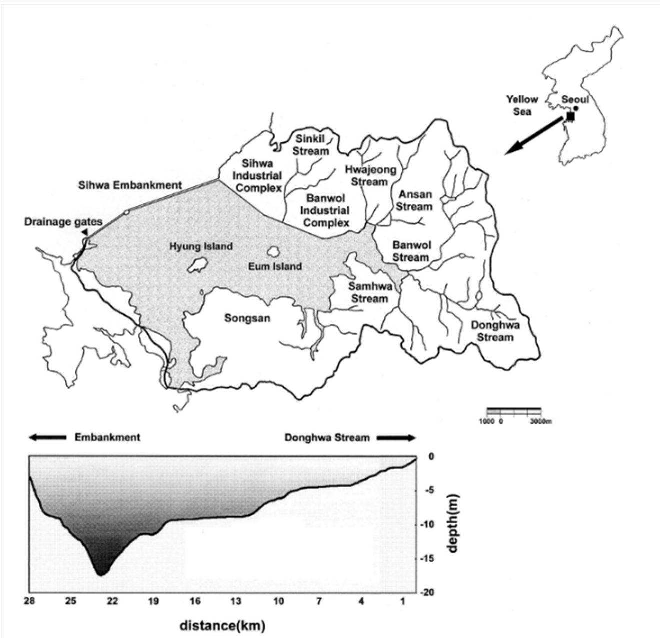

Figure 4. Location of Sihwa Reservoir.

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.

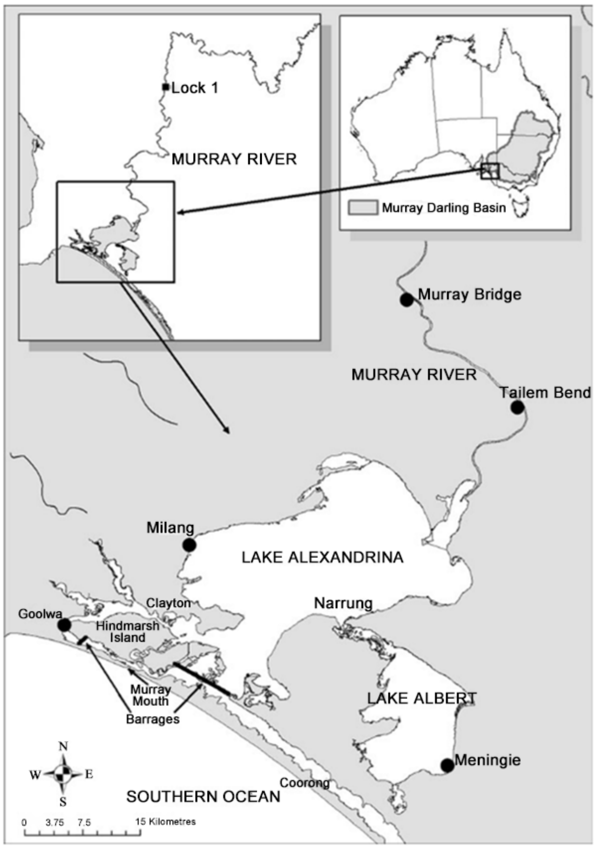

Figure 5. Sampling site locations for Lake Alexandrina [13].

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 salt-water 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" –

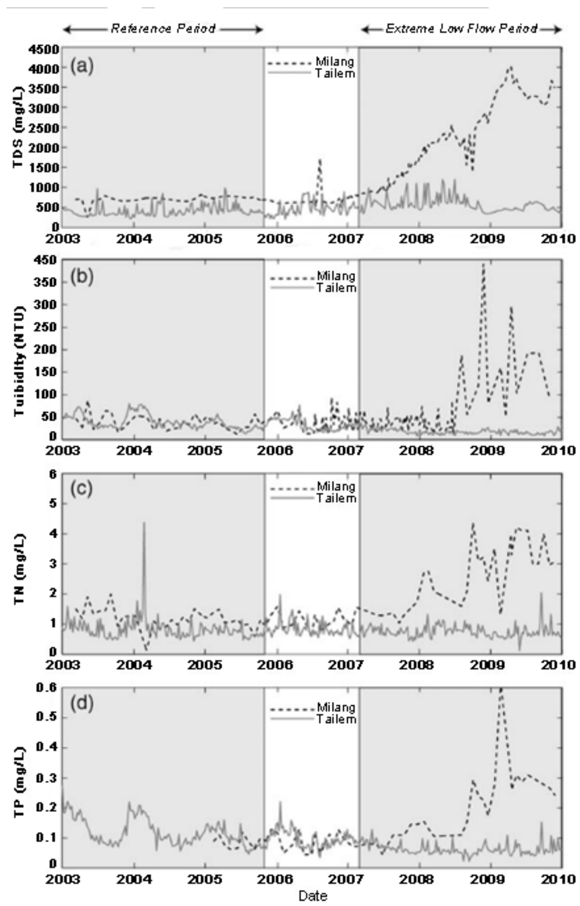

Figure 6. TDS (salinity), TP, TN and turbidity vs flow[13].

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.

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

4.2 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 similar 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.

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.

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.

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.

References

[1] Yang S Q and Kelly S, 2015, The Use of Coastal Reservoirs and SPP Strategy to Provide Sufficient High Quality Water to Coastal Communities. *Journal of Geoscience and Environment Protection*, vol.03(05): 80-92.
http://dx.doi.org/10.4236/gep.2015.35010

[2] Liu J L, Yang S Q and Jiang C B, 2013, Coastal reservoirs strategy for water resource development-a review of future trend. *Journal of Water Resource and Protection*, vol.5(3): 336-342.
https://doi.org/10.4236/jwarp.2013.53A034

[3] Raats P A C, 2015, Salinity management in the coastal region of the Netherlands: A historical perspective. *Agricultural Water Management*, 157: 12-30.
https://doi.org/10.1016/j.agwat.2014.08.022

[4] Yang S Q, (eds) 2014, Coastal Reservoir - The Trend of Water Supply in New Era, *Proceedings of the International Symposium of Next Generation Infrastructure*, October 1-4, 2013, SMART Infrastructure Facility, University of Wollongong, Australia.
https://doi.org/10.14453/isngi2013.proc.51

[5] Ou H S, Wei C H, Deng Y, *et al.*, 2013, Principal component analysis to assess the composition and fate of impurities in a large river-embedded reservoir: Qingcaosha Reservoir. *Environmental Science: Processes & Impacts*, vol.15(8): 1613-1621.
https://doi.org/10.1039/c3em00154g

[6] Xu Y, Luo F, Pal A, *et al.*, 2011, Occurrence of emerging organic contaminants in a tropical urban catchment in Singapore. *Chemosphere*, vol.83(7): 963-969.
https://doi.org/10.1016/j.chemosphere.2011.02.029

[7] Hodgkiss I J, 1974, Studies on Plover Cove Reservoir, Hong Kong: composition and distribution of phytoplankton and its relationship to environmental factors. *Freshwater Biology*, vol.4(2): 111-126.
https://doi.org/10.1111/j.1365-2427.1974.tb00082.x

[8] Hui T H, Low M E Y and Peng K L K, 2010, Fishes of the marina basin, Singapore, before the erection of the Marina Barrage. *The Raffles bulletin of zoology*, vol.58(1): 137-144.
http://lkcnhm.nus.edu.sg/nus/pdf/PUBLICATION/Raffles%20Bulletin%20of%20Zoology/Past%20Volumes/RBZ%2058(1)/58rbz137-144.pdf

[9] Lammens E, van Luijn F, Wessels Y, *et al.*, 2008, Towards ecological goals for the heavily modified lakes in the IJsselmeer area, The Netherlands. *Hydrobiologia*, vol.599(1): 239-247.
https://doi.org/10.1007/s10750-007-9202-2

[10] Lee C H, Lee B Y, Chang W K, *et al.*, 2014, Environmental and ecological effects of Lake Shihwa reclamation project in South Korea: a review. *Ocean & Coastal Management*, vol.102: 545-558.
https://doi.org/10.1016/j.ocecoaman.2013.12.018

[11] Turner A J, Hausler G, Carrard N R, *et al.*, 2007, Review of Water Supply-Demand Options for South East Queensland. Institute for Sustainable Futures, Sydney and Cardno, Brisbane.

[12] Stamatov V and Stamatov A, 2010, Long-term impact of water

desalination plants on the energy and carbon dioxide balance of Victoria, Australia: a case study from Wonthaggi. *Water and Environmental Journal*, vol.24(3): 208-214. http://doi.org/10.1111/j.1747-6593.2009.00179.x

[13] Mosley L M, Zammit B, Leyden E, *et al*., 2012, The impact of extreme low flows on the water quality of the Lower Murray River and Lakes (South Australia). *Water Resources Management*, vol.26(13): 3923-3946. https://doi.org/10.1007/s11269-012-0113-2

[14] Ren X, Yang K, Che Y, *et al*., 2016, Spatial and temporal assessment of the initial pattern of phytoplankton population in a newly built coastal reservoir. *Frontiers of Earth Science*, vol.10(3): 546-559. https://doi.org/10.1007/s11707-015-0543-2

[15] Dai Z, Qi Y L, Tang Y J, *et al*., 2016, Effects of Environmental Factors of Overlying Water on the Release of Nitrogen and Phosphorus from Sediment of Coastal Reservoir. *Research of Environmental Sciences*, vol.29(12): 1766-1772.

[16] Hong J, Maniquiz-Redillas M C, Ham J H, *et al*., 2016, Analysis of water quality improvement efficiency using constructed wetland in a coastal reservoir. *Journal of Wetlands Research*, vol.18(3): 292-300.

[17] Ye Q H, Li Y, Wang W, *et al*., 2015, Numerical simulation of water salinity change process in coastal reservoir influenced by sediment salt release. *Journal of Hohai University (Natural Sciences)*, vol.43(6): 518-523.

[18] Li H M, Ma B, Li Z C, *et al*., 2013, Seasonal Variation and Vertical Distribution of Salinization in Tianjin Coastal Reservoirs. *International Conference on Measuring Technology and Mechatronics Automation*, IEEE, New York, 980-984. https://doi.org/10.1109/ICMTMA.2013.244

[19] Kuang C P, Huang H C, Pan Y, *et al*., 2012, A Literature Review of Tidal Power Generation with Coastal Reservoir. *Advanced Materials Research*, vol.512-515: 900-904. http://doi.org/10.4028/www.scientific.net/AMR.512-515.900

[20] Yang S Q, 2012, Feasibility Study of Coastal Reservoir for Water Supply to Southeast Queensland, Australia. *Proceedings of the 6th International Conference on Apac 2011*, World Scientific Publ. Co. Pte Ltd, Singapore.

[21] Li H M, Ma B, Li Z C, *et al*., 2012, Law of Colloid Release for Sediments in the Exchange Process of Saline Groundwater and Reservoir Water. *Rock and Mineral Analysis*, vol.31(5): 849-854.

[22] López-García J M, Blain H A, Sanz M, *et al*., 2012, A coastal reservoir of terrestrial resources for neanderthal populations in north-eastern Iberia: palaeoenvironmental data inferred from the small-vertebrate assemblage of Cova del Gegant, Sitges, Barcelona. *Journal of Quaternary Science*, vol.27(1): 105-113. https://doi.org/10.1002/jqs.1515

[23] Xie L F, Duan X B and Yang C, 2012, Study on Physical Model Experiment of Dam's Seepage Stability base on Coastal Sand. *Procedia Engineering*, vol.28: 534-541. https://doi.org/10.1016/j.proeng.2012.01.764

[24] Yang S Q, 2010, Coastal Reservoir in Murray-Darling River and its Useful Experience for Yellow River, *Proceedings of the 4th International Yellow River Forum on Ecological Civilization and River Ethics, Vol.II*, Yellow River Conservancy Press, Zhengzhou, China, 65-79.

[25] Yang S Q, 2010, Water Resources Available in Australian's Coastal Zones and its Development by Coastal Reservoirs, *Proceedings of the 5th International Conference on Asian and Pacific Coasts, Vol 2*, World Scientific Publ. Co. Pte Ltd, Singapore, 126-132. http://ro.uow.edu.au/cgi/viewcontent.cgi?article=1767&context=eispapers

[26] Carrión J S, Finlayson C, Fernández S, *et al*., 2008, A coastal reservoir of biodiversity for Upper Pleistocene human populations: palaeoecological investigations in Gorham's Cave (Gibraltar) in the context of the Iberian Peninsula. *Quaternary Science Reviews*, vol.27(23): 2118-2135. http://doi.org/10.1016/j.quascirev.2008.08.016

[27] Shu L C and Li W, 2007, Analysis on the stochastic characteristic of the hydraic conductivity of bottom stratum, Beitang Reservoir, Tianjin City. *Journal of Jilin University (Earth Science Edition)*, vol.37(2): 216-220.

[28] Collier R E L and Gawthorpe R L, 1995, Neotectonics, drainage and sedimentation in central Greece: insights into coastal reservoir geometries in syn-rift sequences. *Geological Society, London, Special Publications*, vol.80(1): 165-181. https://doi.org/10.1144/GSL.SP.1995.080.01.08

[29] Prego R and Vergara J, 1998, Nutrient fluxes to the Bay of Biscay from Cantabrian rivers (Spain). *Oceanologica Acta*, vol.21(2): 271-278. http://archimer.ifremer.fr/doc/00326/43685/43190.pdf

[30] Marche F, 2008, A simple well-balanced model for two-dimensional coastal engineering applications. In *Hyperbolic Problems: Theory, Numerics, Applications: Proceedings of the 11th International Conference on Hyperbolic Problems*, Springer Berlin Heidelberg, 271-283. http://doi.org/10.1007/978-3-540-75712-2_22

[31] Li T H, Han P and Zhao Z J, 2008, Impact analysis of coastal engineering projects on mangrove wetland area change with remote sensing. *China Ocean Engineering*, vol.22(2): 347-358.

[32] Stauble D K, 2003, The use of shoreline change mapping in coastal engineering project assessment. *Journal of Coastal Research*, SPECIAL ISSUE No.38: 178-206. http://www.jstor.org/stable/25736606

[33] Zuo Q H, Dou X P and Duan Z B, 2015, Prospects of coastal engineering technology in China. *The Ocean Engineering*, vol.33(1): 1-13.

RESEARCH ARTICLE

Application of coastal reservoirs in China and its feasibility

Shu-Qing Yang
Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia

Abstract: China is a water-rich country in terms of rainfall and rivers' size, but its urbanization mainly occurs in the eastern coastal cities. The densely populated coastal cities intensify the water stress. To seal the gap between water demand and supply, many ways have been tested like water diversion projects, desalination plants and wastewater recycling plants etc. Different from these solutions, this paper discusses the strategy of coastal reservoirs in China's coastal cities. Its feasibility of using the available water is investigated and its water quality can be ensured if the second generation coastal reservoirs are applied. The results show that the water shortage problems in China coastal cities can be well solved if CRs are applied.
Keywords: urban water supply, coastal reservoir, inter-basin water diversion, inland dams, water quality

Correspondence to: Shu-Qing Yang, Center for Coastal Reservoir Research, University of Wollongong, New South Wales 2522, Australia; Email: shuqing@uow.edu.au

Received: July 14, 2017; **Accepted:** August 20, 2017; **Published Online:** September 30, 2017
Citation: Yang S Q, 2017, Application of coastal reservoirs in China and its feasibility. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 27-33. http://doi.org/10.26789/JSUPP.2017.02.010

1 Introduction

Since 1900, there has been a nearly 16-time increase in population under water scarcity, but the total population has increased only 4-fold. Currently, 80 countries have water shortages, and 2 billion people do not have sufficient clean water, with at least 1 billion people's basic water needs can't be met. In the next decades, the world population may increase by 1 billion every 12 years. Most people will live in coastal cities due to urbanization. An example of global water crisis can be seen in China. Its water availability per capita is similar to Iran, the country's water shortage is about 50 km^3/year. Many expensive attempts have been made to quench China's water crisis, but none of them has been proven successfully. China's total runoff to the sea is about 1,724 km^3/year, the storage is only 2.9% of runoff lost to the sea. So China is not short of water, but its storage; China is not running out of water, but water is running out of China. By decreasing runoff lost to the sea using coastal reservoirs, China's water shortage can be effectively eliminated.

In China, 60% of 1.3 billion people live in 12 coastal provinces. China's per capita availability of water is just 25% of the world's average, and more than 400 Chinese cities are short of water among total 600 cities. This is a paradoxical situation since China is one of the countries that have rich water resources. However, most of the water resources are unevenly distributed. This paper examines the feasibility of coastal reservoirs in large river mouths, and the research outcome shows that China's water thirst can be quenched, water quality of its coastal cities can be improved significantly. China's inland cities' water supply can be also improved once these coastal reservoirs are constructed. It is certain that coastal reservoirs can solve coastal cities' water shortage in China. The following sections show the proposed coastal reservoirs (CRs), where the red lines represent CR's dike, yellow lines are gates to regulate in/out flows, and the shaded areas are the freshwater bodies, long white lines with arrows are clean water paths, black lines are unwanted water.

2 Possible Coastal Reservoirs in Yellow Sea

Yantai is a city on the Bohai Strait, it borders Qingdao on the southwest and Weihai on the east. Its population was 7 million in 2010. Qingdao's area covers 10,654 km^2 which receives 775.6 mm/year rainfall. Dagu River is Qingdao's mother river with 180 km long and 6,131 km^2 catchment, its annual runoff is 0.66 km^3. Yantai's coastline is about 909 km where 121 rivers drain its water to the sea, the top ones are the Dagujia River, Wulong River etc. Their catchment areas and annual runoff are 2,295 km^2/ 0.65 km^3, and 2,806 km^2/ 0.72 km^3, respectively. The annual rainfall is about 680 mm in this region. To solve Qingdao and Yantai's water shortage problem, the coastal reservoirs are proposed as shown in Figure 1 and 2.

3 Possible Coastal Reservoirs in the East China Sea

Ningpo is a coastal city in the northeast of Zhejiang Province in China. Its port is one of the busiest in the world. In 2010, its total population was 7.6 million over 9,365 km^2. The Hangzhou

Figure 1. Potential coastal reservoirs for Qingdao, China.

Figure 2. Potential coastal reservoirs for Yantai, China.

Bay divides Shanghai and Ningbo whose total coastline is 1,562 km including 788 km of mainland coastline and 774 km of island coastline. The city receives an average annual rainfall of 1,440 mm mainly by typhoons and monsoons. The Yong River is Ningbo's mother river, formed by the Fenghua River and the Yao River. The catchment of Yong River is 4,572 km^2 and its annual flow is 3.5 km^3. There are 9 reservoirs to supply water to Ningbo. In May 2015, the water storage dropped to 30.95%. As signs of water supply shortage appeared, the city launched a drought emergency response to ease the water shortage. To increase its water supply, a coastal reservoir is proposed as shown in Figure 3.

Figure 3. A proposed coastal reservoir for Ningbo and a 10 km long canal to be built to divert water with good quality to the coastal reservoir in flood periods.

Taizhou is a coastal city of China's Zhejiang Province, facing the East China Sea. Along its coastline, it is bordered by Ningbo to the north, Wenzhou to the south. In 2010, its population was 5.9 million over 9,413 km^2. Its coastline length is about 651 km including islands' coastline. The largest island is Yuhuan Island where a coastal reservoir was constructed (Figure 4). The original design purpose of coastal reservoir was to supply freshwater, which is located in the Yueqing Bay. The construction started in 1998, and completed in 2004. The reservoir's water surface area is 11 km^2, storage capacity is 59 million m^3. The reservoir's catchment area is 166 km^2 where the annual rainfall is 1,430 mm. Thus the estimated runoff to the reservoir is about 120 million m^3, double the storage capacity. In 2008, it was found that the reservoir was in hyper-eutrophicated state[1]. This is an example of reservoir failure for water supply without bypass channels. The 198 km long Jiao River is the largest river in Taizhou, it drains water from 6,519 km^2 catchment to the Taizhou Bay. A coastal reservoir for Taizhou is shown in Figure 5.

Figure 4. Failed coastal reservoir in Yuhuan constructed in 2004 without SPP scheme.

Figure 5. A proposed coastal reservoir for Taizhou's water supply.

Wenzhou is a city located in the southeast of Zhejiang Province, which shares its borders with Taizhou on the north, and Fujian Province to the south. Its population is about 9.1 million in 2010 and 3 million people live in the city. Its area is 11,784 km^2 and its coastline is nearly 355 km long which gives the city abundant marine resources and many beautiful islands. The Ou River is the largest river in Wenzhou prefecture. Most flood disasters are caused by typhoons. For example, the typhoons "9417" and "9994" caused huge loss by floodwater in the 1990s. After September, the long dry period causes the water shortage crisis. The total runoff in Wenzhou is about 13.9 km^3, some places like its Dongtou County suffers severe water stress. There are some reservoirs to supply water to this city. The total storage capacity is about 2.3 km^3, about 15% of its annual runoff. To solve water shortage in Wenzhou, a coastal reservoir is proposed at the mouth of River Ou as shown in Figure 6.

Figure 6. A proposed coastal reservoir for Wenzhou's water supply.

Fuzhou is the capital city in Fujian Province, China. Its population was 7.11 million in 2010 over 11,968 km^2, 4.4 million people live in urban and rural area was 2.7 million. Its coastline length is 1,137 km. The 562 km long Min River is the longest river in Fujian Province, it drains water from 60,992 km^2 catchment into the sea in Fuzhou at the flowrate of 62.9 km^3/year. There are two passages at its estuary, i.e., the Changmen channel and Meihuagang channel. Similar to other Chinese rivers, the flowrate in January is very small around 619 m^3/s, but the highest flowrate of 4,706 m^3/s occurs in June. Runoff during April-September is about 74.4% of the annual total. The dry period appears from October every year. The proposed coastal reservoir for Fuzhou is shown in Figure 7.

Figure 7. A proposed coastal reservoir for Fuzhou's water supply.

Quanzhou is one of the largest cities in Fujian Province. There were 8.13 million people in 2010 over an area of 11,245 km^2. The 541 km long coastline is separated with Taiwan by a 200 km wide strait. There are in total 207 islands in Quanzhou, where 34 rivers run 8.7 km^3/year water to the sea. Among them, Jinjiang River is the largest one. It is a 182 km long river where water comes from 5,629 km^2 of catchment. Another large river is the Luoyang River which has 229 km^3 of catchment and 39 km of river course. Its annual runoff is about 16.2 km^3. The proposed coastal reservoir is shown in Figure 8.

Figure 8. A proposed coastal reservoir for Fuzhou's water supply.

The second largest river in Fujian is the 1,923 km long Jiulong River, water from 14,700 km^2 of catchment containing cities like Longyan, Zhangzhou and Xiamen cities. The flowrate at Fuhe station is 12.6 km^3/year. Its downstream reach receives another tributary, the Nanxi River. In total, the river drains 26.3 km^3/year of water to the sea at Xiamen. Typhoons often cause floods in this region. The Jiulong River is the water source of Xiamen by a pipeline at 12 m^3/s. In Fujian Province, Xiamen is facing the most severe water shortage problem. Xiamen covers 1,699 km^2 with 3.5 million people in 2010. The total resident population was increased to 4.2 million in December 2014. Xiamen Island was considered to possess one of the world's great natural harbors. A 2.2 km long causeway links the Xiamen Island with the mainland. Xiamen's coastline length is about 234 km, water depth is over 12 m. Its annual rainfall is about 1,200 mm. To solve its water shortage problem, a coastal reservoir is proposed as shown in Figure 9.

Figure 9. A proposed coastal reservoir for Xiamen in the Jiulong Estuary.

4 Possible Coastal Reservoirs in the South China sea

Shantou is a large coastal city on the coast of Guangdong Province, China. Its total population is 5.4 million in 2010 over an area of 2,064 km^2. Shantou was a city significant in Chinese history because it was an important port established for international trade. Shantou is a monsoon-dominated subtropical region. The annual rainfall is around 1,630 mm, about

60% of which occurs from May to August and its runoff depth is about 790 mm. The remaining 8 months only receive 40% of its rainfall. In 2010, the drought caused 55,000 people short of drinking water. The island county Nan'ao in Shantou had more than 42,000 people short of drinking water. There are many rivers in Shantou, the major rivers are Han, Rong, Lian, Hao and Leiling River. The catchments of Han, Rong and Lian Rivers are 30,112 km^2, 4,408 km^2 and 1,353 km^2, respectively. The river lengths are 470 km, 175 km and 72 km, respectively. The average runoffs are 25.4 km^3/year, 3.56 km^3/year and 1.04 km^3/year respectively. In 2014, the total water supply was 1.05 km^3/year. The proposed coastal reservoir at Rong Estuary for Shantou is shown in Figure 10.

Figure 10. The proposed coastal reservoir at Rong Eestuary for Shantou.

Both Shenzhen and Hong Kong are two major cities on the Pearl River Delta. They are rapidly developing cities which are facing water shortage problems in South China. The total area of Shenzhen is 1,997 km^2, and the area of Hong Kong is 1,106 km^2. They are separated by a river called Shenzhen River, thus both of them can be treated as a single city in terms of water supply. The population of Shenzhen and Hong Kong are 11.4 million and 7.33 million in 2015, respectively. Shenzhen is the third largest city next to Shanghai and Beijing in China. Its water supply per capita is only 200 m^3, which is about 1/12 of the national average water supply. Its water consumption was 1.955 km^3 in 2011 and 1.14 billion m^3 was imported from Dong River or East Pearl River. Hong Kong's water consumption in 2012 was 0.935 billion m^3, 80% of it is imported from Dong River and the remaining 20% from local water catchments. Hence Shenzhen and Hong Kong both have a high dependence on importing water. However, The water development of Dong River is already saturated and it is impossible to increase the supply. The reservoir capacity in Shenzhen and Hong Kong are only 0.611 and 0.586 km^3, respectively. The current city reservoirs of water resources can only meet about 20 days of emergency use.

Annual average rainfall and amount of water resources in Shenzhen are about 1,966 mm and 1.872 km^3, respectively. However, the average utilization during 1998 to 2005 was only 0.499 km^3, this is only 14.6% of annual average rainwater. Around 1.8 to 3.0 km^2 of freshwater runs into the ocean every year. Hong Kong also has 0.5 km^3 of freshwater discharged into ocean via Shenzhen River. Apparently, insufficient capacity of reservoirs is the main cause of water shortage. A large reservoir is required to store a large amount of fresh water during the rainy season. However, due to special geographical condition, there are no large natural lakes, rivers and reservoirs in both Hong Kong and Shenzhen. Since Hong Kong and Shenzhen are urbanized areas which have high dense population, the cost of inland reservoirs is very high and the quality of storm water is poor, we have to find suitable locations for this region's coastal reservoirs.

The Pearl River or Zhujiang River is an extensive river system in southern China. The Xi River ("West River"), Bei River ("North River"), and Dong River ("East River") are all considered tributaries of the Pearl River, because they share a common delta, the Pearl River Delta. And the details of these tributaries are listed in Table 1. The 2,400 km long river is the third-longest river in China, after the Yangtze River and the Yellow River, and the second largest by runoff volume, after the Yangtze. Its catchment is about 409,480 km^2 as shown in Figure 11 and its annual rainfall is about 1,470 mm.

Figure 11. The catchment of the Pearl River system (409,480 km^2).

The Pearl River's estuary is regularly dredged to keep it open for navigation. The estuary separates Shiziyang in the north, Lingdingyang in the south, and Jiuzhouyang at the southern tip of the estuary. This bay separates Macau and Zhuhai on the west from Hong Kong and Shenzhen on the east. A capital city of Guangzhou lies on the north. The Dong River provides freshwater for 40 million people living in six cities which are Heyuan, Huizhou, Dongguan, Guangzhou, Shenzhen and Hong Kong. There are three main reservoirs located in the upper, middle and lower reaches of Dong River. They are Fengshu dam, Xinfengjiang dam and Baipenzhu dam (Figure 12). These three large reservoirs which have a large volume of approximately 17 km^3. As small reservoirs such as Shenzhen reservoir (46.1 million m^3) have a limited potential for further enhancement of their water storage capacity in the future, the large reservoirs have potential to regulate their water storage for annual use.

The 562 km long Dong River catches rainwater from 35,340 km^2 drainage area, over which the rainfall is about 1,500-2,400

Table 1. The basic information about Pearl River's catchment and runoff.

Main rivers	Gauge station	Catchment area /km^2	Annual runoff km^3/yr	Max. annual runoff		Minimum annual runoff	
				km^3/yr	year	km^3/yr	year
Xi River	Wuzhou	329,705	229.0	347	1915	107.0	1963
Bei River	Shijiao	38,363	43.0	73	1973	17.0	1963
Dong River	Bolou	25,325	25.7	38	1975	6.1	1963
Pearl River		450,000	333.8				

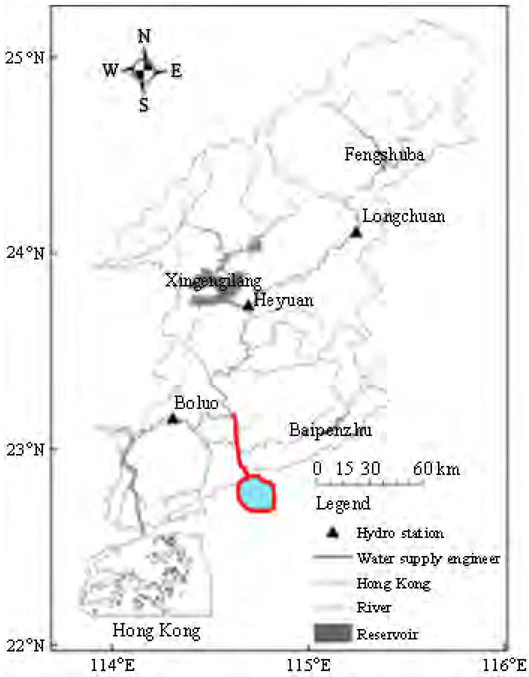

Figure 12. Dong River Basin and water diversion from Dong River to the proposed coastal reservoir (red line and oval).

mm/year and runoff depth is 950.4 mm/year, the annual runoff is about 25.7 km^3. About 80% of rainfall occurs during April-September, thus flood disasters appear in this period, the maximum measured flood discharge was 14,100 m^3/s at Boro station (catchment area is 25,300 km^2) in 1959. But droughts occur in the remaining 7 months with only 20% of rainfall. The recorded minimum flow in Boro station was only 31.4 m^3/s on May 5, 1955. The total water consumption in Guangdong Province is 10.7 km^3/year as shown in Table 1. It is 31.8% of Dong River's runoff or 3.2% of the Pearl River in total.

In 1964, Guangdong constructed the water diversion project from Dong River to Shenzhen and Hong Kong. The water allocation agreement was signed in 2015 under which Guangdong providesabout 70∼80% of water demand from Dong River to Hong Kong. The agreement also allows Hong Kong the flexibility to raise the annual supply ceiling from 0.88 to 1.10 km^3. This ultimate annual supply ceiling was first set out in the water supply agreement signed in 1989, promulgated by the Guangdong authorities in 2008. The Distribution Plan sets out the maximum amount of water which Hong Kong and other seven cities in Guangdong Province can draw from Dong River (Table 2).

Table 2. Water resources distribution plan for cities in Pearl River Delta.

	Allocated annual quantity / km^3		Reliance on Dong River
	Under normal yield	Under drought	
Hong Kong	1.100	1.10	70 ~ 80%
Dongguan	2.100	1.90	90%
Shenzhen	1.700	1.60	70 ~ 80%
Heyuan	1.800	1.70	~ 90%
Huizhou	2.500	2.40	70%
Shaoguan	0.122	0.10	
Meizhou	0.026	0.02	as a supplementary source of water supply only
Guangzhou	1.400	1.30	
Total	10.700	10.20	

A coastal reservoir is suggested in the Dayawan, on the south of Huidong as shown in Figure 13 and 14. A water diversion canal is suggested to divert water from the Dong River and its tributary Xizhi River to the reservoir. The canal's length is about 45 km, its reservoir area is about 40 km^2, and its barrage length is about 10 km. If the mean water depth is 10 m, then the storage capacity is 0.4 km^3. To divert the floodwater into the reservoir, weirs may be needed to be constructed across the Dong River and Xizhi River. This canal mainly diverts the floodwater to the reservoir to supplement water demand of Shenzhen and Hong Kong. The flood disasters in Dong River are expected to be mitigated.

Water shortage is a historical problem in Hong Kong. The last water rationing occurred in May 1982 when fresh water supply was available on a 16-hour basis for 24 days during the month. Hong Kong is the first city to systematically utilize seawater for toilet flushing in the world. A separate piping system is needed to carry seawater. From the 1950s, the network has been extended to cover about 80% of the total population. In 2015, about 0.75 million m^3 of seawater was used for toilet flushing in total, this pipeline costs about 1.3 billion US$ (or 6.5 billion HK$) for the construction of seawater mains, pumping stations, pipes and service reservoirs etc. without the treatment cost like screen and chlorine or hypochlorite, which costs the government 3.4 HK$/m^3.

Hong Kong, the coastal city, has the credit for the first coastal reservoir for a city's drinking purpose. Its local catch-

Figure 13. A 45 km canal to divert Dong River to a coastal reservoir which is enclosed by 10 km seawall, 40 km^2 surface area, about 60 km to Shenzhen and Hong Kong.

Figure 14. Proposed small coastal reservoirs for Hong Kong (red shapes).

ment provides about 20%-30% of water demand and the remaining 70%-80% of water demand comes from the Dong River. The unit cost of fresh water produced from local coastal reservoirs amounted to about 4.0 HK$/m^3 in 2013-2014, while in the same period, the water from Dong River costed 8.6 HK$/m^3, of which 4.6 HK$ was the cost of raw water and 4.0 HK$ was the processing cost. As the Dong River needs to support 40 million people in the deltaic region including Hong Kong and Shenzhen, and the central government ambitiously wants to develop this delta as a world-class industrial base for advanced manufacturing industries, Hong Kong starts to worry about its reliable water supply from the river. Subsequently, the government attempts to build a desalination plant using advanced reverse osmosis technology which is scheduled for completion in 2020 with an annual capacity of 50 GL/year or 5% of the total fresh water supply. It is also expandable to 100 GL/year similar to Sydney's size. The reverse osmosis technology will be used even it is still energy-intensive, and the estimated cost of desalinated water was 12-13 HK$/m^3 in 2013. If the wastewater is reused like the West Corridor Project in Brisbane, the cost will be reduced to 9.8 HK$/m^3.

Obviously, the basic assumption used by Hong Kong government about their decision of desalination plant is that Hong Kong is short of freshwater. In fact, their shortage is water storage. This can be seen from the simple mass conservation, i.e., the annual runoff depth is 950 mm and Hong Kong's total area is 1,106 km^2 or the annual runoff is 1,050 GL/year, about 21 times more than the capacity of proposed desalination plant. This can also be seen from that its local reservoirs release about 20 GL/year over their spillways in typhoon seasons. So it is strange that Hong Kong discharges so large amount of freshwater into the sea, but at the same time, a large amount of energy is used to desalinate seawater. As shown in Figure 13, if every drop of rainwater in Sai Kung East Country Park is collected like Singapore, the 50 GL/year desalination plant can be replaced by small coastal reservoirs whose total catchment area is larger than 53 km^2. Of course, the large coastal reservoir shown in Figure 14 is also a long-term solution.

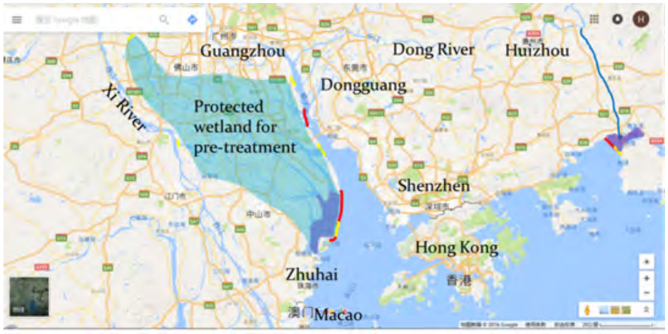

Figure 15. Two major coastal reservoirs (dark purpled). One is to develop water from Dong River for Shenzhen and Hong Kong's water supply. the other is to develop water from Bei River and Xi River for water supply to cities like Zhuhai, Macao, Guangzhou, Zhongshan, Dongguang and Fushan. The red lines are barrages, the yellow lines are hydraulic gates, and the blue line is water diversion canal. The shaded area is protected wetland for water purification.

The master plan of water resources development for cities in the Pearl River Delta is shown in Figure 15, where the dark purple areas are coastal reservoirs, one for Shenzhen and Hong Kong's water supply (on the left), the other for cities like Guangzhou, Dongguang, Zhuhai and Macao. The coastal reservoir on the left has high quality water from the reservoirs like Xinfengjiang and Baipengzhu, but the water from Xi River and Bei River has been polluted, thus wetland treatment is needed. The shaded area is the protected eco-area to pre-treat the river water using wetland, where no domestic, industrial and agricultural chemicals are allowed to enter waterways. The red lines are the barrages and the yellow lines are gates to regulate the flow. At its inlets, the gates at the Dongping, Shunde or Donghai waterways will be open when good quality water appears in Xi River in flood seasons. The inlet gates at Lianhuasan, Shawan etc will be open when good quality water appears in the Pearl River (Shiziyang). The gates at outlets of these two coastal reservoirs will be open to improve its water quality or to mitigate flood disasters.

5 Conclusions

This paper analyses the water availability and water demand in China and finds that the water shortage occurs in coastal cities can be effectively solved by coastal reservoirs, the conceptual designs of these coastal reservoirs have been conducted. By doing so, the following conclusions can be drawn from this study:

1) Currently, almost all coastal cities have a water shortage and in future, it becomes worsened due to the population growth.

2) The technology of coastal reservoirs is a sustainable, cost-effective and clean way for water supply, it will dominate water supply in future.

3) These coastal reservoirs proposed in this paper are cost-effective, environmental friendly and social acceptable.

References

[1] Lin J and Sun G M, 2008, Analysis on water environment of Xuanmen Water Storage Works in Yuhuan. *Journal of Zhejiang Water Conservancy and Hydropower College*, vol.20(3): 57-59.

RESEARCH ARTICLE

Feasibility study on formation of fresh water reservoir and impounding the surface runoff for urban water survival in a coastal brackish water region of Kollam, India

T.G. Sitharam[1]*, **Sreevalsa Kolathayar**[2], **Manoj P Samuel**[3] **and R Subba Rao**[4]
[1] Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India
[2] Department of Civil Engineering, Amrita University, Coimbatore 641112, India
[3] Engineering Division, Central Institute of Fisheries Technology, Cochin 682029, India
[4] Department of Chemical Engineering and Material Science, Amrita University, Coimbatore 641112, India

Abstract: The paper presents the feasibility study on the formation of fresh water reservoir and impounding the surface runoff in a typical brackish water lake of southern India, Ashtamudi Lake for urban water survival of coastal town, Kollam, India. The concept envisages of building a barrage at the outlet of Ashtamudi Lake at the mouth of the Arabian Sea to serve the purpose of preventing seawater intrusion into the lake, avoiding the contamination of the freshwater supply from sea water. To validate the concept, it is proposed to conduct a feasibility study which addresses the concerns about the availability of runoff from Kallada River. The paper also presents possible schemes for storing fresh water within Ashtamudi Lake by constructing dikes at appropriate locations. The length of dike and the volume of water that can be stored with proposed schemes are outlined in the paper.
Keywords: coastal reservoir, brackish water, dike, runoff

*Correspondence to: T G Sitharam, Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India; Email: sitharam@civil.iisc.ernet.in

Received: July 2, 2017; **Accepted:** August 10, 2017; **Published Online:** September 30, 2017
Citation: Sitharam T G, Kolathayar S, Samuel M P, *et al.*, 2017, Feasibility study on formation of fresh water reservoir and impounding the surface runoff for urban water survival in a coastal brackish water region of Kollam, India. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 34-37. http://doi.org/10.26789/JSUPP.2017.02.004

1 Introduction

As the available fresh water sources are very less throughout the world, there is a stress upon the available sources and in conservation structures. The focus of desalination and other techniques are increased, but for a developing country like India, it is very difficult for a huge investment in projects like desalination which demands high maintenance cost as well. The coastal cities are normally more urbanized. There is a rapid migration of people there because of the job opportunities. There would be rapid increase in population where the demand for water would increase exponentially. Presently the solution for this issue would be a Coastal Reservoir (fresh water reservoir) i.e. a reservoir near the sea. Coastal reservoir is a unique structure constructed at an estuary (point where a river meets a sea) to store the excess water at flood times. This coastal reservoir has its own advantages in case of land acquisition and forest clearance. They are already put to work in countries like Netherland, Singapore etc and proven to be beneficial also. This plan would be the only clear source of fresh water during drought times. The construction follows a unique concept which can cater the action of both saline and sea water. They are designed with gates so that the excess flood water more than the capacity of the reservoir can be discharged into the sea [1].

Kollam city is the fourth largest city in the state of Kerala, India, with a population of 389 thousand. The Kollam district accounts for 2.64 million population. As per Census 2011, the city has a gross population density of 6,090 persons per km^2, which is second highest in the state.

The Kallada River has its origin in Papanasam range South of Kulathupuzha in Kollam district itself at an altitude of 900 m above MSL. The river has a length of 121 km, and drains an area of 1,699 km^2 before confluencing with the Ashtamudi Lake. Even though the monsoon period of the basin is considered from June to November, the basin gets most of the rainfall during June to August. The Kallada Basin recieves good rainfall with annual rainfall varying from 2,225 mm to 4,038 mm [2].

Ashtamudi Lake is the second largest lake, next to Vembanad Lake in the state of Kerala, India. Ashtamudi wetland is an estuary filled with brackish water and this lake has eight

Figure 1. Location of study region along with proposed dyke.

arms and all the arms converge into a single outlet at Neendakara, to enter the Arabian Sea. Ashtamudi is the deepest estuary in Kerala with a maximum depth of 6.4 m at the convergence zone.

2 Need of the Study

In-spite of high rainfall in the district, Kollam city and surrounding regions are facing water shortage in summer due to storage shortage. Kollam city has a total water demand of 60 MLD of water per day and the current availability is 28 million liters per day. The total current water requirement in Kollam city is 0.77 TMC ft. Kollam Municipal Corporation draws 16 MLD of water from Sasthamkotta Lake, which goes almost dry in summer months. Ashtamudi Lake is a much bigger lake (6,424 ha) which contains brackish water and hence unqualified for domestic use. This necessitates a feasibility study on the concept of formation of a fresh water reservoir to augment the water demands of Kollam city by converting Ashtamudi Lake to a fresh water lake (partially or fully). Besides this, the sea level rise, according to researchers, is of serious concern in the state of Kerala which has a 590 km-long coastline and large expands of backwaters and estuaries and low-lying areas such as filtration ponds. Some tiny islands in Ashtamudi Lake like Munroe Thuruthu Islands seem to be gradually sinking due to subsiding coasts, eroded shoreline, loss of wetlands, reduced sediment deposits and sea-level rise. Nearby areas are facing frequent and increased tidal flooding through the year. The role of proposed project in saving these islands and other low lying areas from tidal flooding and sea level rise will be investigated and presented. This paper proposes the concept of constructing a dike at the mouth of a popular brackish water lake of southern India, to check sea water intrusion into the lake and to save tiny islands in the lake from the after effects of sea level rise and climate change. Salt water intrusion is perceived in the shallow aquifer in the western part of Kollam district which is in connection with the back water. There is water scarcity along the eastern hilly areas and water logging issue is observed in rainy season along the western part of the district bordering the back water.

3 Gist of the Study

This study aims to conduct a comprehensive feasibility of the concept of conversion of brackish Ashtamudi Lake to a fresh water reservoir by building a barrage at the outlet of lake at the mouth of the Arabian Sea (Neendakara) and also suggest the remdial measures to clean up the lake from the sewage disposal. On one side, it will block freshwater flowing from Kallada River to the lake from being dispersed into the sea. On the other side, the barrage will prevent seawater from entering the lake, avoiding the contamination of the freshwater supply from saltwater. The project schemes comprise mainly two steps, first is the construction of the dike at the mouth of Ashtamudi Lake, and second is the process of natural replacement of salty water by rainwater and surface runoff to the lake. The dike must be designed to separate fresh water from the salty waters of the Arabian Sea. The quantity of flood water has to be estimated and the possibility to alleviate flooding during high tides in the ocean. Large steel/concrete gates are suggested, that can be raised or lowered depending on the need during low tide and high tide. As the water level in the reservoir rises, the gates incline downwards, releasing water out to sea but preventing the entry of water from the sea into the reservoir. The dike has to be supported on pile foundation founded on the rock.

4 Kallada River Basin Details

Kallada river basin with geographical coordinates 9°10'0" N to 8°44'0" latitudes and 76°30'0" E to 77°20'0" longitude is one of the major river basins in Kerala with an area of 1,654 km^2. Kallada River originates from the Karimalaikadakkal ranges (1,524 m) of Western Ghats, flows towards the west and ultimately drains into the Ashtamudi Lake in Kollam District. Average annual rainfall of the basins is found to be 2,800 mm and average annual streamflow is found to be 3,374.86 mm^3. Important rainguage stations are Punalur, Quilon, Kottarakara, and Thenmala and discharge stations are Enath, Punalur and Thenmala [3].

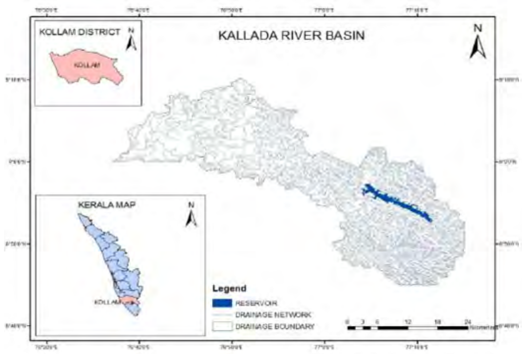

Figure 2. Stream network of drainage basin for Kallada River Basin.

For Characterization/classification and analysis of coastal sub-watersheds (Ashtamudi Basin) with Morphological, and Hydrological parameters, clustering algorithms can be useful for urban watersheds classification to form homogenous groups, particularly if many parameters are associated with watersheds. In the study, clustering analysis techniques including Kohonen Neural Networks (KNN), K-means Cluster Analysis (KCA), Principal Component Analysis (PCA) will be adopted and a genetic programming based Hybrid clustering algorithm will be proposed for characterization/classification of sub-watersheds in the study region of brackish Ashtamudi basin. High nitrogen and phosphorus concentrations in storm water runoff have the potential to impact ecosystem integrity and river ecology. Suspended solids and industrial wastes are discharged into Ashtamudi Lake from shores and river absorb various substances such as heavy metals and nutrients. In this context, a study has been contemplated in the proposed project to continuously monitor the quality of Ashtamudi Lake water through periodical sampling and conducting standard physico-chemical analysis and subsequently design a water filtration system in the proposed barrage complex.

5 Marina Barrage

The details of Marina Barrage are included herewith due to slight resemblance of the proposed project with the Marina Barrage in terms of construction and geography. The Marina Barrage acts as a barrier between fresh water in the Marina Bay and salt water of the South Chinese Sea. Nine large steel gates were installed at the site that can be raised or lowered. As the water level in the reservoir rises, the gates angle downwards, discharging water out to sea and stopping the passage of sea water into the reservoir. When the barrage was first instituted, the reservoir contained a mixture of freshwater and seawater. The reservoir water was turned completely freshwater through the natural process of replacement by rainwater, which began in April 2009. In 15 months the bay has become a freshwater reservoir with a stable water level [4].

6 Proposed Fresh Water Storage Strategy

Sasthamkotta Lake is rain fed and has no visible fresh water source or tributaries. The groundwater recharge to lake is greatly reduced these days. But it is not the best option to take Kallada water to Sasthamkotta. Because during rainy season it is already fed and there is no point in taking flood water to Sasthamkotta. In contrary, Ashtamudi is a brackish lake and even if one mudi (arm) is replaced with fresh water, it can augment the water demand of Kollam and adjacent regions throughout the year which is not possible from Sasthamkotta which has insufficient water in summer. Three schemes are proposed here as shown in Figure 4. Scheme 1 is planned in Chittumalachira which is already connected to Ashtamudi through a canal. If we can have a canal from Kallada to Chittumalachira, fresh water from Kallada can be drawn for Scheme 1. Scheme 2 envisages to convert one arm of the lake into complete freshwater reservoir. Scheme 3 aims at converting entire Ashtamudi Lake into a fresh water reservoir for which the dike has to be constructed at the outlet of Ashtamudi Lake into the sea at Neendakara. Details of proposed storage schemes with storage capacity and dike lengths are shown in Table 1. The annual yield of Kallada River is about 80 TMC ft and enough water is available every year to supply fresh water to proposed schemes in Ashtamudi Lake.

Table 1. Proposed storage schemes.

	Location of storage	Storage capacity (TMC)	Length of dike (m)
Scheme 1	Chittumalachira, part of Ashtamudi	0.3	775.25
Scheme 2	Ashtamudi partially	3.0	267.00
Scheme 3	Ashtamudi full	12.0	622.02

7 Conclusion and Recommendations

This study proposed the concept of constructing a dike at the mouth of Ashtamudi Lake, to check seawater intrusion into the lake and to save tiny islands in the lake from the after effects of sea level rise and climate change.

Conversion of brackish Ashtamudi Lake to a fresh water reservoir is feasible by building a barrage at the outlet of lake at the mouth of the Arabian Sea (Neendakara). On one side,

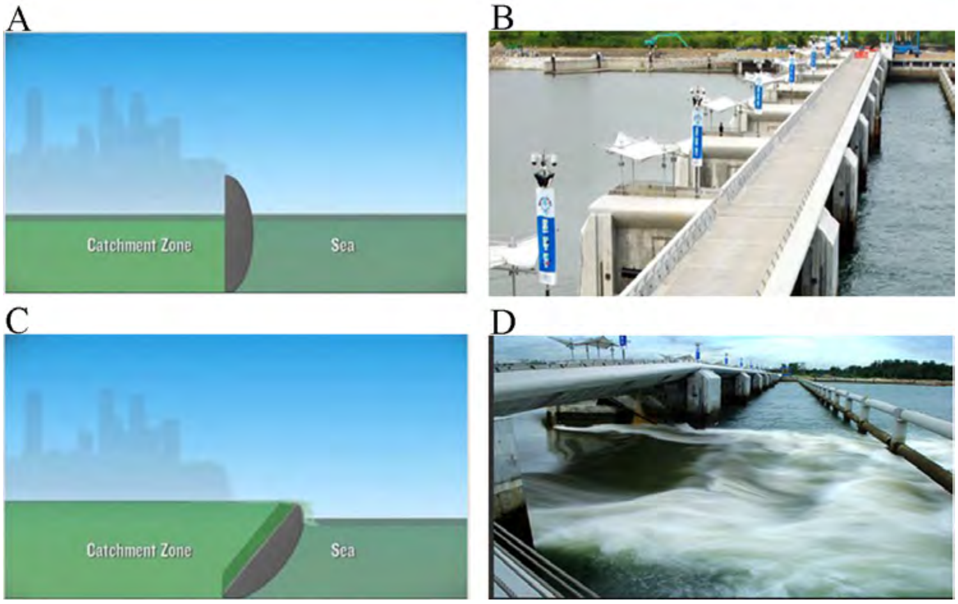

Figure 3. Marina Barrage mechanism. (A) Mechanism, showing vertical "closed" gates. (B) Marina Barrage, with "closed" gates. (C) Mechanism, showing diagonally tilted "open" gates. (D) Marina Barrage, with "open" gates.

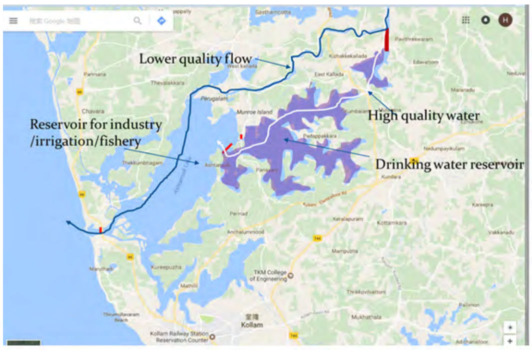

Figure 4. Proposed schemes of fresh water storage strategy in Ashtamudi Lake.

it will block freshwater flowing from Kallada River to the lake from being dispersed into the sea. On the other side, the barrage will prevent seawater from entering the lake, avoiding the contamination of the freshwater supply from saltwater. This paper presented three different possible schemes to meet the water demands of Kollam city, Kollam district and entire state of Kerala. The required lengths of dikes for these schemes are presented along with storage capacities. Scheme 1 can supply water to entire Kollam Muncipal Corporation. Scheme 2 can meet water demands of Kollam, Cochin and Thiruvananthapuram cities. Scheme 3 will suffice to supply water to entire state of Kerala. Coastal reservoirs use the

sustainable storm flood waters which are reasonably cleaner. This will emerge as a sustainable strategy for water resource development in the coming years. The annual yield of Kallada River is 80 TMC ft and hence enough water is available every

year to supply fresh water to proposed schemes in Ashtamudi Lake.

References

[1] Yang S Q, Liu J L, Lin P Z, *et al*., 2013, Coastal reservoir strategy and its applications. In *Water Resources Planning, Development and Management*, InTech, 95-115. http://doi.org/10.5772/52315

[2] Central Water Commission, 2006, *Central Water Commission Report*, Government of India.

[3] James E J, 1995, *Water Atlas of Kerala*, Centre for Water Resources Development and Management, Kozhikode.

[4] Schmid S, 2015, Catching Rainfall in Marina Bay: Water Necessity, Policy, and Innovation in Singapore, IGEL, University of Pennsylvaniya. https://igel.wharton.upenn.edu/wp-content/uploads/2012/09/IGEL-Marina-Barrage.pdf

[5] Central Ground Water Board, 2009, *Groundwater Information Booklet of Kozhikode District, Kerala State*. Ministry of Water Resources, Government of India.

RESEARCH ARTICLE

Feasibility of creating a fresh water reservoir in the Arabian Sea impounding the flood waters of Netravathi River

Sreevalsa Kolathayar[1*], T.G. Sitharam[2], R Ramkrishnan[1] and R Subba Rao[3]
[1]Department of Civil Engineering, Amrita University, Coimbatore 641112, India
[2]Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India
[3]Department of Chemical Engineering and Material Science, Amrita University, Coimbatore 641112, India

Abstract: This paper addresses the feasibility of creating a fresh water reservoir in the Arabian sea impounding the flood waters from Netravathi River. The project schemes comprises mainly two steps: first, the construction of the dyke in the Arabian Sea; and second, the process of natural replacement of salty water by rainwater and surface runoff to the reservoir. The study presents the detailed hydrological analysis of Netravati and Gurupura rivers including estimation of runoff into the sea. The study estimates the surface runoff at inlet and outlets of Netravati Basin along the costal lines of Arabian Sea. The existing land use along the costal lines of Netravati Basin is assessed. The dyke must be designed to separate fresh water from the salty waters of the Arabian Sea considering the tidal variations and wave heights. The bathymetric profiles of the sea bed has been created and presented in the paper. The annual runoff at the mouth of Netravati River was estimated as 388 TMC and just 2.5% of this would be sufficient to meet the present water shortfall of Bengaluru and Mangaluru. The annual sediment load was found to be negligible. The water quality parameters are well within permissible limits ensuring quality water from Netravathi to the proposed coastal reservoir.

Keywords: Netravathi, rainfall, coastal reservoir, bathymetry, runoff

*Correspondence to: Sreevalsa Kolathayar, Department of Civil Engineering, Amrita University, Coimbatore 641112, India; Email: k_sreevalsa@cb.amrita.edu

Received: July 2, 2017; **Accepted:** August 10, 2017; **Published Online:** September 30, 2017
Citation: Kolathayar S, Sitharam T G, Ramkrishnan R, *et al.*, 2017, Feasibility of creating a fresh water reservoir in the Arabian Sea impounding the flood waters of Netravathi River. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 38-42. http://doi.org/10.26789/JSUPP.2017.02.006

1 Introduction

Development and civilization of human race started with the availability of water in abundance. Mangalore is blessed with River Nethravathi which carries great quantity of water during monsoon and at last end up in the sea. Coastal reservoir (CR) is a very innovative concept which has the potential to store the flood water of river joining the sea and meet the water requirement of water starved cities[1,2]. A fresh water reservoir near the coast would bring a positive transformation in coastal Mangalore in terms of cleanliness, living standard of the people, human resource development and livelihoods.

The project schemes comprises mainly two steps, the first is the construction of the dyke in the Arabian Sea, and the second is the process of natural replacement of salty water by rainwater and surface runoff to the reservoir. Considering the tidal variations and wave heights, the dyke must be designed to separate fresh water from the salty waters of the Arabian Sea. The quantity of flood water will be estimated the possibility to alleviate flooding during high tides in ocean.

2 Study Area

Mangalore (Mangaluru), a coastal city, situated between the Arabian Sea and the mountain ranges of Western Ghats, is the chief port city of Karnataka. Located at 12°52’N latitude and 74°49’E longitude, it is the largest city in Dakshina Kannada district of Karnataka and is one of the most cosmopolitan non metro cities of India. The city is located in the confluence of Netravati and Gurupura rivers with an average elevation of 22 m (72 ft) above mean sea level (Figure 1).

The geology of the city is characterised by hard laterite in the hilly tracts and sandy soil along the seashore[3]. Mangalore is moderately earthquake-prone urban center and is categorised under Seismic III Zone in seismic zonation map of India. Mangalore lies on the backwaters of the Netravati and Gurupura rivers and these rivers effectively encompass the city. The rivers form an estuary at the south-western region of the city and then discharge into the Arabian Sea. Mangalore city has a population of 484,785 as per the 2011 census of India.

2.1 Geography of Netravati River

Globally, this river can be pinpointed at coordinates 12°54’30” N and 75°20’56” E. This river has an apparent breadth of about 200 yards. Its drainage area is about 1,353 m^2. The river bed mainly comprises of hornblende rock containing spangles of mica and small garnets. They act to fetter the river bed. A train passing through Mangalore called Netravati Express is named after this river. A railway bridge was constructed on

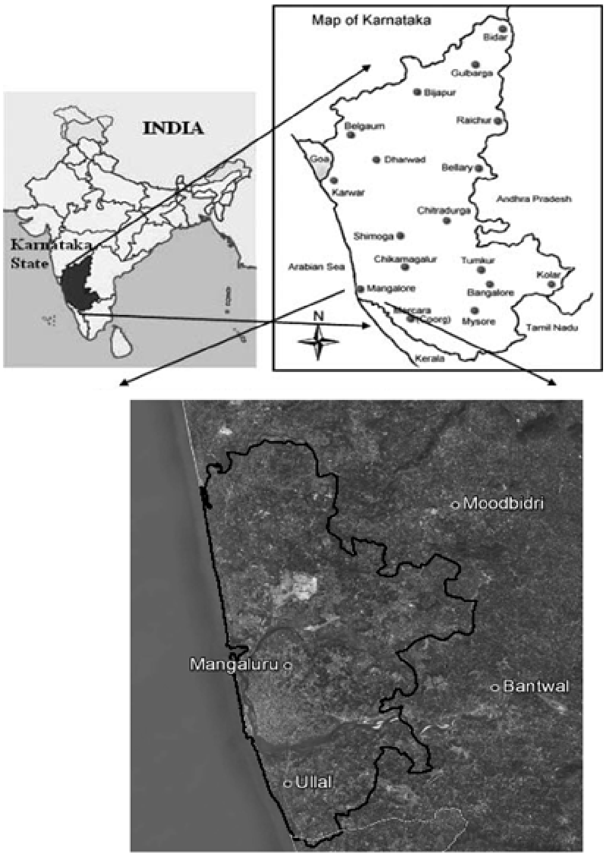

Figure 1. Mangalore map.

the Netravati River which served as one of the major gateways to Mangalore. Netravati Rivers railway bridge is considered to be the longest railway bridge built atop a river bank. The nearby cities of Netravati River are Bangady, IshaqIndabettu and Nellyady Town. The catchment area of Netravathi and Gurupura rivers is shown in Figure 2.

2.2 Course of Netravati River

Netravati River originates in the Western Ghats in Bangrabalike forest Valley in Yellaner Ghats of Kudremukha range in Karnataka. The Netravati amalgamates with the Kumaradhara River near Uppinangadi village. Kumaradhara River also originates in Western Ghats in the Subramanya range. When it flows from Uppinangadi, it arrives in the city of Mangalore. After merging with Kumaradhara River, the Netravati then joins the Arabian Sea. As estimated, this river drains large quantity of water into the Arabian Sea every year. Along its course, the Netravati also flows through a popular pilgrim place called Dharmasthala. The navigability of the Netravati River is dependent on small country craft, which has the potential to travel many miles in the river.

2.3 Bathymetry

Bathymetric data gives descriptive picture of the ocean bottom terrain with size, shape and distribution of underwater features.

Figure 2. Catchment area of Netravati and Gurupur River. (Source: Satellite image from Google)

The Bathymetric profile of the ocean bed near the Netravati River is shown in Figure 3.

3 Annual Runoff at Netravati Basin

The Annual Runoff at terminal site of Netravati Basin was estimated and the average annual runoff in Netravati Basin during 1989-2013 was 388.5 TMC (Figure 4). The maximum Runoff was 528.34 TMC during 2007-2008. A minimum runoff was experienced in the year 2012-2013. The standard deviation was 78 TMC during the period.

4 Average Annual Rainfall

The average annual rainfall at Netravati Basin over the decade 2003-2013 is 3,922.5 mm. The standard deviation of rainfall over the decade was 383 mm. A maximum rainfall of 4,427.8 mm was experienced in the year 2009-2010. A major variation in rainfall has not be experienced over the decade (Figure 5). Figure 6 presents the annual sediment load in Netravati River and it is clear that the sediment load is very negligible and hence silting issue in coastal reservoir will not be a major problem.

5 Land Use Analysis

Land Use of the area was analysed using remote sensing data from LANDSAT 8 images of resolution – 30 m (visible, NIR, SWIR); 100 m (thermal); and 15 m (panchromatic) downloaded from a public domain (https://earthexplorer.usgs.gov/). The remote sensing data obtained were geo-referenced and the study area was cropped and extracted. The Landsat 8 satellites has a spatial resolution of 30 m × 30 m (nominal resolution) followed by nearest-neighbour interpolation. A False Colour Composite (FCC) of remote sensing data (bandsgreen, red and NIR) was generated so as to enable the user to identify heterogeneous patches in the landscape. Training polygons were identified and delineated on the identified heterogeneous patches by overlaying the FCC layer on a google earth image

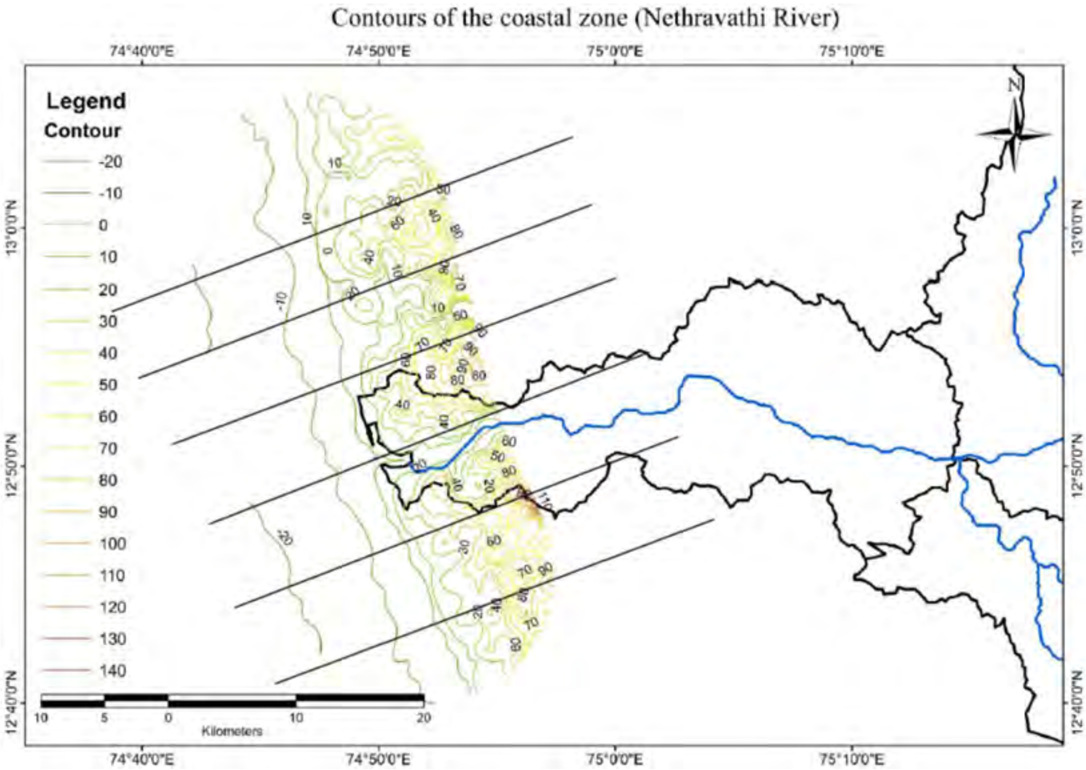

Figure 3. Bathymetry of the ocean bed near the Netravati River.

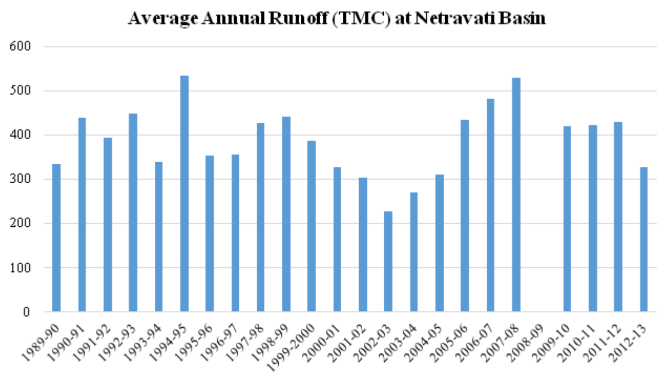

Figure 4. Average annual runoff at Netravati Basin.

using the built-in plug-in in the GIS tools. Uniform distribution and accurate marking of these training polygons was ensured in the study area[4]. Land use analysis was carried out using the built in supervised Gaussian maximum likelihood algorithm. The results obtained are shown in Figure 7 and the statistics are tabulated in Table 1.

From Figure 7, it is clearly visible that most of the population is concentrated towards the Mangalore City bounds, near the mouth of Netravati. Population density keeps on decreasing from the coast to the inlands and a large portion of the area inland is utilized for agricultural purposes. Out of the total 568.6 km^2 area, more than 50% of total area is utilized for agriculture and plantations as visible from the statistics, about 14.5% of the total area (82.5 km^2) is forest area and 18.7%

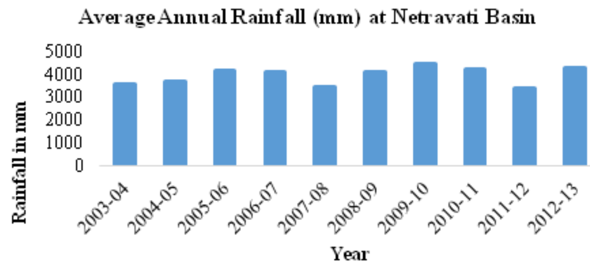

Figure 5. Average annual rainfall at Netravati Basin.

Table 1. Land use statistics of Mangalore.

Sl No.	Category descrption	km^2	Acres	Hectares	% Cover
1	Forest	82.4211	20,366.70	8,242.11	14.50
2	Plantations	38.0133	9,393.29	3,801.33	6.69
3	Agricultural Land	269.7543	66,657.74	26,975.43	47.44
4	Water Bodies	13.8627	3,425.55	1,386.27	2.44
5	Built-up area	106.6617	26,356.68	10,666.17	18.76
6	Open Areas	57.8781	14,301.99	5,787.81	10.18
	TOTAL	568.5912	140,501.95	56,859.12	100.00

of the total area (106.6 km^2) builts up land. The area covered by water bodies and open areas can vary in different seasons, when the river flows at different levels or when different crops/plants grow respectively.

6 Conclusions

The average annual runoff in Netravati Basin is eastimated as 388.5 TMC during 1989-2013. Hence it is imperative that a

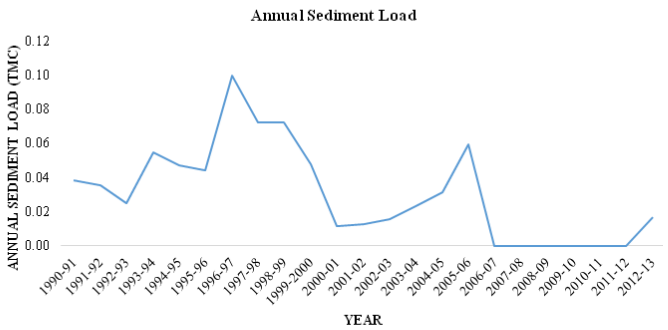

Figure 6. Annual sediment load in Netravati River.

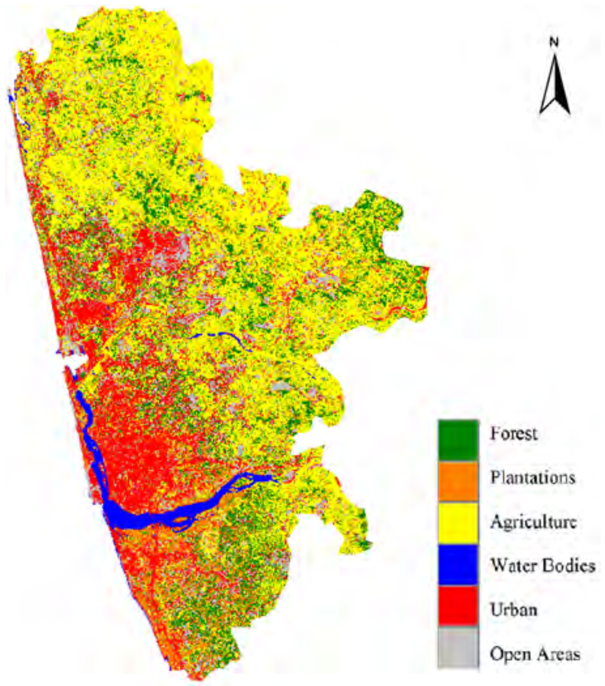

Figure 7. Land use pattern of Mangalore.

small percentage of runoff of Netravathi is more than sufficient to cater the water requirements of Mangalore and Bangalore. From the data for last few decades, there are hardly any chances of scarcity of water availability in Netravati River. On one side, we are having shortage of water, whereas on the other side, large quantity of water is just flowing into the sea. This necessitates to revisit the current water storage strategies and explore new ways to tap at least a small amount of runoff water to meet the water demands of people, which otherwise just flow into the sea. The concept of coastal reservoir emerges as the best solution to meet the future water demands of both Bangalore and Mangalore. The feasibility implications are summarized below.

• The average annual runoff in Netravathi is 388.5 TMC. As per Bangalore Water Supply and Sewerage Board (BWSSB), shortfall in demand in Bangalore for 2051 is 26.16 TMC which is 7% of average annual runoff through Netravathi. In 2021, the shortfall in demand is only 8 TMC which is just 2.1% of the runoff.

• There is hardly any chance of silting of reservoir as the average annual sediment load in Netravathi River is 0.04 TMC.

• Iron concentration in ground water is beyond BIS Norms (>1.0 mg/L) in Dakshina Kannada district.

• Radioactive minerals like monazite and zircon are concealed under non radioactive sand layers which attenuates gamma ray activity in Ullal Beach and hence there is no perceptible danger to the human health due to radioactivity.

• The water quality parameters in Netravathi and Gurupura Rivers are in tolerable limits for safe drinking water (far better than that of Godavari and Cauvery) and the water can thus be directly utilised without any major treatment.

• Benefiting sectors due to coastal reservoir are agriculture, prawn culture and sand dredging.

• Creation of coastal reservoir may affect the marine fishing in the area, but it opens up huge possibility of freshwater fishing.

• The seismic hazard in the area is very marginal and hence safe in terms of seismicity (below 0.05g).

• Coastal reservoir can act as a safety structure to safeguard the coastal region from Tsunami hazards.

• The possible renewable energy generation implies that the system will be self-sufficient in energy to meet the energy demands for pumping, lighting and other requirements.

Acknowledgement

The authors acknowledge the contribution of Mr. Prem Kumar, Ms. Amala Krishnan U S, Mr. Harinath Reddy C, Ms. Nimmy Therese, Mr. Rahesh Hari, Mr. Sharook S and Ms. Sivapriya J for their valuable contributions to this paper. The authors acknowledge Bangalore Water Supply and Sewerage Board, Govt. of Karnataka for funding the feasibility study on coastal reservoir across Netravathi River.

References

[1] Yang S Q, Liu J L, Lin P Z, *et al*., 2013, Coastal reservoir strategy and its applications. In *Water Resources Planning, Development and Management*, InTech, 95-115. http://dx.doi.org/10.5772/52315

[2] Sitharam T G, Rao R S and Kushal S, 2017, Innovative sea based fresh water reservoir to impound river flood waters: an initiative for India's water shortage, E-proceedings of the 37th IAHR World Congress, August 13-18, 2017, Kuala Lumpur, Malaysia.

[3] Hegde A V and Reju V R, 2007, Development of coastal vulnerability index for Mangalore Coast, India. *Journal of Coastal Research*, vol.23(5): 1106-1111. http://dx.doi.org/10.2112/04-0259.1

[4] Ramachandra T V, Aithal B H and Sanna D D, 2012, Insights to urban dynamics through landscape spatial pattern analysis. *International Journal of Applied Earth Observation and Geoinformation*, 18: 329-343. http://dx.doi.org/10.1016/j.jag.2012.03.005

[5] Dakshina Kannada at a Glance, 2015-16, Published by District Statistical Officer, D.K. Mangalore. http://www.censusindia.gov.in/pca

[6] Central Water Commission, 2013, Integrated Hydrological Data Book.

RESEARCH ARTICLE

Characteristics of water purification pattern of Caofeidian freshwater reservoir

Xin-Yong Chen[1*], Jian-Jian Lu[1], Qiang Wang[2], Feng-Yi Wang[3], Mao-Qing Pei[1], Jing Zhu[4], Yue-Bo Zhou[5] and Wen-Jun An[5]
[1]School of Ecological and Environmental Sciences, East China Normal University (ECNU), Shanghai 200241, China
[2]Shanghai Key Laboratory for Urban Ecological Processes and Eco-Restoration, School of Ecological and Environmental Sciences, East China Normal University, Shanghai 200241, China
[3]State Key Laboratory of Estuarine and Coastal Research, ECNU, Shanghai 200062, China
[4]Hebei Provincial Academy of Environmental Sciences, Shijiazhuang City 050000, China
[5]Water Resources Bureau of Fengnan District, Tangshan City 063300, China

Abstract: Caofeidian freshwater reservoir is nearly to the lower reaches of Shuanglong River area, which is located on the coast of Bohai Sea. However, the two sides of the Shuanglong River are the agricultural production and cultivation and aquaculture areas, that resulting in serious agricultural non-point source pollution. In this paper, we introduce a water purification pattern of freshwater reservoir based on floodplain wetland and ecological ditch. We set up floodplain wetlands to purify water with Shuanglong River floodplain and the reservoir surrounding idle beach, and lay out ecological ditch to purify rice paddy fields drainage with rice paddy ditch. Calculated, the water purification system of floodplain wetland could reduce the storage of pollutants, including 450 tons of COD, 18 tons of total nitrogen, 3.6 tons of total phosphorus annually, and reduce the water evaporation of 14,000 m^3 annually. Paddy field ecological ditch strengthen the water purification pattern, can effectively remove the storage of pollutants with 4 tons of total nitrogen, 0.8 tons of total phosphorus annually, and conserve 1,000 m^3 water nearly. It could improve the water quality of the storage river by the water purification pattern of Caofeidian freshwater reservoir, which also has environmental and economic benefits and provide inspiration for the construction of similar freshwater reservoirs.
Keywords: Caofeidian, freshwater reservoir, floodplain wetland, ecological ditch, water purification pattern

*Correspondence to: Xin-Yong Chen, School of Ecological and Environmental Sciences, East China Normal University (ECNU), Shanghai 200241, China; Email: chenxinyong2007@163.com

Received: July 10, 2017; **Accepted:** August 15, 2017; **Published Online:** September 30, 2017
Citation: Chen X Y, Lu J J, Wang Q, *et al.*, 2017, Characteristics of water purification pattern of Caofeidian freshwater reservoir. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 43-48. http://doi.org/10.26789/JSUPP.2017.02.007

1 Introduction

Caofeidian freshwater reservoir is located on the coast of Bohai Sea, and its water supply is mainly composed of two parts: the runoff of Shuanglong River and the paddy fields drainage. Shuanglong River has distinctive seasonal characteristics. The two sides of the river are the agricultural production and cultivation and aquaculture areas, which results in serious agricultural non-point source pollution, which leads to serious water pollution of the reservoir.

The sewage has been effectively purified by constructing environmental remediation projects in Shuanglong River, which is able to enhance the water quality of reservoir water supply security. Beside the Shuanglong River, floodplain wetlands were set up to purify water using Shuanglong River floodplain and the reservoir surrounding idle beach, and ecological ditches were laid out to purify paddy fields drainage using rice paddy ditches.

Wetland technology in sewage purification research and application is of a wide range[1–7]. In this paper, we introduce a water purification pattern of freshwater reservoir based on floodplain wetland and ecological ditch to provide inspiration for the construction of similar freshwater reservoirs.

2 Study Area

2.1 Natural Environment

Caofeidian freshwater reservoir is the original seven farm plain reservoirs in Tanghai County, which is located on the coast of Bohai Sea (39°14’95”N, 118°19’50”E), and is near the lower reaches of Shuanglong River (Figure 1). The reservoir is 30 km away from Caofeidian industrial zone, but only 100 meters away from the water supply pipeline of Caofeidian industrial zone. The reservoir is a substantially rectangular region, north-south length is about 1,720 m, 4,387 m long from east to west, with a total storage capacity of 23.65 million m^3.

The water supply of the reservoir is mainly composed of two parts: the runoff of Shuanglong River and the paddy fields drainage. According to the calculations and analyses, the annual runoff of Shuangyong River (26.14 million m^3) and the available amount of paddy fields drainage (11.14 million m^3) are 37.28 million m^3. So it can meet 23.65 million m^3 of wa-

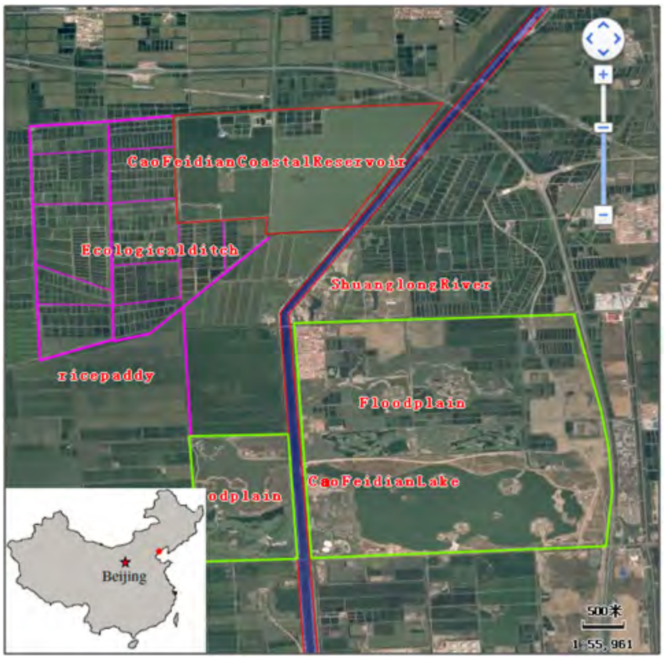

Figure 1. Study site.

ter storage requirements of the freshwater reservoir in normal years.

The reservoir area belongs to the eastern monsoon region which is warm and humid zone with semi-humid, mild climate and four distinct seasons. The average annual temperature of the region is 10.8°C, the coldest monthly average temperature is -5.9°C (January), the hottest monthly average temperature is 25.3°C (July). The average annual rainfall of 635.7 mm, up to 1,184.5 mm (1964), the lowest annual rainfall is only 335.3 mm (1968). The annual rainfall is generally concentrated in July to August, with an average of 407 mm, accounting for 64% of annual rainfall. The average annual surface evaporation of the project area is 1,050 mm.

A total of nine flows of Luanhe river and canal pass through Caofeidian District, finally flow into the Bohai Sea. Shuanglong River in Caofeidian District is 37 km long, and the basin area is 256 km^2. Shuanglong River has distinctive seasonal characteristics, resulting in the maximum runoff is generally in June to September (flood season).

Reservoir area includes six serious water shortage regions in North China, where the per capita possession of water resources is 380 m^3, lower than the internationally recognized water crisis protection limit of 500 m^3. The annual water storage of Caofeidian industrial zone will be 360 million m^3 after the completion of the planned project. Water has become one of the main factors restricting the local economic and social development. It is a very urgent and long-term major issue to solve the water shortage problem.

2.2 Question

The water of Caofeidian freshwater reservoir mainly from Shuanglong River, where water quality is V class (GB3838-2002, CHN), unable to meet requirements (GB5749-85, CHN). The agricultural production and aquaculture lead to serious river water pollution in the downstream of Shuanglong River, because of large scale of aquaculture, large loss of fertilizer and lack of governance means. At the same time, a large number of nitrogen and phosphorus and other organic pollutants entry into the reservoir through the rice paddy ditch due to the soil erosion. Therefore, how to solve the problem of non-point source pollution of river water is becoming the key to improve the water quality guarantee of Caofeidian freshwater reservoir.

Practice has proved that the construction of freshwater reservoir, cutting flood water and purificating water for reuse is an effective way to solve the current water shortage problem.

3 Water Purification Pattern

Sewage purification technology in wetland has been recognized all over the world[8–13]. Its research and application is of a wide range[4,5,7,14]. The results show that different plants have different effects on sewage purification[15–22] (Table 1). Meanwhile, they exist between floodplain wetlands and subsurface flow constructed wetlands[1,3,24,28,29] (Table 2).

In this paper, a water quality purification pattern of floodplain wetland is introduced to treat Shuanglong River runoff water, which is the surface flow wetland and subsurface flow wetland. And an ecological ditch purification pattern, using rice paddy ditch, is introduced to purify paddy fields drainage[30–33]. Then a reservoir water purification pattern is constructed: floodplain wetland and ecological ditch (Figure 2).

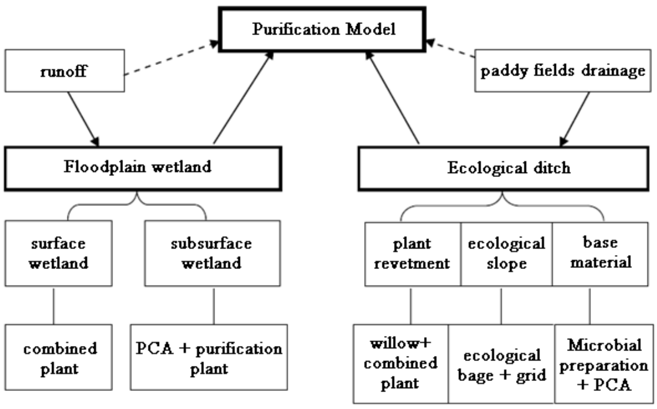

Figure 2. Governance pattern.

3.1 A Floodplain Wetland Purification Pattern

The local government has implemented about 20,000 mu (1 mu equal to 666.7 m^2) for the construction of Caofeidian wetland park, including 5,000 mu of the lake area, 12,000 mu of surface flow wetland and 3,000 mu of subsurface wetlands. The total possession of water storage capacity is about 20 million m^3.

Surface flow wetland system (Figure 3a) is surrounded by an embankment with certain height to maintain certain thick-

Table 1. Summary of water purification effects of wetland plants (%).

No.	Plant type	Pollutant type			References
		COD	TN	TP	
1	Phragrnitas communis	47.0～66.0	64.5	25.0～29.0	Peng Juwei *et al* .,2010[17]; Chen Junmin *et al* ., 2006[12]
2	Phragrnitas communis / Typha angustifolia	13.0～40.0	35.0～52.0	27.0～38.0	Zhou Linfei *et al* ., 2014[18]
3	Phragrnitas communis / zizania latifolia / Acorus calamus	43.2～48.9	52.2	45.3～73.5	Wan Jinbao *et al* ., 2010[23]; Lu Shaoyong *et al* ., 2006[15]
4	Scirpus validus / Phragrnitas communis / Canna glauca	81.0～83.0	68.0～85.0	57.0～70.0	Zhang Wenyi, 2012[24]; Wei Cheng, 2008[25]
5	Scirpus validus / Phragrnitas communis / Iris wilsonii / Pontederia cordata	30.0～64.4	25.0～72.8	23.0～60.0	Liao Weimin et al., 2011[26]; Guo Xiao *et al* ., 2010[14]
6	Zizania latifolia / Hydrilla verticillata / Hydrocharis dubia	28.0	45.0	32.0	Guo Xiao *et al* ., 2010[14]
7	Acorus calamus / Canna glauca / Scirpus validus / Oenanthe javanica	37.0～66.8	35.0～83.4	32.0～64.9	Deng Futang et al., 2006[27]
8	Hymenocallis Americana / Phragrnitas communis / Canna glauca / Vetiveria zizanioides /Acorus calamus / Cyperus alternifolius	65.0～87.0	57.0～90.0	28.0～53.0	Zhao Jiangang *et al* ., 2006[3]

Table 2. Summary of water purification effect of wetland type (%).

No.	Wetland type	Pollutant type			References
		COD	TN	TP	
1	Surface wetland	50～60	30～50	35～70	Zhao Jiangang *et al* ., 2006[3]; Zhang Wenyin *et al* ., 2012[24]
2	Subsurface wetland	55～75	40～70	70～80	Zhao Jiangang *et al* ., 2006[3]; Liu Bingwei *et al* .,2016[30]; Zhang Wenyin *et al* ., 2012[24]

ness of the water layer (usually 10～30 cm). And combination plants were planted in wetlands (Phragmites communis/-Typha angustifolia, Zizania caduciflora, Hydrilla verticillata). The flow of water in the wetland surface was pushed forward, in the process of flow, the sewage is purified through physical, chemical and biological reactions, with the biofilm of soil, plants and plant roots[34–36].

Subsurface wetland is a subsurface flow constructed wetland, which is designed to receive surface streams (Figure 3b). The substrate is laid according to the needs of different pollutants (phosphorus contaminants)[3,24,25,29,38], and different types of purified plants are planted.

The sewage is purified under the combined effects of the matrix, plants and microbial physical, chemical and biological through the pattern of surface flow wetland + subsurface wetland. Where the chemical oxygen demand (COD), total phosphorus (TP), total nitrogen (TN), algae, oil and other significant removal are efficient (COD 40.6%～94.2%; TN 52.2%～72.25%; TP 23%～74%)[25,35,37,38].

In this paper, river water quality (COD 50 mg/L, TN 2.0 mg/L, TP 0.4 mg/L) is calculated. The removal rate of COD, nitrogen and phosphorus are 30%. The pattern can reduce the storage of pollutants, 450 tons of COD, 18 tons of total nitrogen, 3.6 tons of total phosphorus each year. 1,000 mu of phragmites communis wetlands is contained in surface wetlands, the evaporation is 0.2 mm/h (Relative to the ground 1.05 mm/h), the reduction of evaporation is 14,000 m^3 annually.

3.2 Ecological Ditch Purification Pattern

On both sides of the rice paddy ditch bank slope, there are structures plant revetment with the willow and phragmites communis, calamus and others. On the ditch bank slope, the slope dyke layer was constructed by the ecological bag and ecological grid[39]. Compared with the local rice paddy ditch ecological water purification base material[40]. A water purification pattern for paddy field ecological ditch was constructed based on plant revetment, ecological slope and water purification base material[33,41–43] (Figure 3c). The results showed that the removal rate of nitrogen and phosphorus pollution of agricultural non-point source reached 48% ∼ 64% and 41% ∼ 70%[44–46].

In this article, according to the current situation of existing paddy field planting area and ditch, the ecological ditch is 10 km long. The paddy fields drainage are 5 million m^3, the water quality of total nitrogen is 2.0 mg/L, total phosphorus is 0.4 mg/L. The removal rate of nitrogen and phosphorus pollution is 40% and 40% respectively. And then, the system will remove the storage of pollutants total nitrogen 4 tons, total phosphorus 0.8 tons effectively each year. At the same time, it can add 50 mu of woodland on both sides of ecological ditch. The average moisture content of forest land is 20 m^3 [47], and it can conserve nearly 1,000 m^3 water each year.

There is a total result of the reservoir water purification pattern in Table 3. The system will remove the storage of pollutants for the COD 450 tons, total nitrogen (TN) 4 tons, total phosphorus (TP) 0.8 tons, and it can conserve water 15,000 m^3 nearly each year.

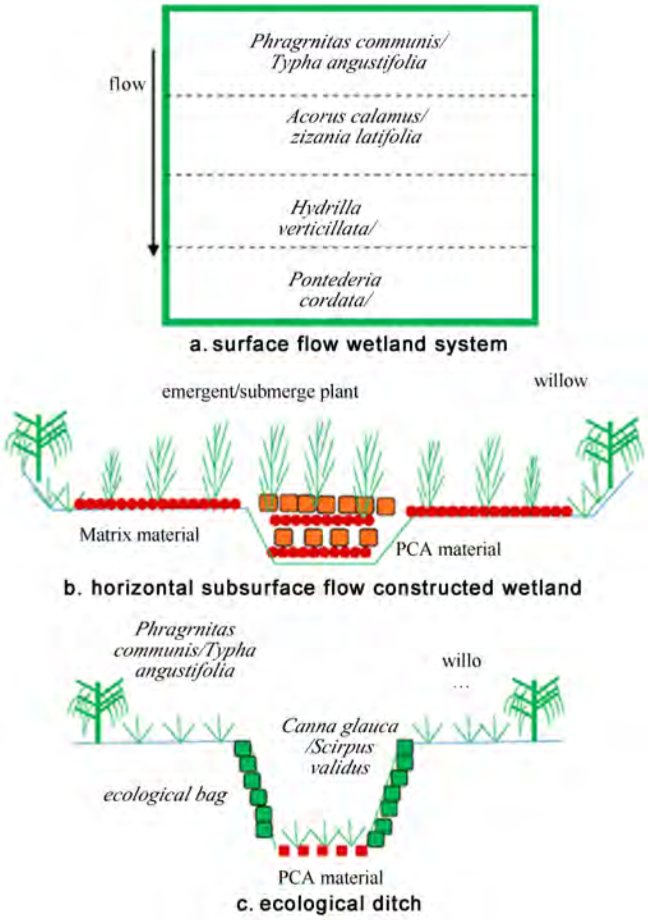

Figure 3. Water purification pattern.

4 Conclusions

(1) Caofeidian freshwater reservoir is located on the coast of Bohai Sea. And the water supply is mainly composed of two parts: the runoff of Shuanglong River and the paddy fields drainage.

(2) The agricultural production and aquaculture lead to serious water pollution in the downstream of Shuanglong River, because of large scale of aquaculture, large loss of fertilizer and lack of governance means. At the same time, a large number of nitrogen and phosphorus and other organic pollutants entry into the reservoir through the rice paddy ditch due to the soil erosion.

(3) The Caofeidian freshwater reservoir water purification pattern is introduced: floodplain wetland + ecological ditch.

Table 3. Total result of the reservoir water purification pattern.

No.	Wetland type	Pollutant type (ton)			Remove rate (%)	Conservate water (m^3)
		COD	TN	TP		
1	floodplain wetland	450	18	3.6	30	14,000
2	ecological ditch	/	4	0.8	40	1,000
3	total	450	22	4.4	>30	15,000

(4) A floodplain wetland water quality purification pattern is introduced to treat Shuanglong River runoff water, which is the surface flow and subsurface. Calculated, it can reduce the storage of pollutants COD 450 tons, 18 tons of total nitrogen, 3.6 tons of total phosphorus, and reduce the water evaporation of 14,000 m^3 annually.

(5) A water purification pattern for paddy field ecological ditch is introduced based on plant revetment, leach slope and water purification base material. Calculated, it can remove the storage of pollutants total nitrogen 4 tons, 0.8 tons of total phosphorus effectively annually, and 1,000 m^3 water is conserved.

References

[1] Nairn R W and Mitsch W J, 1999, Phosphorus removal in created wetland ponds receiving river overflow. *Ecological Engineering*, vol.14(1): 107-126. https://doi.org/10.1016/S0925-8574(99)00023-3

[2] Lu J J, He W S, Tong C F, *et al.*, 2006, *Wetland Ecology*, Higher Education Press, Beijing.

[3] Zhao J G, Liu L N and Chen Z H, 2006, Study on removal rate of pollutants and plant growth in subsurface and surface flow constructed wetlands. *Ecologic Science*, vol.25(1): 74-77.

[4] Guo J, Li Z F, Zhu Q L, *et al.*, 2011, Nitrogen removal of urban river water by ecological pond-constructed wetland-ecological pond hybrid system. *Transactions of the Chinese Society Agricultural Engineering*, vol.27(Supp.2): 191-195. http://dx.doi.org/10.3969/j.issn.1002-6819.2011.z2.038

[5] Zhang T, Xu D, He F, *et al.*, 2012, Application of constructed wetland for water pollution control in China during 1990-2010. *Ecological Engineering*, 47: 189-197. https://doi.org/10.1016/j.ecoleng.2012.06.022

[6] Nõlvak H, Truu M, Tiirik K, *et al.*, 2013, Dynamics of antibiotic resistance genes and their relationships with system treatment efficiency in a horizontal subsurface flow constructed wetland. *Science of the Total Environment*, vol.461: 636-644. https://doi.org/10.1016/j.scitotenv.2013.05.052

[7] Han C T, 2016, Design and application of artificial wetland technology in advanced treatment of sewage. *Urban Roads Bridge & Flood Control*, 6: 160-163. http://doi.org10.16799/j.cnki.csdqyfh.2016.06.046

[8] Wang C, Wang P F, Tang J S, *et al.*, 2003, The reduction propertiesof ammonia of red belt along the river. *Advances in Water Science*, vol.14(3): 311-317. http://dx.doi.org/10.14042/j.cnki.32.1309.2003.03.012

[9] Wu J Q, Huang S F, Ruan X H, *et al.*, 2006, Treatment of pollutedriver water using surface flow constructed wetlands in XinYi River Floodplain, Jiangsu Province. *Journal of Lake Science*, vol.18(3): 238-242. https://doi.org/10.18307/2006.0307

[10] Li R H, Guan Y T, He M, *et al.*, 2006, Pilot-scale study on riparian phragmites communis, zizania latifolia and typha angustifolia L. Zones treating polluted river water. *Environmental Science*, vol.27(3): 493-497.

[11] Zhu H Y, Zhou M, Liu X, *et al.*, 2014, Application of ecological wetland for water pollution control in rural area. *Water Purification Technology*, vol.33(4): 84-86.

[12] Chen J M, Qin J, Zhou Q C, *et al.*, 2015, Technology water purification on wetland ecological the region of returning pond to lake in plateau lakes. *Environmental Science & Technology*, vol.38(S2): 42-47.
http://dx.doi.org/10.3969/j.issn.1003-6504.2015.12Q.010

[13] Zhao X S, Cui L J, Li W, *et al.*, 2016, Analysis and valuation of water quality purification by Jilin Province wetlands. *Journal of Hydroecology*, vol.37(1): 10-17.
http://dx.doi.org/10.15928/j.1674-3075.2017.01.002

[14] Guo X, Ye X C, Zhao A N, *et al.*, 2010, Purification effect of N,P and COD of cascaded surface flow wetland model on polluted river water. *Ecology and Environmental Sciences*, vol.19(7): 1710-1714.
http://dx.doi.org/10.16258/j.cnki.1674-5906.2010.07.016

[15] Lu S Y, Zhang P Y, Yu G, *et al.*, 2006, Operation of a Kunming constructed wetland in winter. *China Water & Wastewater*, vol.22(12): 59-62.

[16] Chen J, Jia B and Fu Y, 2006, Experiment of surface flow in constructed wetland for farmer household tourism wastewate. *Joumal of Agro-Environment Science*, vol.25(S1): 191-193.

[17] Peng J W, Kang C L, Cui Y B, *et al.*, 2010, Application on wastewater treatment of produced furfurai byfree water surface flow constructed wetland. *Journal of Jilin University (Earth Science Edition)*, vol.40(6): 1419-1424.
http://dx.doi.org/10.13278/j.cnki.jjuese.2010.06.028

[18] Zhou L F, Zou F and Li Y Z, 2014, The Purification effect of the Liaohe River water quality on shifosi surface flow constructed wetland. *China Rural Water and Hydropower*, 2:1-5,12.
http://doi.org/10.3969/j.issn.1007-2284.2014.02.001

[19] Liu Y, Wang S H, Huang J, *et al.*, 2006, Long-run research of twowetland effects. *Ecology and Environment*, vol.15(6): 1156-1159.
http://dx.doi.org/10.16258/j.cnki.1674-5906.2006.06.006

[20] Liu C C, An S Q, Xia H P, *et al.*, 2007, Treatment effect of severalplants in the growth process. *Ecology and Environment*, vol.16(3): 860-865.
http://dx.doi.org/10.16258/j.cnki.1674-5906.2007.03.031

[21] Sun G, Ma Y S and Zhao R, 2008, Wastewater purification efficiency of different plant constructed wetlands. *Ecology and Environment*, vol.17(6): 2192-2194.
http://dx.doi.org/10.16258/j.cnki.1674-5906.2008.06.015

[22] Hu S Q, 2017, Research on domestic sewage purification efficiencies of plants and N, P accumulation in biomass in contructed wetland. *Research of soil and water conservation*, vol.24(1): 200-206.
http://dx.doi.org/10.13869/j.cnki.rswc.2017.01.026

[23] Wan J B, Lan X Y and Tang A P, 2010, Application of multi-surface flow constructed wetland to rural non-pointsource pollution control in poyang lake region. *Bulletin of Soil and Water Conservation*, vol.30(5): 118-121,146.
http://dx.doi.org/10.13961/j.cnki.stbctb.2010.05.009

[24] Zhang W Y, Liu M Y, Luo X, *et al.*, 2012, The project of surface flow consructed wetland in the south of Jiangsu Province. *China Rural Water and Hydropower*, 2: 78-80,83.

[25] Wei C, Liu P, and Qin J, *et al.*, 2008, Effects of substrates and plants on purification efficiency of constructed wetland. *Acta Ecologica Sinica*, vol.28(8): 3691-3697.

[26] Liao W M, Long J, Wang J, *et al.*, 2011, Study on domestic wastewater treatment in the subsurface constructed wetland. *Journal of Anhui Agricultural Sciences*, vol.39(3): 1649-1650.
http://dx.doi.org/10.13989/j.cnki.0517-6611.2011.03.041

[27] Deng F T, Sun P S, Li Q, *et al.*, 2006, Treatment of river sewage by technology of constructed wetland. *Environmental Engineering*, vol.24(3): 90-92.

[28] Nõlvak H, Truu M, Tiirik K, *et al.*, 2013, Dynamics of antibiotic resistance genes and their relationships with system treatment efficiency in a horizontal subsurface flow constructed wetland. *Science of the Total Environment*, vol.461-462: 636-644.
https://doi.org/10.1016/j.scitotenv.2013.05.052

[29] Liu B W, Wang Y, Guo S H, *et al.*, 2016, Study on landscape technology of sewage reuse for sewage treatment plant with horizontal submerged type 9 km ecological wetland. *Low Carbon World*, 33: 14-15.
http://dx.doi.org/10.16844/j.cnki.cn10-1007/tk.2016.33.011

[30] Cooper C M, Moore M T, Bennett E R, *et al.*, 2004, Innovative uses of vegetated drainage ditches for reducing agricultural runoff. *Water Science and Technology*, vol.49(3): 117-123.

[31] Gu B J, 2006, Study on the construction of ecological ditch in irrigation district. *China Rural Water and Hydropower*, 10: 4-6.

[32] Kaushal S S, Groffman P M, Band L E, *et al.*, 2011, Tracking nonpoint source nitrogen pollution in human-impacted watersheds. *Environmental Sciences & technology*, vol.45(19): 8225-8232.
https://doi.org/10.1021/es200779e

[33] Yao J T, Ding H M and Xu J, 2012, Study on Intercepting Method for Nitrogen and Phosphorus in Ecological Ditches and Pond. *Meteorological and Environmental Research*, vol.3(11): 58-60,70.

[34] Alley B L, Willis B, Rodgers J, *et al.*, 2013, Water depths and treatment performance of pilot-scale free water surface constructed wetland treatment systems for simulated fresh oilfield produced water. *Ecological Engineering*, vol.61: 190-199.
https://doi.org/10.1016/j.ecoleng.2013.09.021

[35] Zhang H and Sun S, 2015, Review of surface flow constructed wetland removal of contaminants in China. *Guangdong Forestry Science and Technology*, vol.31(4): 121-127.

[36] Wan Y W, Guo C Q, Mao Z, *et al.*, 2016, Sewage purification effect of multi-seriessurface flow constructed wetland. *Transactions of the Chinese Society of Agricultural Engineering*, vol.32(3): 220-227.
http://dx.doi.org/10.11975/j.issn.1002-6819.2016.03.032

[37] Zhang C L, Chen X J, Wei B M, *et al.*, 2009, Comparison of purification efficiency of traditional and improved integrated vertical flow constructed wetlands system with different plants on sewage. *Journal of Agro-Environment Science*, vol.28(10): 2161-2166.

[38] Wang Z Q, Shen G X, Qian X Y, *et al.*, 2014, Construction of anti-erosion ecological ditch and its application effect in paddy field. *Chinese Journal of Environmental Engineering*, vol.8(9): 4047-4052.

[39] Wang Q Z and Lu J J, 2014, *Multi-stage subsurface ecological water purification system*, 8th Annual Conference of US-China EcoPartnership on Wetland (Research and Eco-Development), December 7-10, 2014, CA, USA.

[40] Li H B, Lv X D, Wang H, *et al.*, 2015, Strengthening measures and applications of paddy fields drainage ditch for nitro-

genand phosphorus removal: a review. *Hubei Agricultural Sciences*, vol.54(20): 4985-4990.
http://dx.doi.org/10.14088/j.cnki.issn0439-8114.2015.20.016

[41] Liu F, Xiao R L, Wang Y, *et al*., 2013, Effect of a novel constructed drainage ditch on the phosphorus sorption capacity of ditch soils in an agricultural headwater catchment in subtropical central China. *Ecological Engineering*. vol.58: 69-76.
https://doi.org/10.1016/j.ecoleng.2013.06.008

[42] Zhang S N, Xiao R L, Liu F, *et al*., 2015, Interception effect of vegetated drainage ditch on nitrogen and phosphorusfrom drainage ditches. *Environmental Science*, vol.36(12): 4516-4522.
http://dx.doi.org/10.13227/j.hjkx.2015.12.025

[43] Li H F, Liu F, Xiao R L, *et al*., 2016, Effects of aquatic plants on phosphorus adsorption characteristics by sediments in ecological ditches. *Journal of Agro-Environment Science*, vol.35(1): 157-163.
http://dx.doi.org/10.11654/jaes.2016.01.021

[44] Zhang M K, He Z L, Calvert D V, *et al*., 2003, Spatial and temporal variations of water quality in drainage ditches within vegetable farms and citrus groves. *Agricultural Water Management*, vol.65(1): 39-57.
https://doi.org/10.1016/j.agwat.2003.07.005

[45] Wu Y H, Kerr P G, Hu Z Y, *et al*., 2010, Eco-restoration: Simultaneous nutrient removal from soil and water in a complex residential-cropland area. *Environmental Pollution*, vol.158(7): 2472-2477.
https://doi.org/10.1016/j.envpol.2010.03.020

[46] Yu H B, Xiao R L, Yang Z J, *et al*., 2014, Study on the characteristics of nitrogen and phosphorus transportation through ecological ditch during irrigation and rainfall. *Resouces and Envionment in the Yangtze Basin*, vol.23(5): 686-692.

[47] Ci W S, 2011, The ecological environment effect of phragmites australis wetland. *Science and Technology of Tianjin Agriculture and Forestry*, 219: 29-31.

[48] Wang Z Q, Shen G X, Qian X Y, *et al*., 2014, Construction of anti-erosion ecological ditch and its application effect in paddy field. *Chinese Journal of Environmental Engineering*, vol.8(9): 4047-4052.

RESEARCH ARTICLE

Efficacy of coastal reservoirs to address India's water shortage by impounding excess river flood waters near the coast

T. G. Sitharam
Department of Civil Engineering, Indian Institute of Science, Bangalore, India;
International Association for Coastal Reservoir Research (IACRR).

Abstract: India is a sub-continent where presently 320 million people remain in the water-starved parts of the country and according to the UN, this number is expected to increase to 840 million in the year 2050. There is a severe demand-supply mismatch. Though there has been no significant change in India's rainfall pattern, the number of areas under drought in India is increasing every year. Increase in population is one of the reasons for water scarcity but the inefficient management of the received precipitation stands as the major cause. Though extreme rainfall events are significantly increasing, there is a spatial non-uniformity in the rainfall events that occur. This makes it difficult to pre-plan large scale water storage at different locations. Out of the 4,000 billion m^3 of freshwater available from precipitation per annum, major portion run off into the sea. The solution to India's water problem is to conserve the abundant monsoon water bounty, store it in coastal reservoirs, and use this water in areas which have occasional inadequate rainfall or are known to be drought-prone or in those times of the year when water supplies become scarce. It is estimated that about 4,400 thousand million cubic feet of rainwater just simply drains into the sea. This paper focuses on the concept of Coastal Reservoir. This basically means building a storage structure near the mouth of river. In this way, the amount of water that is wasted as run-off can be stored. The construction of a coastal reservoir does not involve many risk factors and disadvantages like relocation which would occur in an inland dam construction. The paper also presents the concept of Sarovarmala - a chain of coastal reservoirs which is an innovative concept that has the potential to ensure water availability to India throughout the year.
Keywords: coastal reservoirs, flood water, India's water resources, storage per capita

Correspondence to: T. G. Sitharam, Department of Civil Engineering, Indian Institute of Science, Bangalore, India; International Association for Coastal Reservoir Research (IACRR); Email: sitharam@civil.iisc.ernet.in

Received: July 10, 2017; **Accepted:** August 12, 2017; **Published Online:** September 29, 2017
Citation: Sitharam T G, 2017, Efficacy of coastal reservoirs to address India's water shortage by impounding excess river flood waters near the coast. *Journal of Sustainable Urbanization, Planning and Progress*, vol.2(2): 49-54. http://doi.org/10.26789/JSUPP.2017.02.008

1 Introduction

Demand for water keeps on increasing day by day. However, average rainfall has remained constant and it is plentiful. In India, it is about 4,000 billion m^3. But most of India's rainfall comes over a 4-month period starting from June to September. India also experiences years of excess monsoons and floods, followed by below average or late monsoons with droughts. Despite abundant rains in July to September, some regions face a shortage of drinking water, while some other parts of the country receive excessive rains resulting in floods. This geographical and time variance in the availability of natural water versus the year-round demand for irrigation, drinking and industrial water creates a demand-supply gap that keeps worsening with rising population. It is estimated that about 4,400 TMC ft of river flood water from west flowing rivers alone drains into the Arabian Sea. From this, it is very clear that India is not water-starved but storage-starved.

The solution to India's water problem is to conserve the abundant monsoon water bounty, store it in coastal reservoirs, and use this water in areas which have occasional inadequate rainfall or are known to be drought-prone or in those times of the year when water supplies become scarce. Per capita storage of water in India for domestic purpose is too small when compared with developed countries. It is wise to invest in storage of this excess flood water (which is reasonably diluted and cleaner) in the coastal reservoirs close to the places where rivers join the sea.

The currently available solutions are unable to satisfy people's increasing need for water. As far as rain water is concerned, one area receives too much rain in the wet seasons thereby causing floods and excess rainwater discharge into the sea, while receiving a shortage of rain fall in dry seasons. Hence, the solution lies in utilizing or conserving the abundant monsoon water which runs off to the ocean.

There is a need for a method for developing a sustainable water source for managing rain water. There is further a need for storing flood water in sea based reservoirs by building impermeable sea walls and interlinking these reservoirs for transfer of water from one place to another. The primary objective of the present paper is to present a method for developing a sustainable water source for managing rain water. And highlight the potential of coastal reservoirs for storing flood water.

2 Current Water Solutions

There are different 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. Each of these has its own characteristics. The primary renewable source of freshwater is rainfall. Rainwater, surface water, subsurface flow, ground water and sea water are other sources of water available for water supply options. Following are the different options:

1. More inland reservoirs - Very few large dams after the year 2000; more and more people have realized the problems of large dam construction on land. Silting process reduces storage - 75% of silt will be left on land. Further, India is the third largest dam building nation in the world with more than 6,000 dams (large dams).
2. Interlinking of rivers - to optimize the surface water.
3. Ground water.
4. Desalination plants.
5. Wastewater reuse facilities.
6. Coastal (sea based) reservoirs.

As the available fresh water sources are very less throughout the world, there is a stress upon the available sources and conservation structures. The focus of desalination and other techniques is increasing. However, for a developing country like India, it is very difficult to make a huge investment in projects like desalination, which requires a high maintenance cost.

Desalination is not environmentally viable and it affects marine environment where waste water is released. The coastal cities are normally more urbanized, and more and more urbanization is concentrated along the coasts. There is a rapid migration of people because of the job opportunities. There would be a rapid increase in population and the demand for water would increase exponentially. Presently, the solution for this issue would be a coastal reservoir, i.e. a reservoir in the sea to store a portion of the river flood waters which is joining the ocean in the monsoon periods and use it during the drought periods.

3 Coastal Reservoir to Store Flood Water

Coastal reservoir is a unique structure constructed at an estuary or gulf, bay or in the sea (point where a river meets a sea) to store the portion of excess water at flood time. This sea wall or dike structure may run for kilometers together in the coast line. Coastal reservoir has many advantages, such as no land acquisition problems, no land submergence and forest submergence like in inland reservoirs. They are already put to work in countries like the Netherlands, Singapore, China, India, South Korea, Hong Kong, United Kingdom, etc and proven to be beneficial. They are designed with gates so that the excess flood water which is more than the capacity of the reservoir can be discharged into the sea. Even inlets and outlets are controlled so that only good-quality water enters the reservoir with very little stagnation of water. One can adopt very innovative designs with smart sensor networks to operate the coastal reservoirs efficiently.

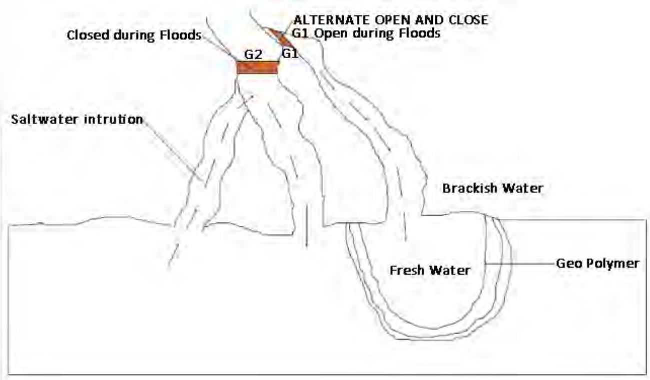

Figure 1. Schematic of a coastal reservoir that enables storage of freshwater during river floods.

Figure 1 shows a typical schematic of a coastal reservoir which enables storing of fresh water during river floods. The fresh water reservoir includes an impermeable sea wall for containing the fresh water and preventing a mixing of the fresh water with the sea water. The sea wall is located on the sea bed having three-sided structure to prevent ingress of sea water into the fresh water/river course. By keeping out seawater, the construction of sea wall along with one or two barrages (with sluice gates) close to the mouth of river forms the fresh water reservoir in the ocean. Sea based reservoir is a part of the river watershed which is formed by the convergence of the rivers and allows fresh water and salts to join the ocean. The reservoir will be shallow waters and have an average depth of 10 to 20 m with a maximum depth of about 30 m. When it rains heavily during low-tide, the sea reservoir outflow crest gates will be lowered to release the excess rain water from the reservoir into the sea. If heavy rain falls during high-tide, the outflow crest gates remain closed and large reservoir can be designed so as to absorb the flood water shocks and release water out to sea only during low tides. The method further includes interlinking of these reservoirs at different locations across different rivers through underwater subsurface pipes for transferring water from one reservoir to another in shallow sea water (herein, we called this as Sarovar Mala; Sarovar means freshwater pond in Sanskrit and mala means necklace around the land)[1].

4 Scenario in India

India is a peninsula surrounded by ocean on three sides, enjoys a lot of monsoon rainfall because of its physical features. Indian peninsula receives an average annual rainfall of 4,000 BCM and this number has not changed much in the last 100 years. However, due to climate change, very intense rainfall events are causing floods in many regions in India. In some other areas, average annual rainfall is 300-650 mm, but

Table 1. Comparison of sea based reservoir vs land based reservoir.

Item	Sea based reservoir	On land reservoir
Dam Site	Sea (Inside/outside river mouth)	Valley (limited area)
Water level	At sea level	Above sea level
Pressure	Low pressure along with wave surges	High water pressures
Catchment area	Entire Catchment of the river course	Partial catchment
Seepage	By density difference (Slow)	By head difference (fast)
Pollutant	Land based and sea water	Land based
Land acquisition	Nil	High
Environmental damage	Nil (no forest damage, no displacement of people, etc.)	Very high (difficult to build dams nowadays)
Water supply	By pumping	Mainly by gravity
Construction cost	Low	High

it is very unreliable and the southwest monsoon accounts for most of the precipitation. Different regions receive different amounts of rainfall, varying from 20 cm to over 800 cm. Despite that, we have a massive network of both perennial and non-perennial rivers that form a network within the country. India also has various water storing and conservation structures. India is the third largest dam building country in the world after USA and China. India has built more than 6,200 dams which are taller than 15 m and the majority of them ($>$ 80%) are earthen dams. Various storage structures lie at conflicting spots and hinder the socioeconomic condition of the people whenever there is a problem. Even these structures act as hotspots in both national and international borders. Inter-state water disputes have only increased in the recent times. As per the government of India information, there are 8 major inter-state water disputes in the country.

Due to various climatic factors, the total rainfall that should be received throughout the year is just received in 30-40 days. This would result in torrential rainfall and flash floods during monsoon. This precipitation water ultimately would mix in the ocean without any use during the time of need. Close to 80% of the total precipitation received over Indian peninsula joins the ocean in just 3 to 4 months every year. Because of the lack of the storage structures within the country (even with more than 5,000 large dams), we have a burning need of more storage structures to cater to water demands during times of drought. Even though land based reservoirs like dams have various advantages, they also have their own disadvantages. Land acquisition, clearing of forest areas, loss of bio-diversity, submergence of lands and forests, diversion works during construction etc are some of them.

5 Benefits of Coastal Reservoir

Table 1 shows the comparison of sea based reservoirs to the land based reservoirs. There are many advantages of the sea based reservoirs when compared with any conventional land based reservoirs [2].

Listed below are the advantages of coastal reservoirs:

1. No harm to any of the river basins and no alteration to the river course (no temporary diversions as well).
2. No disturbance to any forest cover and no submergence of land.
3. No physical displacement of people and their villages/-towns.
4. Agriculture activities can be augmented.
5. Coastal erosion can be minimized.
6. Ground water recharge due to fresh water in estuarine areas.
7. Intrusion of saline water into wells will reduce.
8. Freshwater dredging will provide sand for construction.
9. Earthquake resistant sea walls.
10. Solar panels on the sea wall - solar energy.
11. Tidal energy at the wall.
12. Roadways over the sea wall, Fresh water Fishing, Navigation and Tourism.
13. Real estate opportunities.
14. Length and width of sea wall - serve as a deep-water fishing harbour - benefit the fishing community.
15. Increase in industrial, recreational and fisheries activities around this fresh water.

Table 2 shows the existing coastal reservoirs in the world along with the purpose [3].

Table 2. Existing sea based reservoirs around the world.

Country	Name	Purpose
Netherlands	Afsluitdijk in the Ijsselmeer, 1932	Flood control
India	Thanneermukkom Bund, 1974	Agriculture
South Korea	1. Sihwa, 1994	Tidal energy
	2. Saemanguem, 2010	Land reclamation and fresh water
Hong Kong	1. Shek Pik, 1968 2. Plover Cove 3. High land	Fresh water
China	1. Qingcaosha, 2011 2. Chenhang, 1992 3. Baogang, 1985	Fresh water
Singapore	Marina Barrage, 2008	Fresh water
United Kingdom	Cardiff Bay Barrage, 1987	Fresh water lake

note: Under Planning Stage: 1. Pluit Reservoir Revitalization Project, Jakarta, Indonesia; 2. Kalpasar Project, Gulf of Khambhat, Indian Water Project, Gujarat; 3. Sydney and other coastal cities, Australia; 4. New York, USA.

Table 3. Cost of water and cost of construction.

	Cost per kilolitre of water in Indian Rupees (Rs)	Cost of construction / Billion Cubic Meters (in Indian Rupees)
Sea based reservoirs	Rs 2-10 (sea level)	Rs 20,000 Million / BCM
Inland reservoirs	Rs 30-100 (above the sea level)	Rs 100,000 Millions / BCM
Desalination	Rs 60-80 (sea level)	Rs 80,000 Millions / BCM

Table 3 gives the cost of water and cost of construction using coastal reservoirs in comparison to desalination, inland reservoirs, water recycling (from waste water). Cost of water per 1,000 liters (1 m^3 or Kilo liters) and cost of construction for storing 1 Billion Cubic Meter (BCM) of water has been estimated considering the costs of labor, materials and execution in India. Cost of water has been estimated at the location of coastal reservoir without considering the cost of pumping.

6 Coastal Reservoirs in India

6.1 Thanneermukkom Bund

Theneermokkum Bund (Figure 2) was constructed in 1974 as a part of Kuttanad low land development scheme and creation of fresh water reservoir in the coastal area of Kerala. Thaneermukkom salt water barrier/bund is considered the largest mud regulator in the country and is in operation since 1976. It divides the Vembanad Lake into fresh water lake fed by the rivers draining into the lake and brackish water lake fed by ocean currents into low lands of Kuttanadu. The Four major rivers of Kerala, the Pamba, Meenachil, Achankovil and Manimala flow into the region before they confluence into the Arabian Sea. It also has a major portion of the largest lake in Kerala "the Vembanad Lake". Lake is fed by ten rivers of which the above four major rivers form the main part. The region receives a good amount of annual rainfall which is above 3,000 mm and these four rivers bring a large quantity of water into the lake before joining sea. By constructing the salt water barrier, a coastal reservoir having fresh water has been created for increasing agricultural activities in the area in addition to land development. However, there are reports of environmental and ecological damage such as rampant propagation of water hyacinth in fresh water and deterioration of brackish water fishing in the area. However, these are related to the wrong operations of the reservoir and not the fully functional plan of Thaneermukkum Bund. The problems faced by fisherman and water hyacinth problems need to be addressed with innovative alternative schemes of operations. In fact, this fresh water reservoir is need of the hour and needs to be restored to its capacity for the supply of drinking water to nearby areas and also supply fresh water for irrigation in the low lands of Kuttandu, which helps farmers.

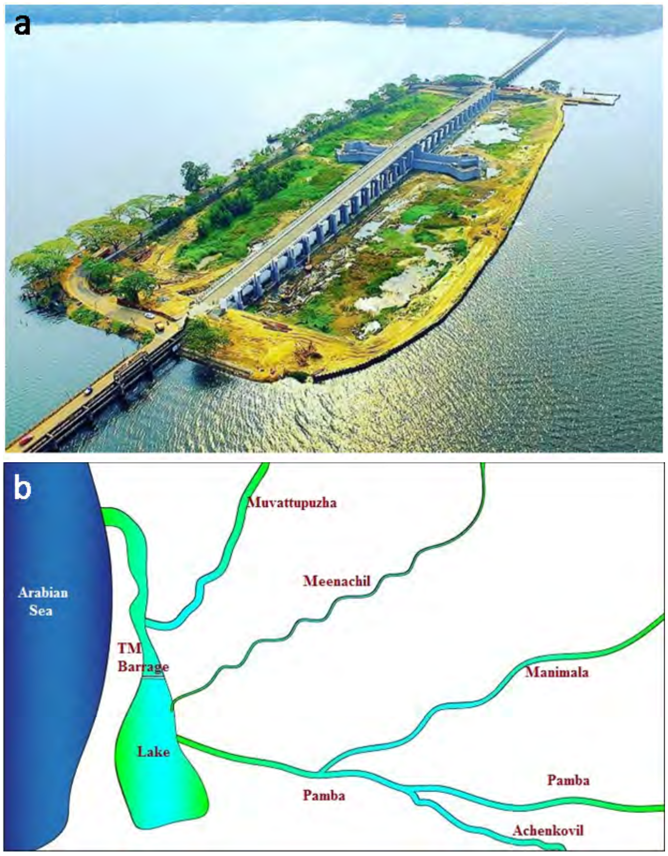

Figure 2. a) Bird eye view of Thanneermukkom Barrage. b) Location of barrage across Vembanadu Lake.

6.2 Kalpasar Project

The Gulf of Khambhat Development Project is mainly water resources project involving the creation of fresh water reservoir in the Gulf of Khambhat for meeting demand of irrigation, domestic and industrial water supply. Associated components related to the fresh water reservoir are use of top of the dam across the gulf as a surface transport link, potential development of fisheries, reclamation of saline land around the fresh water reservoir. The Gulf of Khambhat extends about 200 km from north to south and the width varies from 25 km at the inner end to 150 km at the outer mouth, covering an area of around 17,000 km^2, of which only 2,000 km^2 will be enclosed by constructing a dam across the gulf between Bhavnagar and Dahej. Figure 2 shows the Kalpasar project location and detailed plan of Gulf of Khambhat development wherein is a coastal reservoir is envisaged in Gulf of Khambhat and using contour canals to supply water the entire Gujarat Coast. The Kalpasar Project envisages building a dam across the Gulf of Khambat for establishing a huge fresh water reservoir for irrigation, drinking and industrial purposes. A 10 lane road link will also be set up over the dam, greatly reducing the distance between Saurashtra and South Gujarat by 225 km. A state government release said the Rs 55,000 crore (US$ 11.7 billion) project to be completed by 2020, will have a vast fresh water reservoir with gross storage of 16,791 million m^3 of water. The 64 km long dam across the Gulf of Khambhat connects Ghogha in Bhavnagar with Hansot in Bharuch District. The state government of Gujarat has signed an MOU with a Korean consortium to build the first ambitious sea wall project in the Gulf of Khambhat in the first quarter of 2016[4]. Once constructed, it will be one of the large freshwater reservoirs in the sea with highest priority for irrigation and drinking water in the region for Saurashtra and Central Gujarat regions of India.

6.3 Feasibility Study of Coastal Reservoir at Mangaluru from Flood Waters of Netravati River

Author has carried out a detailed feasibility study with a large multidisciplinary team on developing a sustainable water source for Bengaluru and Mangaluru using the coastal reservoir as a storage area for Netravati/Gurupura River flood waters, Karnataka, India. The principal objective of the project was to assess the feasibility of storing fresh water in a reservoir along the coast, by building a sea dike in the Arabian Sea. On one side, the dike will ensure the required quantity of fresh water which flows from the Netravati River to the reservoir, without being drained completely into the sea. On the other side, the sea dike will prevent the sea water from entering the reservoir avoiding salt contamination of the fresh water supply. The study addresses the coastal urban watershed management of Mangaluru city and agricultural land along the river and the coast, in the context of the proposed project of building a sea dike for the creation of a fresh water reservoir impounding river flood waters [5].

It is imperative that a small percentage of runoff of Netravati River is more than sufficient to cater the water requirements of Mangalore and Bangalore. From the data of last few decades, there are hardly any chances of scarcity of water availability in Netravati River. The concept of coastal reservoir emerges as the best solution to meet the future water demands of both Bangalore and Mangalore. The average annual runoff in Netravati River is 388.5 TMC. As per Bangalore Water Supply and Sewerage Board (BWSSB), shortfall in demand in Bangalore in 2051 is 26.16 TMC which is 7% of average annual runoff through Netravati. In 2021, the shortfall in demand is only 8 TMC which is just 2.1% of the runoff. There is hardly any chance of silting of reservoir as the average annual sediment load in Netravati River is 0.04 TMC. The water quality parameters in Netravati and Gurupura Rivers are in tolerable limits for safe drinking water, thus the water can be directly utilized without any major treatment. Benefiting sectors due to coastal reservoir are agriculture, prawn culture and sand dredging. The possible renewable energy generation implies that the system will be self-sufficient in energy to meet the energy demands for pumping, lighting and other requirements. Consultation and inputs from renewable energy developers would strongly support in the planning for cost-effective and sustainable technology installations for renewable energy generation. The coastal reservoir will not affect the built-up area. The land use indicates that built-up area is less, while the vegetation cover is more. Also, due to fresh water reservoir, a reduction of salinity of water is expected after the construction of coastal reservoir, its effects on the vegetation must be pre-assessed and analyzed.

6.4 Sarovar Mala (Garland of Reservoirs for India)

Sarovar Mala (Figure 3) is a concept of linking sea based/-coastal reservoirs (Sarovar's in the ocean) at the mouth of rivers (where rivers in Indian Peninsula join the ocean. The main objective is to create a large of fresh water for developmental activities including drinking/agricultural activities and increase water storage per capita in the coastal areas. This is a strategic plan to increase the water storage per capita in India along the Indian coast by storing the excess flood waters from major rivers in southern Indian Peninsula, once these Sarovar's are connected by pipelines in shallow ocean waters along the coast (by using a shallow water spud barge which has side way lowering).

Along with the initiative of the Government of India to modernize India's ports, this fresh water reservoir (Sarovar) will aid the development of coastal areas. With the increased fresh water availability in the coast, the coastlines can be developed to contribute to India's growth. Sarovar Mala provides a good connectivity for non-perennial rivers and will provide a storage plan for fresh water from the excess river flood waters and can develop the industrial clusters and hinterland up to a radius of 100 km, which resulting in Sarovar becoming the drivers of economic activity in coastal areas.

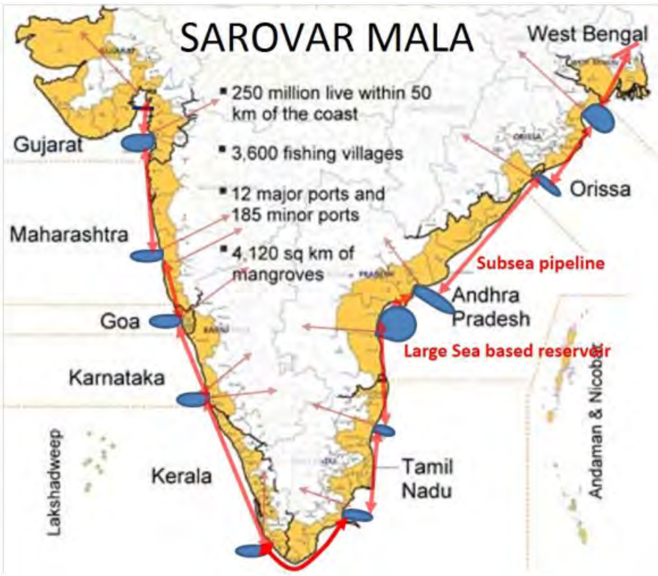

Figure 3. Sarovar Mala, a chain of freshwater reservoirs along the coastal line of India.

7 Concluding Remarks

India receives most of its fresh water during a four-month monsoon period during which time the lakes are filled, rivers experience floods and ground water is recharged. But due to the onset of climate change, the rainfall pattern changed resulting extreme variability of the rainfall is experienced. While some rivers receive huge quantities of rain resulting extreme flooding, other rivers and water bodies are bone dry. Indian population over the decades has increased so much, the density of population and dwindling forest coverage is not allowing the creation of fresh land based reservoirs. The original proposal of interlinking of rivers to overcome the ill effects of variable rainfall in India is practically dead and impossible to implement under the changed circumstances and huge cost of the project. Considering all the above, the solution lies in storing flood water in sea based reservoirs which are of immense value as they do not submerge lands. If heavy rain falls during high-tide, the outflow crest gates remain a closed and large reservoir of about $>$ 100 TMC ft (2.8 BCM) can be designed so as to absorb the flood water shocks and releases water out to sea only during low tides. Even the sand, silts and salts can join the ocean partly through the sea based reservoir. Sea based reservoir can be constructed in shallow waters at appropriate locations close to the mouth of the river along with a barrage at one or two ends. A detailed study is needed even considering salt water intrusion through estuaries, bays and gulfs. By connecting coastal reservoirs around the Indian Peninsula, Sarovar Mala will be a sustainable solution for Indian water requirements specifically in the coastal areas. More species of fish call these ponds home! This reservoir will increase Indias fresh water supply for generations to come and use the rivers flowing into Arabian Sea and Bay of Bengal.

Acknowledgements

We would like to acknowledge Dr. Sreevalsa K, Ms. Amala Krishnan (credit for Figure 2b), Ms Praharsha B S (credit for Figure 1) and Nimmy Therese, M.Tech students in the Department of Civil Engineering at Amrita University, for providing information on Thanneermukkom Bund. I also profusely thank all my team which feasibility study of coastal reservoir at Mangaluru to impound Netravati River flood waters: A feasibility study in India. Also thanks to Bangalore Water Supply and Sewerage Board (BWSSB) for their funding.

References

[1] Sitharam T G, 2016, Smart water network to store river flood water in sea based reservoirs and a method of interlinking these reservoirs (Sarovar Mala). India patent no. TEMP/E-1/44294/2016-CHE.

[2] Yang S Q, Liu J L, Lin P Z, *et al.*, 2013, Coastal reservoir strategy and its applications, in *Water Resources Planning, Development and Management*, Intech, United States, 95-115. http://ro.uow.edu.au/eispapers/1763/

[3] Yang S Q and Kelly S, 2015, The use of coastal reservoirs and SPP strategy to provide sufficient high quality water to coastal communities. *Journal of Geoscience and Environment Protection*, vol.3(5): 80-92. http://dx.doi.org/10.4236/gep.2015.35010

[4] Kalpasar Government, 2016, The Gulf of Kambhat Development Project, Gujarat, KALPASAR. https://doi.org/10.14453/isngi2013.proc.51

[5] Bangalore Water Supply and Sewerage Board (BWSSB) Report, 2017, Sitharam *et al.*, *Coastal reservoir at Mangaluru to impound Netravati River flood waters - A feasibility study in India*, 178.

Journal of Sustainable Urbanization, Planning and Progress

Author Guidelines

Before your submission, please check that your manuscript has been prepared in accordance to the step-by-step instructions for submitting a manuscript to our online submission system. We recommend that you keep this page open for your reference as you move through the submission process.

Do not follow these instructions if you are re-submitting a revised manuscript, are responding to a technical check inquiry, or have otherwise already submitted this paper to *Journal of Sustainable Urbanization, Planning and Progress*.

Manuscript Format

Your manuscript should be in MS Word or LaTeX format. Your manuscript must be written in clear, comprehensible English. If you have concerns about the level of English in your submission, please ensure that it is proofread before submission by a native English speaker or a scientific editing service.

Cover Letter

All submissions should include a cover letter as a separate file. A cover letter should contain a brief explanation of what was previously known, the conceptual advancement with the findings and its significance to broad readership. The cover letter is confidential and will be read only by the editors. It will not be seen by reviewers.

Title

The title should capture the conceptual significance for a broad audience. The title should not be more than 50 words and should be able to give readers an overall view of the paper's significance. Titles should avoid using uncommon jargons, abbreviations and punctuation.

List of Authors

The names of authors must be spelled out rather than set in initials with their affiliations footnoted. Affiliations should contain the following core information: department, institution, city, state, postal code, and country. For contact, email address of the corresponding authors has to be included. Please note that all authors must see and approve the final version of the manuscript before submitting.

Abstract

Articles must include an abstract of 200–300 words. The purpose of abstract is to provide sufficient information for a reader to determine whether or not to proceed to the full text of the article. After the abstract, please give 5–8 keywords; please avoid using the same words as those already used in the title.

Section Headings

Please number the section headings (e.g. **1**, **2**, **3**, **4**, etc.) in boldface. Likewise, use boldface to identify subheadings too but please distinguish it from major headings using numbers (e.g. **1.1**, **1.2**, **2.1**, **2.2**, etc.). Further sub-sections of subheadings should be differentiated with the numbers **1.1.1**, **1.1.2**, **2.1.1**, **2.1.2**, etc.

Introduction

The introduction should provide a background that gives a broad readership an overall outlook on the field and the research performed. It tackles a problem and states its importance regarding the significance of the study. The introduction can conclude with a brief statement of the aim of the work and a comment about whether that aim was achieved.

Materials and Methods

This section provides the general experimental design and methodologies used. The aim is to provide enough details for other investigators to fully replicate your results. It is also required to facilitate better understanding of the results obtained. Protocols and procedures for new methods must be included in detail to reproduce the experiments.

Ethics

Ethics information, including IACUC permit numbers and/or IRB name if applicable, should be included in a subheading labeled "Ethics Statement" in the "Methods" section of your manuscript file, in as much detail as possible.

Results

This section can be divided into subheadings. This section focuses on the results of the experiments performed.

Discussion and Conclusion

This section should provide the significance of the results and identify the impact of the research in a broader context. It should not be redundant or similar to the content of the results section.

Please use the conclusion section for interpretation only, and not to summarize information already presented in the text or abstract.

Conflict of Interest and Funding

This section should include a declaration of any conflict of interest. It should also acknowledge funding sources if any.

Acknowledgements

This section should acknowledge contribution(s) from non-authors.

In-text Citations

References must be listed at the end of the manuscript and numbered in the order that they appear in the text. In the text, citations should be indicated by the reference number in superscript square brackets. An example: Negotiation research spans many disciplines[3,4].

References should include papers already published and those in "press". Authors cannot cite any unavailable and unpublished work.

Please use the style shown in the template of submission of manuscript. Note that "*et al*." should only be used after three authors.

Text

The text of the manuscript should be in Microsoft Word or LaTeX. The length of the manuscript cannot be more than 50000 characters (inclusive of spaces) or approximately 7000 words.

Figures

Authors should include all figures into the manuscript and submit it as one file in the OJS system. Reference to the "Instructions for Typesetting Manuscript" is strongly encouraged. Figures include photographs, scanned images, graphs, charts and schematic diagrams. Figures submitted should avoid unnecessary decorative effects (e.g. 3D graphs) as well as be minimally processed (e.g. changes in brightness and contrast applied uniformly for the entire figure). It should also be set against a white background. Please remember to label all figures (e.g. axis etc.) and add in captions (below the figure) as required. These captions should be numbered (e.g. **Figure 1**, **Figure 2**, etc.) in boldface. All figures must have a caption that describes the entire figure without citing specific panels, followed by a legend defined as description of each panel. Please identify each panel with uppercase letters in parenthesis (e.g. (A), (B), (C), etc.)

The preferred file formats for any separately submitted figure(s) are TIFF or JPEG. All figures should be legible in print form and of optimal resolution. Optimal resolutions preferred are 300 dots per inch for RBG coloured, 600 dots per inch for greyscale and 1200 dots per inch for line art. Although there are no file size limitation imposed, authors are highly encouraged to compress their figures to an ideal size without unduly affecting legibility and resolution of figures. This will also speed up the process of uploading in the submission system if necessary.

The Editor-in-Chief and Publisher reserve the right to request from author(s) the high-resolution files and un-processed data and metadata files should the need arise at any point after manuscript submission for reasons such as production, evaluation or other purposes. The file name should allow for ease in identifying the associated manuscript submitted.

Tables, Lists and Equations

Tables created using Microsoft Word table function are preferred. The tables should include a title at the top. Titles and footnotes/legends should be concise. These must be submitted together with the manuscript. Likewise, lists and equations should be properly aligned and its meaning clear to readers. For listing things within the main body of the manuscript, please use roman numbers in parenthesis (e.g. (i), (ii), (iii), (iv), etc.).

References

This section is compulsory and should be placed at the end of all manuscripts. Do not use footnotes or endnotes as a substitute for a reference list. The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should be excluded from this section.

For references in reference list, all authors must be stated. Authors referenced are listed with their surname followed by their initials. All references should be numbered (e.g. 1. 2. 3. etc.) and sequenced according to the order it appears as an in-text citation. References should follow the following pattern: Author(s) followed by year of publication, title of publication, full journal name in italics, volume number, issue number in parenthesis and lastly, page range. If the referred article has more than three authors, list only the first three authors and abbreviate the remaining authors to italicized '*et al*.' (meaning: "and others"). If the DOI is available, please include it after the page range.

Journal

Journal article (print) with one to three authors
Younger P, 2004, Using the internet to conduct a literature search. *Nursing Standard*, vol.19(6): 45–51.

Journal article (print) with more than three authors
Gamelin F X, Baquet G, Berthoin S, *et al*. 2009, Effect of high intensity intermittent training on heart rate variability in prepubescent children. *European Journal of Applied Physiology*, vol.105: 731–738.

Journal article (online) with one to three authors
Jackson D, Firtko A and Edenborough M, 2007, Personal resilience as a strategy for surviving and thriving in the face of workplace adversity: A literature review. *Journal of Advanced Nursing*, vol.60(1): 1–9. http://dx.doi.org/10.1111/j.1365-2648.2007.04412.x.

Journal article (online) with more than three authors
Hargreave M, Jensen A, Nielsen T S S, *et al*. 2015, Maternal use of fertility drugs and risk of cancer in children—A nationwide population-based cohort study in Denmark. *International Journal of Cancer*, vol.136(8): 1931–1939. http://dx.doi.org/10.1002/ijc.29235.

Book

Book with one to three authors
Schneider Z, Whitehead D and Elliott D 2007, *Nursing and Midwifery Research: Methods and Appraisal for Evidence-based Practice*, 3rd edn, Elsevier Australia, Marrickville, NSW.

Book with more than three authors
Davis M, Charles L, Curry M J, *et al*. 2003, *Challenging Spatial Norms*, Routledge, London.

Chapter or article in book
Knowles M S 1986, Independent study, in *Using Learning Contracts*, Jossey-Bass, San Francisco, 89–96.

Others

Proceedings of meetings and symposiums, conference papers
Chang S S, Liaw L and Ruppenhofer J, (eds) 2000, *Proceedings of the twenty-fifth annual meeting of the Berkeley Linguistics Society, February 12–15, 1999: General session and parasession on loan word phenomena*. Berkeley Linguistics Society, Berkeley.

Conference proceedings (from electronic database)
Bukowski R M, 2009, Prognostic factors for survival in metastatic renal cell carcinoma: update 2008, Innovations and challenges in renal cancer: Proceedings of the third Cambridge Conference, *Cancer*, vol.115(10): 2273, viewed May 19, 2009, Academic OneFile database.

Online document with author names
Este J, Warren C, Connor L, *et al*. 2008, *Life in the clickstream: The future of journalism*, Media Entertainment and Arts Alliance, viewed May 27, 2009, http://www.alliance.org.au/documents/foj_report_final.pdf

Online document without author name
Developing an argument, n.d., viewed March 30, 2009, http://web.princeton.edu/sites/writing/Writing_Center/WCWritingResources.htm

Thesis/Dissertation
Gale L, 2000, *The relationship between leadership and employee empowerment for successful total quality management*, thesis, University of Western Sydney, viewed March 31, 2009, Australasian Digital Thesis database.

Standards
Standards Australia Online 2006, *Glass in buildings: Selection and installation, AS 1288-2006*, amended January 31, 2008, viewed May 19, 2009, SAI Global database.

Government report
National Commission of Audit 1996, *Report to the Commonwealth Government*, Australian Government Publishing Service, Canberra.

Government report (online)
Department of Health and Ageing 2008, *Ageing and aged care in Australia*, viewed November 10, 2008, http://www.health.gov.au/internet/main/publishing.nsf/Content/ageing

Patent
Rencher W F, 1995, Bioadhesive pharmaceutical carrier. US Patent 5462749 A.

No author
Guide to agricultural meteorological practices 1981, 2nd edn, Secretariat of the World Meteorological Organization, Geneva.

Note: When referencing an entry from a dictionary or an encyclopedia with no author there is no requirement to include the source in the reference list. In these cases, only cite the title and year of the source in-text. For an authored dictionary/encyclopedia, treat the source as an authored book.

JOURNAL OF SUSTAINABLE URBANIZATION, PLANNING AND PROGRESS

ISSN: 2424-8053 (PRINT)
ISSN: 2424-9882 (ONLINE)

Focus and Scope

The *Journal of Sustainable Urbanization, Planning and Progress* (JSUPP) is a multidisciplinary journal of research papers, opinion articles, technical notes and monographs/special issues with a global readership. It offers an outlet for extended papers in the field of urbanization process, sustainable planning techniques, and progress made worldwide in developing sustainable cities. We welcome papers on any aspect of urbanization process, spatial and environmental planning, sustainable practices of urban planning and progress made in the areas of sustainable cities, that make a contribution to urbanization, planning and progress scholarship.

About the Publisher

Urban Development Scientific (UDS) Publishing Pte. Ltd. was established in Singapore in 2016 with a global orientation. The core business of the company focuses on publication of academic journals, organisation of international academic conferences.

Albeit being a young company, UDS Publishing Pte. Ltd. has placed huge focus on initiating and publishing top quality international academic journals. The eventual aim is to be indexed by top-notch databases such as EI, SCI, SSCI and AHCI.

Editorial Office

Urban Development Scientific Publishing Pte. Ltd.
6 Eu Tong Sen Srteet #10-08, The Central Singapore 059817, Republic of Singapore
Tel: +65 98107233
Website: www.udspub.com