

Coastal Reservoir-The Trend Of Water Supply In New Era

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Abstract: Water shortage can be caused by population growth that drives the growth of water demand for domestic, agricultural and industrial purposes. Water shortage in water-rich areas can be also caused by water pollution. The water problem caused by poor quality and insufficient quantity has been widely noted and well informed among the researchers, decision makers and ordinary people, but not much research considers these facts: 1) more and more people migrate to coastal areas; 2) sedimentation by soil erosion reduces the storage capacity of existing reservoirs and many of them will be out of use in the next 50 years; 3) for developed countries like Australia, it is almost impossible to build new inland dams to replace the lost storage. Thus, a major issue is to find new sources of drinking water for the future. This paper describes the potential benefit of expanding the use of coastal reservoirs for human consumption. First, we review current issues associated with water supply; then, we identify key differences between inland and coastal reservoirs before highlighting advantages of coastal reservoirs in the future.

Key words: Coastal reservoirs; Inland reservoirs; Seawater intrusion; Freshwater development; Runoff harvest.

I. Current Water Supply Infrastructure Under Pressure

Water is the foundation of life. Unfortunately, approximately 1.1 billion people can't access safe drinking water; 2.6 billion people lack adequate sanitation, and 2 to 5 million people die every year from water-related diseases¹. To meet irrigation demand for agriculture by 2025, the World will need an additional 192 cubic miles of water per year; a volume equivalent to ten times the annual flow of the Nile river². Thus it is urgent to identify new sources of water that will meet future human, agricultural and industrial needs.

A. Increasing Demographic Pressure on Coastal Areas

As shown on Figure 1, World and Australian populations steadily increase. At current rate, total population could double within the next 50 years. A significant proportion of this growth will be concentrated along coastal areas thanks to regional migrations.

Figure 2 shows the percentage of people living in coastal areas. In Australia, 70% of people lived along coastal areas in the 1950s; this percentage has now reached 90%. Similarly, 30% of

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the World population lived along coastal areas in the 1950s and this proportion has now reached 70%. Historically, major reasons for this attraction include the fact that coastal and deltaic areas are very productive ones in terms of agricultural and fisheries resources. They also offer natural waterways for transport and relatively flat topographies for industrial and residential development. More recently, increased mobility and attention to lifestyle associated with ageing populations retiring down the coast *en masse* have increased migration flows. Unfortunately, current water reservoirs are located and sized according to past demographic patterns and it is fair to ask whether coastal areas, especially in Australia, are ready to accommodate so many people in a near future?

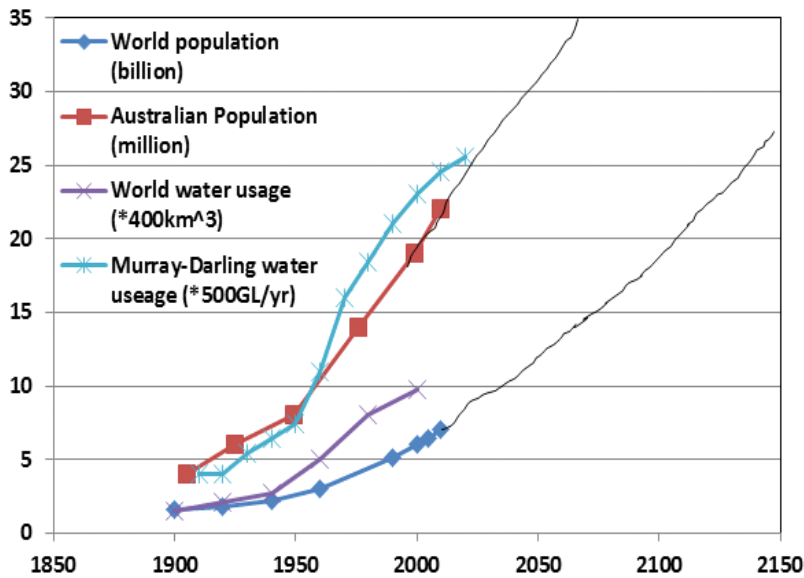


Figure 1. Australian and World population growth and water usage, 1850-2150 period.

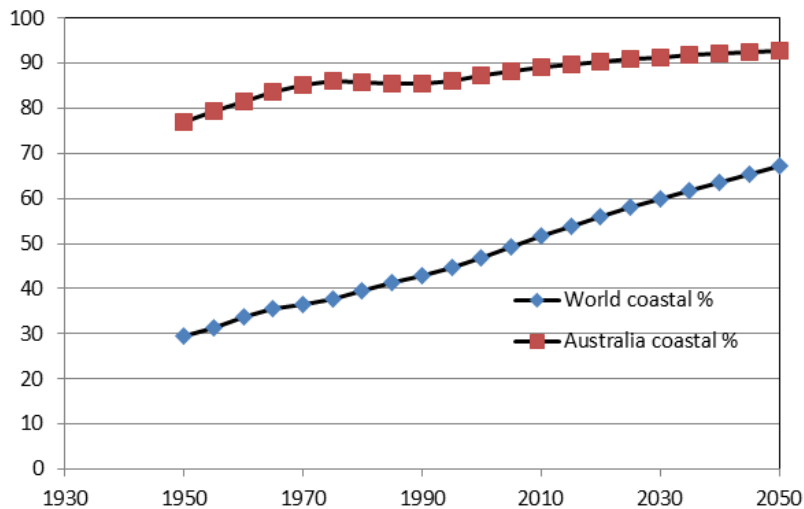


Figure 2. Percentage of coastal population in Australia and in the World, 1950-2050 period.

B. Lifespan of Existing Reservoirs

The lifespan of a concrete dam is usually between 100 and 200 years. But the lifespan of a reservoir also depends on its sedimentation rate³. The total sediment yield in the world is estimated to be 13.5×10^9 tons/year or 150 tons/km² per year. About 25% of this is transported into the oceans and 75% is trapped, retained and stored in the lakes, reservoirs and river systems (Batuca and Jordaan, 2000). As a consequence, silting is reducing the storage capacity of water reservoirs world-wide by more than 1% per year.

James and Chanson⁴ argue that “Australian reservoirs [are] subjected to very high siltation rates that are comparable to overseas most extreme ones”. Australian reservoirs, compared to the rest of the world, are subjected to extreme arid and semi-arid climatic conditions whereby dam volumes can range from near-empty to full, often with rapid filling periods⁵. Under such abrupt conditions, river flows carrying upstream sediments into a reservoir are unsteady and non-uniform. Unfortunately, we still have a limited understanding of sediment transport in non-uniform stream flows while its consequences matter for many engineers and other professionals.

Sediment is also the largest single pollutant to ecosystems as stressed by the Environmental Protection Agency in their Report to the US Congress (National Water Quality Inventory Section 305b). In Australia, every year, algal blooms cost between A\$180 and A\$240 million⁶. Eutrophication, a major factor of coastal algal blooms, often result from a high sediment load that has elevated levels of colloidal material, phosphorus and Nitrogen. Davies-Colley et al⁷ showed that an increase in suspended sediment of ~30 mg/l in a previously clear stream can result in a 50% reduction in plant production. Hence the prediction of sediment transport is crucial in addressing many environmental problems, including impacts on river morphology and ecosystems.

C. Can We Build New Inland Dams?

As per Figure 2 above, most people will live in coastal areas by 2050. Meanwhile, many existing inland reservoirs will be out of service due to the gradual decrease of their storage capacity through siltation. Unfortunately, the number of suitable sites for inland reservoirs near the coast is very limited. Figure 3 (right) shows that the number of new dams being built world-wide has sharply decreased since the 70s. All suitable locations will probably be exploited by 2050. In Australia (Figure 3, left), construction of new inland dams has come to an halt. For example, proposals for the Tillegra dam on the Williams River (NSW) and the Traveston Crossing dam on the Mary River (QLD), were both cancelled due to fierce campaigns from local communities. As a matter of fact, public opinion is increasingly concerned with inland reservoir's potential devastating effects on rivers, freshwater ecosystems, and the people who depend on them. Currently, the Australian and State Governments embrace a ‘no more dam’ strategy preferring to turn towards more expensive and sophisticated technologies like the construction of desalination plants or wastewater recycling plants. Are people ready to pay the real cost associated with these new sources of water? Coastal reservoirs might provide an alternate sustainable and affordable solution.

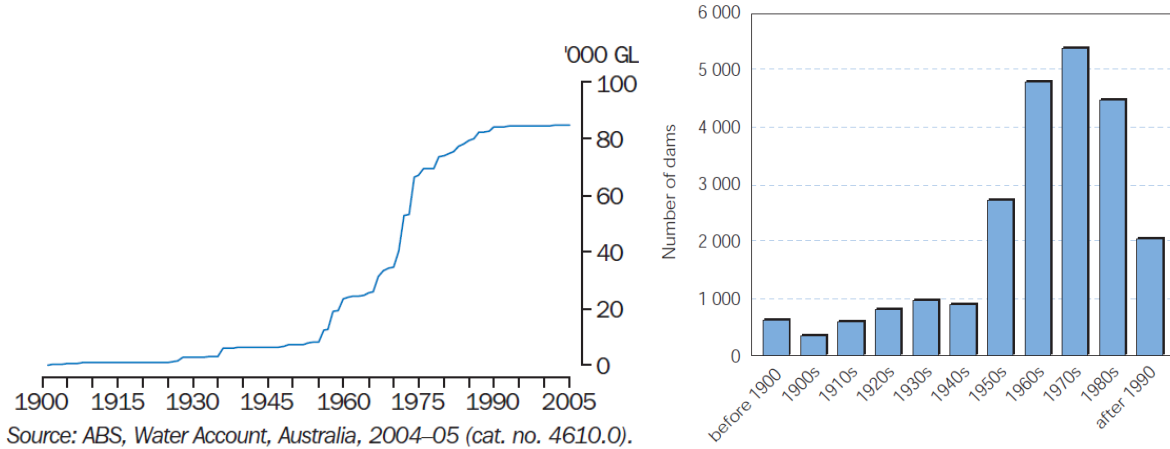


Figure 3. Cumulated storage capacity in Australia (left) and number of dams built in the World (right), 1900-2000 period.

II. Coastal Reservoirs, Definition And Applications

Coastal reservoirs have the potential to become a major source of freshwater in coastal areas, alongside existing inland reservoirs, desalination plants, wastewater recycling plants and rainwater tanks. By definition, a coastal reservoir is a freshwater storage located in coastal waters (river mouth, lagoon or protected bay) being fed by a sustainable freshwater flow. Coastal reservoirs have an impermeable barrier protects the freshwater storage from intrusion by the surrounding brakish seawater. Depending on its location, water captured in a coastal reservoir will be of varying quality for domestic, agricultural or industrial water use. In some cases, integration with other water schemes is possible (desalination or wasterwater recycling). Currently the world only uses about 1/6 of its surface runoff, the remaining being lost to the oceans. Despite its overall arid climate, Australia sees approximately 279,000GL of freshwater being flushed to the oceans every year, while only 21,000GL is being harvested and used. Henceforth, Australia only uses 7.5% of its annual runoff , which is one of the lowest harvesting rate in the world.

Coastal Reservoirs have significant advantages due to their positioning near a river mouth. As reservoir and sea levels are nearly the same and thanks to the lower density of freshwater compared with seawater, risks of seepage are minimal. Likewise, as water pressure tends to reach an equilibrium on both side of the impermeable barrier, this barrier does not need to be highly resistant to pressure as it is the case with inland dams. Coastal Reservoirs are already being used in China, South Korea, Hong Kong and Singapore (see Table 1) and have been largely successful, especially in places where there are no more opportunities to build inland reservoirs. Plover Cove dam in Hong Kong is the first coastal reservoir in the world specially designed for providing drinking water. The Qingchaosha reservoir, located at the mouth of the Yangtze river, has the longest dam.

Table 1. Existing coastal reservoirs in the World

Name	Catchment (km ²)	Dam length (m)	Capacity (10 ⁶ m ³)	Year completed	Country/river
Qing Chaosha/Shanghai	1.8million	43,000	553	On-going	China/Yangtze
Saemanguem	332	33000	530	2011	South Korea
Sihwa		12400	323	1994	South Korea
Marina Barrage	113	350		2008	Singapore
Chen Hang/Shanghai	1.8million	4700	8.3	1992	China/Yangtze
Yu Huan	166	1080	64.1	1998	China/ Zhejiang
Baogang/Shanghai	1.8million		12	1985	China/Yangtze
Plover Cove	45.9	2000	230	1968	Hong Kong



Figure 4. Plover Cove Dam, the first coastal reservoir for drinking purpose in the World.

Comparing characteristics of inland and coastal reservoirs (Table 2), we may conclude that the two of them are totally different. For example, inland reservoirs can only collect water from part of a catchment, and their size is generally whereas coastal reservoir have the potential to harvest any single drop of rain from the catchment as its size is theoretically unlimited. The construction cost of an inland reservoir is generally very high due to the need to build high and strong dam walls, while the pressure force on both sides of the barrier of a coastal reservoir is generally small, although wave surge and tides might be of concern for its design. The most challenging problem for designing a coastal reservoir is to prevent excessive pollution as pollutants carried by the river from the whole catchment are likely to be collected by and trapped in the reservoir. Sihwa Lake, located in South Korea, provides a dramatic demonstration of such a failure. This coastal reservoir was initially designed as a freshwater supply source. In 1994, a 12.4 km-long wall was built to separate Sihwa Lake from the sea; but severe water contamination occurred, resulting from an excessive inflow of polluted wastewaters, mainly from a nearby industrial complex. In order to improve the water quality of the lake, the decision was to abandon the original freshwater reservoir scheme and allow seawater exchange. In 2005,

seawater entered into the lake and the reservoir has been converted into a tidal power generation plant.

Table 2. Difference between inland and coastal reservoirs.

	Inland Reservoir	Coastal Reservoir
Dam-site	Limited by topography	Unlimited (inside/outside river mouth)
Dam design	High pressure	Low pressure but with wave/tidal surge
Seepage	By pressure difference	By density difference
Pollutant	Land based	Land-based + seawater
emigrant cost	High	No
Water supply	By gravity	By pump
Water catchment	Small part	Whole catchment

Table 3. Comparison of different proposals to provide 500GL/year

	Inland dams	Desalination	Recycled wastewater	Coastal reservoir
Energy used (in 10^9 kWh)	0	2.0	1.0	0
CO2 emission (in 10^6 ton)	0	3.33	1.67	0
Construction cost (in billion A\$)	11.42	9.28	10	2.8
Maintenance and operation cost	Low	High	High	Low
Ecological Impact	Loss of biodiversity	Low	Low	No impact
Life span	100 years	20 years	20 years	Infinity
Sustainability	permanent damage	remediable damage	sustainable	sustainable

III. A New Era For Water Supply Infrastructure Provision

Existing solutions to alleviate current and future water deficit world-wide include inland dams, wastewater recycling plants, desalination plants and coastal reservoirs. Table 3 compares these different technologies assuming, by way of simplification, that unit costs (energy or gas emission) per GL of water remains constant when it is expanded to 500GL. For example, if one method costs x (in A\$/GL), then $500x$ (in A\$) is needed for this method in Table 3. The comparison clearly indicates that coastal reservoirs are technically feasible, environment-friendly, sustainable and cost effective. Table 4 provides suggestions for future coastal reservoirs around the World.

Table 4. Potential sites for future coastal reservoirs around the World.

Location	Rivers & annual runoff (10^9 m^3)	Specific Conditions
West coast of USA	Hood, Klamath, Eel, Sacramento (21)	River mouths + coastal canal
Egypt	Nile (11)	Using existing lagoons (Mariut, Edku, Burullus...)
Iran, Iraq and Kuwait	Kishop, Tigris and Euphrates (55)	Cross-boundaries management
China: Beijing, Tianjin, Shanghai & Guangzhou	Yellow, Yangtze and Pearl (2000)	Reservoirs on river outlets
Kuala Lumpur and Singapore	Langat, Selangor, Bersama and Johor (150)	Reservoirs on river outlets
Australia: Brisbane, Newcastle & Adelaide	Richmond River, Hunter River, Shoalhaven River, Murray Darling River (?)	Reservoirs on river outlets

IV. Conclusion

After analysing future population growth and water demand we have reviewed existing technological solutions and the following conclusions can be drawn from this study:

- 1) In the next 100 years, the population and water demands may continue to increase significantly;
- 2) Most of people in future will live in coastal and deltaic areas.
- 3) The distribution of existing inland reservoirs will not match the future population distribution;
- 4) Many existing inland reservoirs will be out of service by 2050 due to siltation;
- 5) Coastal reservoirs offer a sustainable, cost-effective and clean solution for futurer water supply.

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