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A paradigm shift from upstream reservoir to downstream/coastal reservoirs management in Malaysia to meet SDG6

A PARADIGM SHIFT FROM UPSTREAM RESERVOIR TO DOWNSTREAM/COASTAL RESERVOIRS MANAGEMENT IN MALAYSIA TO MEET SDG6

BY TAN YEW CHONG, MD NASIR BIN MOHD NOH, LIM SIN POH & MICHEAL TEH JIN CHOONG

Water is the core of sustainable development. Water scarcity affects more than 40% of the global population and this percentage is projected to rise. Malaysia, despite having abundant annual rainfall, experiences water stress in major cities. In order to achieve Sustainable Development Goal 6 (SDG6), the Malaysian government recognizes the need to harvest water using alternative methods. As a result, Malaysia has recently seen a paradigm shift in water resources development works from traditional upstream reservoirs to downstream reservoirs.

In the recent 2018 budget, the Malaysian government listed several water resource development projects emphasizing off-river storage (ORS), a downstream reservoir concept. This concept is gaining popularity after several successful ORS implemented projects, solving both quantity and quality problems that persist in the traditional approaches of Run-Off River Schemes or Regulated Dam systems. It has also been proven to be more economically, socially and environmentally friendly.

Introduction

Malaysian water demands are anticipated to escalate over the next twenty years as the country continues to develop. The population is estimated to increase to 41.5 Million by year 2040, compared to the present population of about 30 Million, (2010 Population Census). This translates to an increase of an 11.5 million population increase over the next 20 years. Figure 1 shows the projected demand used for planning purposes and the water supply system development from 2010 until 2050, (National Water Resources Study 2010). This indicates a need for water supply system development with capacity of about 10,000 million liters per day (MLd) from 2010 to 2030. Considering the present stress on water resources quantity and quality in major cities, this has become one of the key issues for development in Malaysia. Figure 2 shows a map of Malaysia with the location of the major cities. A sustainable solution to water resources development is critical in order to support the increasing water demand.

Evolution of water resources development in Malaysia

Currently, there are three main approaches to raw water abstraction in Malaysia. Surface water is the most extensively developed resource due to the abundance of rainfall in Malaysia, which can be as high as 3310 mm annually at Terengganu (East Coast) and 3640 mm annually at Sarawak (East Malaysia). Figure 3 shows the average annual rainfall at each state in Malaysia. About 81% of raw water resources is directly abstracted from rivers for water treatment plants (WTPs). Flow regulation or direct supply from dams comprises 17%, while the remainder is supported by ground water.

Figure 1. Long term water demand and supply development requirements for Malaysia

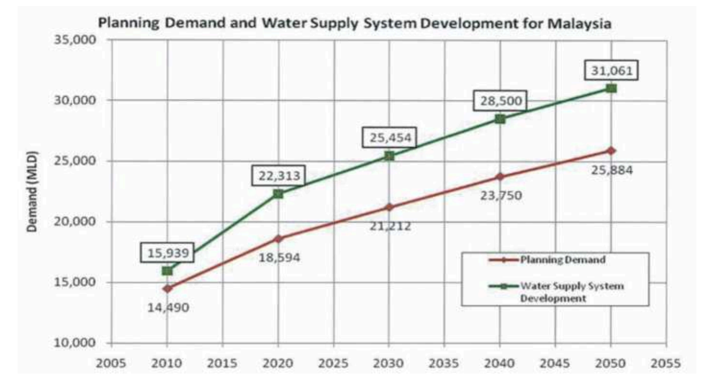
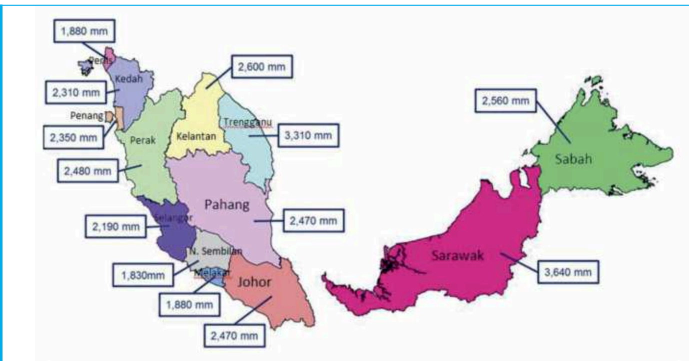


Figure 2. Map of Malaysia with the location of the major cities, which are mostly located near the coast

Figure 3. Malaysian annual rainfall distribution in each state



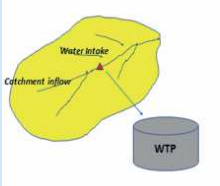
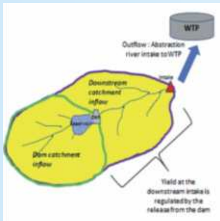
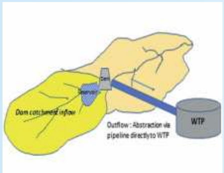
Runoff river schemes are facing both water quantity and quality problems. As more and more intakes are built along rivers to supply developments in the same catchment, drought effects on flow and water levels become more pronounced. Intake yields are thus affected based on land use and development scenarios, and WTPs cease operations when river water quality does not meet required standards. High ammonia content is a frequently reported cause of disruption. WTPs at Cheras Batu 11, Bukit Tampoi, Skudai, Linggi, Sembrong in particular have been struggling with river water pollution problems during the dry season.

Water resources development by means of dam construction has become less favorable since its portrayal as a non-environmentally friendly solution, facing strong objections from the public and NGOs. Dam construction is counterproductive to government efforts and commitments to reduce the carbon footprint of the country. State governments also express concerns about losing huge land areas, which are submerged underwater in the reservoirs formed by dams, as well as about the constraints in developing the dam catchment post-construction.

The uneven distribution of rainfall, particularly in the West Coast urban centers where water demand is concentrated, has led to extensive interstate pipeline water transfers, which are known to suffer significant (as much as 50%) non-revenue water losses over time. The Malaysian Government embarked on the biggest interstate water transfer scheme in 2010, the Pahang-Selangor raw water transfer scheme, which involved transferring of raw water from Sg. Semantan at Pahang through three diversion tunnels measuring 44.6 km in length, to the recently completed Langat 2 water treatment plant at Selangor. Other interstate transfer schemes currently at the planning stage include the Johor-Melaka, Melaka-Negeri Sembilan, and Perak-Selangor water transfer scheme. These transfer schemes need to be reviewed as the energy cost for their operation is high.

In the interest of developing newer and more innovative water resources technologies, the Selangor government initiated the Hybrid Off-River Augmentation System (HORAS) in year 2014. The scheme utilized the abandoned tin mining pits located within the water catchment as storage to store sufficient water for river flow regulation during the dry season. While HORAS managed to increase the water resources yield, there were water quality concerns due to the residuals of heavy metals in the beds of the abandoned tin mining pits.

Table 1. Issues and challenges of the current approaches to water resources development and management

Approach	Challenges
1. Direct river intake 	(i) Low river water levels during drought do not allow water to enter intakes, and result in limited operation or shutdown of WTPs. (ii) Sedimentation at river intakes requires dredging maintenance. (iii) Saline intrusion moves further upstream due to increase in upstream abstraction and the impacts of sea level rise. (iv) River pollution results in poor water quality, especially during dry seasons. Increasingly frequent exceedance of acceptable limits for WTPs, such as high ammonia content, has caused shutdowns. (v) High total suspended solids (TSS) content result in high treatment cost. (vi) Lower river yield due to increase in upstream abstraction and climate change.
2. Regulating Dam 	(i) Reservoir water levels drop during droughts due to the inland location of dams and reduced rainfall. (ii) Active land development and agricultural activities upstream of the dam catchment causes reservoir water quality deterioration. (iii) Illegal encroachment into dam reservoir areas or fringe developments. (iv) As the intake lies on a river, it will still face similar issues as per 1. (i) to (v).
3. Direct Supply Dam 	(i) Same challenges as 2.(i), 2(ii) and 2(iii). (ii) Extremely difficult to mitigate when reservoir water starts to deteriorate.
4. Groundwater 	(i) Development is discouraged due to abundance of available surface runoff. (ii) Geologically dependent, and more suitable for remote areas where water supply networks are not extensive. (iii) Involves high pumping and drilling costs. (iv) Inventory not available.
5. Interstate/Inter catchment Transfer	(i) Involved high capital expenditure (CAPEX) and operating expenses (OPEX). (ii) High pumping costs. (iii) Involves interstate contractual issues.

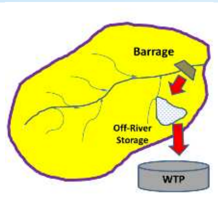
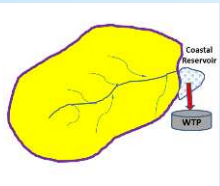
An alternative solution is needed to increase storage capacity without compromising water quality. The downstream/coastal reservoir (CR) concept could serve this purpose very well. The introduction of coastal reservoirs, as promoted by the International Association of Coastal Reservoir Research (IACRR), provides another innovative solution in addition to ORS. While ORS utilizes existing pond storage facilities, the CR concept can be a good alternative if suitable pond sites for ORS have been exhausted. Compared to ORS which utilizes land space, a CR creates additional space which can be potentially utilized not only for water resources, but for other purposes such as waterfront development, power generation, and tourist facilities. CR can be one of the sustainable solutions utilized to solve the water scarcity problems in many coastal cities globally and in Malaysia, thus meeting the SDG 6 set by the United Nations. Table 2 summarizes the issues and challenges of new water management approaches.

Coastal reservoir as an innovative and sustainable solution

Water Availability

Based on the rainfall depths and recipient land surface area in Malaysia, there is an annual rainfall volume of roughly 971 Bm^3. Assuming that 50% of rainfall becomes surface runoff, after evaporation losses and groundwater recharge, the surface runoff volume is approximately 496 billion m^3. The total water demand as of 2020 is about 18.2 Bm^3 for all sectors, only 4% of this volume, See Figure 4.

Table 2. Approach and challenges of policy shifts to downstream water management

Approach	Challenges/Remark
6. Off-River Storage 	(i) Utilizing an existing former mining pit, or a natural pond to store water to regulate flow. This is viable as it utilizes the water storage and does not involve changes in the water surface area. (ii) When former mining pits and natural ponds are exhausted, the construction of new ponds changes parts of the land to water areas. Disadvantages: - (i) May potentially create environmental problems by changing part of the land cover to a water body. (ii) Loss of land areas for land development. (iii) High land acquisition cost. (iv) High excavation and disposal costs (lower if the soil is of sand that can be excavated easily).
7. Downstream/Coastal Reservoir 	(ii) CR configuration is site specific. Requires detailed study and planning before implementation. Specialist input is required. (iii) Main issues in planning, study and design are saline intrusion, water quality and costing.

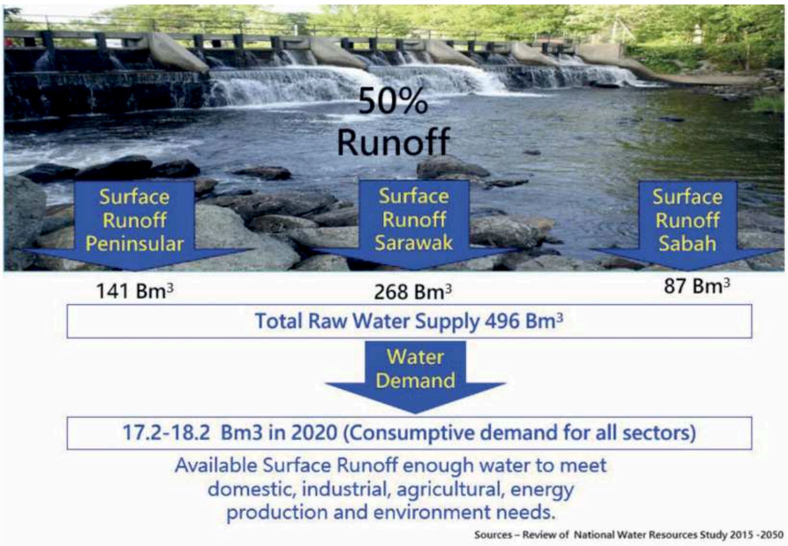


Figure 4. Water availability in Malaysia

As such, Malaysia is not running out of water but water is running out of Malaysia. Downstream/coastal reservoir technology can potentially be a long-term and sustainable solution for water resources in Malaysia. The present river runoff and dam system utilizes about only 3.7% of the available water, with most of the remaining water discharged into the sea. Water shortage is primarily an issue of storage rather than availability.

Why Coastal Reservoir

Instead of using abandoned mining pits, storage can be created downstream or nearshore by utilizing river reservoirs, oxbow lakes, or by constructing reservoirs nearshore (see Table 2). Considering the demand increase of an additional 10,000 ML/d over the next 20 years, with provision of 3 months of storage, this will require a total volume of about 900 Mm^3, which is less 1% of the total runoff available. This suggests that utilization of downstream/coastal reservoirs to store the required water would be sufficient to meet the long term water demand in Malaysia and resolve the water shortage problem during droughts by storing the excess water during wet seasons.

Traditionally, dams and reservoirs are sited in the upper catchment, river intakes are located at the middle catchment to avoid saline intrusion while most demand centers are located in coastal regions. Locating the water supply reservoirs closer to the demand centers downstream, makes it possible to harvest runoff from bigger catchments, with lower environmental flow requirements, and much shorter water distribution networks. In contrast to conventional downstream river intakes, downstream/coastal reservoirs are also protected from salinity intrusion by virtue of their containing structures. Real-time water quality monitoring systems can be used to allow only high quality water to enter these reservoirs. Depending on the demand at each specific locality, water from coastal reservoirs can be utilized for various purposes such as domestic, irrigation or industrial usage.

Downstream/coastal reservoir as sustainable solution to meet SDG 6

The SDGs of the 2030 Agenda for Sustainable Development adopted by the world leaders at the United Nations Sustainable Development Summit in September 2015 cover a broad range of social and economic development issues, including poverty, hunger, health, education, climate change, gender equality, water, sanitation, energy, environment and social justice. They build on the achievements and experiences of the Millennium Development Goals set in year 2000, and focus on 17 goals and 168 targets. The SDGs are a global call to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. SDG 6 aims at ensuring the availability and sustainable management of water and access to sanitation for all. CRs can be one of the sustainable solutions to ensure the availability and sustainability of water supply in Malaysia.

Downstream/coastal reservoirs have limited local environmental impact compared to inland dams and reservoirs. They can be designed to minimize environmental impacts, as demonstrated in the case of Shanghai's QingCaoSha reservoir which took advantage of the existing river alignment and geographical condition (see Figure 5). Located at the river mouth, QingCaoSha reservoir is capable of providing extensive water storage capacity as it is not limited by land area restrictions.

Downstream/coastal reservoirs are designed in such a way that they can be adapted to different locations without blocking off entire waterways as shown in Figure 5 and thus do not disturb environmental flows or require the rerouting of channels.

The retaining structures of a downstream/coastal reservoir can be constructed with concrete, earth or other materials depending on the soil condition. The primary barrier should be high enough to avoid tidal influx and significant wave height, and be able to withstand the forces imparted on the wall by wave and tidal actions. The QingCaoSha reservoir was formed by a dike structure with a depth of about 25 m, which is a comparatively lower risk structure compared to higher conventional dams. The relative construction costs are reduced by utilizing local sand material as part of the dike body.

A freshwater reservoir such as QingCaoSha also creates a man-made wetland making it environmentally and aesthetically friendly. Figure 5 shows the constructed wetland at QingCaoSha Reservoir.

Ensuring Good Water Quality for Coastal Reservoir

Water quality is critical for downstream coastal reservoirs. However, the QingCaoSha Reservoir has successfully addressed this problem through the following measures:

- Installation of series of real time water quality monitoring stations upstream of the inlet structures.
  By doing so, the inlet gate opens only when the water quality at the inlet meets the required water quality standards. Therefore, a system was designed to allow only selective good water quality water to enter the reservoir.
- Construction of a wetland at the upper part of the reservoir intended to function as a natural filtration system to improve the water quality, see Figure 5. The same concept can be adopted for CRs in Malaysia.

In Malaysia, the Putrajaya constructed wetland is one of the success stories of using wetlands to improve the water quality in the Putrajaya Lake. Figure 6 shows the Putrajaya Wetland system, including its conceptual design and site conditions. By having the upstream wetland system, the water quality in the Putrajaya Lake managed to achieve Class IIA water quality, which represents water bodies of good quality.

Malaysian monsoon weather patterns, with seasonal rainfall and monthly distribution as such shown in Figure 7 make for the use of CRs attractive. The highest rainfall typically falls towards the end of the year, while dry seasons last typically about 2 to 3 months during which time water shortages occur. Storage of excess flood water during the wet season can ensure adequate water supply during the next dry spell. The amount of storage required at the downstream/coastal reservoir can be estimated by assuming zero inflow into the reservoir during drought to account for the worst case scenario. Actual storage requirements can be further refined during detailed design and detailed reservoir storage simulations.

Way forward

Malaysia is a water-rich country. Improving water resources management by adopting the new and innovative approach of downstream/coastal reservoirs can potentially increase the utilization of raw water resources. In order for Malaysia to meet its projected water demand in 2050, it is sufficient to increase the utilization of surface

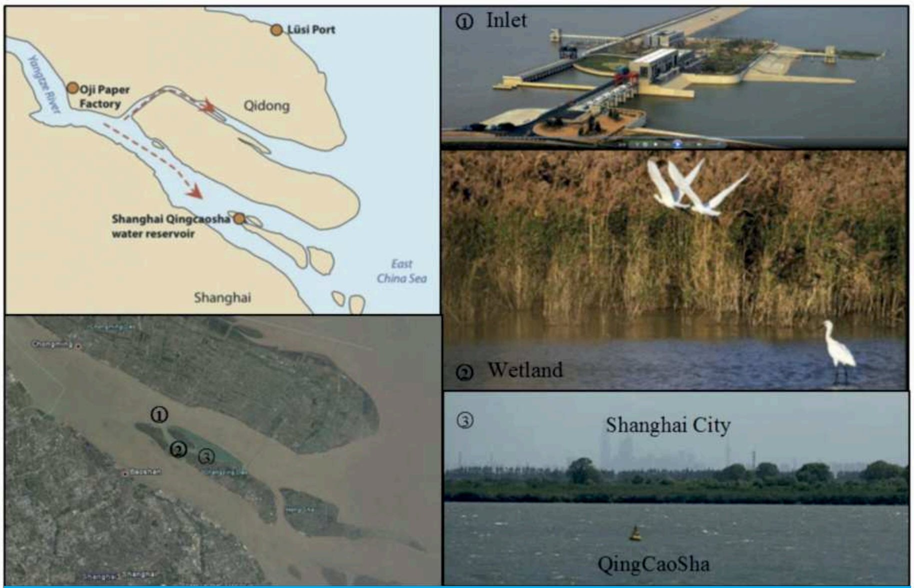


Figure 5. The QingCaoSha reservoir maintains freshwater storage without obstructing waterways

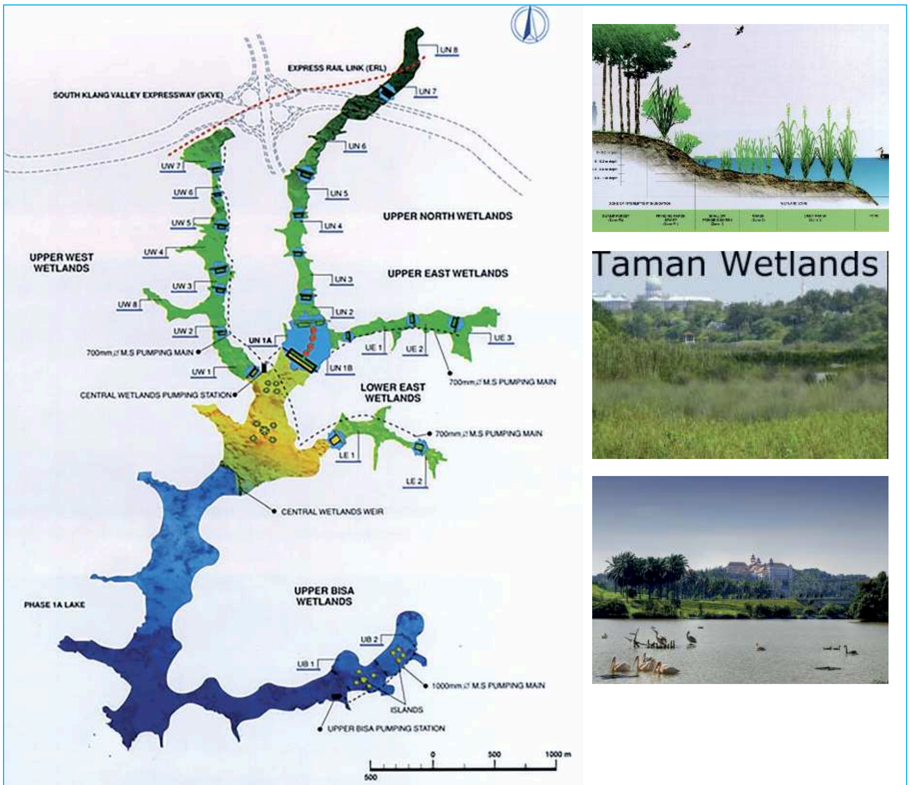


Figure 6. Putrajaya Wetland system with Class IIA water quality at the downstream Putrajaya Lake

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runoff from the present 3.7% to 5%. This potentially would solve the water shortage problem during droughts by storing the excess water during wet seasons. There are many significant advantages to adopting downstream/coastal reservoirs when compared to inland dam reservoirs, or other alternative solutions such as desalination plants, which do not make sense for Malaysia with its abundant raw water resources. The use of CRs is, overall,

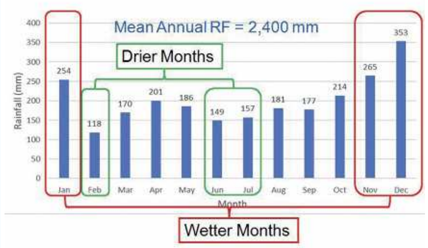

Figure 7. Typical monthly rainfall distribution of Malaysia

a cost-effective, environmentally friendly, green and sustainable solution for the development of water resources in Malaysia.

In order to expedite the implementation of the CR system, it is recommended that the State Government of Malaysia consider the construction of CRs for major coastal cities in the country such as Johor Bahru, Melaka, Penang, Kuantan, Bintulu. Setting CRs as one of the requirement for new onshore, nearshore or reclamation land development at these areas can be one way to incentivize the development of CRs.

CR planning and future operations require significant research in topics such as saline intrusion and water quality. The establishment of CR research centres at local universities is strongly recommended. Support from government agencies in terms of research and study is important to ensure the effective implementation of the CR system in Malaysia for the near future. The CR concept should be incorporated in the National Water Balance System (NAWABS), a newly established programme by Malaysia Government.

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PLWMOS, Putrajaya Lake and Wetland Management & Operational System.

Table 3. Comparison of downstream/coastal reservoirs against conventional dams

Comparison	Dams	Downstream/Coastal Reservoirs
1. Land Acquisition	A large land area must be inundated riparian zones, buffers, waterways, shore	Minimal land acquisition required, using river area, etc.
	Loss of productive land	Potentially creates new land area and enhances surrounding property value with a significant waterbody
2. Environmental impact	Loss of fauna and flora	Create man-made wetlands and new ecosystems
	Loss of green area and thus carbon absorption	Minimum impact
3. Social impact	Creates social issues and face strong objection from locals and public	Less social issues as site selection can be very flexible
4. Heritage/ Historical site	May inundate heritage or historic sites	Can be avoided as site selection is flexible
5. Distance to demand point	- Very far, can be up to hundreds of km - High energy cost for pumping from sources to demand points - More losses due to longer conveyance works	- Site near demand points - Low energy cost - Fewer losses due to much shorter conveyance works
6. Catchment area	- Often sited upstream, thus having smaller catchment areas - During droughts, reservoirs receive no runoff	- Sited downstream, thus having much larger catchment areas - Receive water even during low flows
7. Expandability	Limited and difficult	Can be easily expanded
8. Risk	Pose dambreak risk to downstream population and properties	Low risk
9. Construction	Difficult and slower	Simpler and faster
10. Maintenance cot	Higher	Lower
11. Life span	Limited	Longer