POTENTIAL DEVELOPMENT OF COASTAL RESERVOIR IN MALAYSIA

M.R. Razali[1*], A.F. Hamzah[2], I.K. Othman[3], H.L. Lee[1], N.S. Rosli[4], W.A.H. W.M. Azhary[1], A. Ahmad[1], S.B. Hamzah[1], M.H. Jamal[3]

[1] Coastal & Oceanography Research Centre, National Water Research Institute of Malaysia (NAHRIM), Seri Kembangan, Selangor, Malaysia

E-mail : mrizal@nahrim.gov.my, hllee@nahrim.gov.my, wanhafiz@nahrim.gov.my, saiful@nahrim.gov.my, anizawati@nahrim.gov.my

[2] Hydraulic & Instrumentation Laboratory, National Water Research Institute of Malaysia (NAHRIM), Seri Kembangan, Selangor, Malaysia

E-mail : ahmadfarhan@nahrim.gov.my

[3] Center for Coastal and Offshore Engineering (COEI), School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

E-mail : ilya@utm.my, mhidayat@utm.my

[4] Corporate Planning Division, National Water Research Institute of Malaysia (NAHRIM), Seri Kembangan, Selangor, Malaysia

E-mail : shahida@nahrim.gov.my

Malaysia is a tropical country in Southeast Asia with a consistent trend of annual rainfall and river flow pattern. The vast river networks provide sufficient supply for establishing a coastal reservoir study which in time with the government's goal to explore additional raw water storage and supply options. This paper reviews the current state of knowledge, technical aspects and studies about coastal reservoirs worldwide. Feasibility studies are ongoing with promising findings despite the probability of high cost on the reservoir embankment and water supply. This paper finds out that the embankment design and reservoir operation must cater for the climate change impacts such as rising rea level, variable streamflow discharge during extreme and extended droughts, floods and water quality problems. The paper provides also an evaluation of Malaysian coastal conditions in terms of their potentials for developing coastal reservoirs. Although various technical aspects require further research current state of knowledge and technology are sufficient.

Keywords: coastal reservoir; freshwater; water resources; shoreline; downstream

Introduction on coastal reservoir

The present water resources situation is already experiencing stress in terms of both quantity and quality. Thus, water resources planning is one of the main concerns of the Malaysia Government. A sustainable solution to water resources development is critical to support the increasing water demand due to the population growth and needs demand for local agricultural activities. The concept of coastal reservoir has been adopted and successfully implemented in many countries (Yang et al., 2015) such as India, China, Singapore, North/South Korea, Netherlands and United Kingdom as shown in Table 1. This concept can be similarly implemented in Malaysia, which has an abundance of rainwater but faces water supply shortage.

Table 1: Existing sea based reservoirs around the world with their usage

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

The coastal fresh water reservoir is a new emerging concept of storing flood water in the sea close to the shoreline. Coastal reservoirs can be constructed in shallow waters at appropriate locations close to the river's mouth along with a barrage at one or two ends (Parthasarathy et al., 2018). River /tidal gates and barrages, preferably at the watershed’s lower boundary, especially near the coastal region (Heng et al., 2017). These are barriers between saline and fresh water environments in the coastal or river mouth. The water in the coastal reservoir can be used for drinking, irrigation or industrial usage compared with water from seawater desalination processes. The water quality is similar to storm water or dam water in the inland reservoir, which saves costs

by using natural resources. There is a severe demand-supply mismatch. Though there has been no significant change in Malaysia's rainfall pattern, the number of areas under the dry season most probably is increasing due to climate change. An increase in population is one of the reasons for water scarcity but the inefficient management of the received precipitation stands as the major cause (Heng et al., 2017). Though extreme rainfall events are significantly increasing, there is a spatial non-uniformity in the rainfall events. This makes it difficult to pre-plan large-scale water storage at different locations.

Demand for water keeps on increasing day by day. However, average rainfall has remained constant and it is plentiful. Based on the National Water Resources Study (2000-2050) and the Formulation of National Water Resources Policy, the wet season in Malaysia falls on over three months, starting from November to January and a dry season from February to July, with some regions facing water shortage. We need some planning to manage freshwater from the rainfall during the wet season in these current situations.

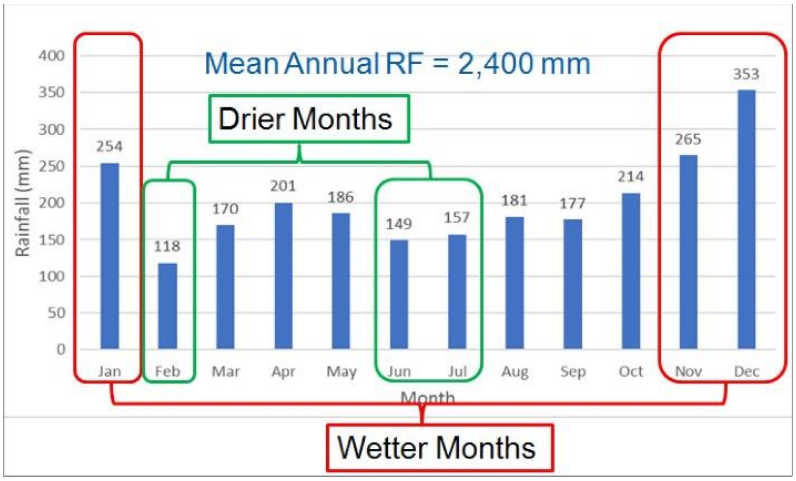

Figure 1: Typical monthly rainfall distribution of Malaysia

The currently available solutions are unable to satisfy people's increasing need for water. As far as rainwater is concerned, one area receives too much rain in the wet seasons, causing floods and excess rainwater to discharge into the sea while receiving a shortage of rainfall in dry seasons. Hence, the solution lies in utilizing or conserving the abundant monsoon water that runs off the ocean. There is a need for a method for developing a sustainable water source for managing rainwater. There is further a need to store floodwater in sea-based reservoirs by building impermeable sea walls and interlinking these reservoirs to transfer water from one place to another. The primary objective of the present paper is to highlight the potential of coastal reservoirs for storing runoff and floodwater.

Application and function

The coastal freshwater reservoir is a new emerging concept of storing floodwater in the sea close to the shoreline. Coastal reservoirs can be constructed in shallow waters at appropriate locations close to the river's mouth, along with a barrage at one or two ends (Parthasarathy et al., 2018). A coastal reservoir with fresh water has been created by constructing the saltwater barrier to increase agricultural activities and facilitate land development (Sitharam et al., 2018). 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 kilometres together in the coastline. Coastal reservoir means building a storage structure near the mouth of a river. In this way, the amount of water that is wasted as runoff can be stored.

Coastal reservoirs do not require land acquisition and do not cause land submergence like inland reservoirs. The construction of a coastal reservoir does not involve many risk factors and disadvantages like relocation in an inland dam construction. Land-based reservoirs like dams have various advantages. They also have their disadvantages. Land acquisition, clearing of forest areas, loss of biodiversity, submergence of lands and forests, diversion works during construction. The comparison between the land-based reservoir and sea-based reservoir (Yang, 2010; Yang et al., 2013) as shown below;

Table 2: Comparison of sea based reservoir vs land based reservoir

Criteria	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 Construction cost	By pumping Low	Mainly by gravity High

Globally, the advantages of coastal reservoirs against conventional dams (Yang et al., 2013) are;

Table 3: The advantages of coastal reservoirs against conventional dams

Comparison	Dam	Coastal Reservoir
Land acquisition	▪ A large land area is required to be inundated ▪ Loss of productive land	▪ Minimum land acquisition, utilizing river reserves, buffers, waterways, shore area etc. ▪ Potentially creates new land area and enhances surrounding property value with a significant water body.
Environmental impact	▪ Loss of fauna and flora ▪ Loss of green area and thus carbon absorption	▪ Minimum or no impact
Social impact	▪ Creates social issues and faces strong objection from locals and public	▪ Less social issues as site selection can be very flexible
Heritage/historical site	▪ Sometimes may inundate heritage or historical site ▪ Very far, up to hundreds of km	▪ Unlikely and can be avoided as site selection is flexible ▪ Very near to demand points
Distance to demand point	▪ High energy cost as it involves booster pumping from source to demand points ▪ More losses due to longer pipe length	▪ Low energy ▪ Less losses due to much shorter pipe length
Catchment area	▪ Often site at upstream, thus having smaller catchment area ▪ During drought, reservoir gathers no rainfall	▪ Sited downstream thus having much larger catchment area ▪ Gathers flow potentially throughout the year
Expandability	▪ Limited and difficult	▪ Can be easily expanded

Risk	▪ Create dam break risk to downstream population and properties	▪ Minimal or no risk
Maintenance cost	▪ higher	▪ lower
construction	▪ slower	▪ faster

By considering the advantages of the sea-based reservoirs in Table 3, the solution lies in storing floodwater in sea-based reservoirs, which are of immense value as they do not submerge lands.

Design concept and issues on coastal reservoir

Currently, the main source of water is river runoff. Surface water is the most extensively developed resource due to the abundance of rainfall in Malaysia as shown in Figure 2.

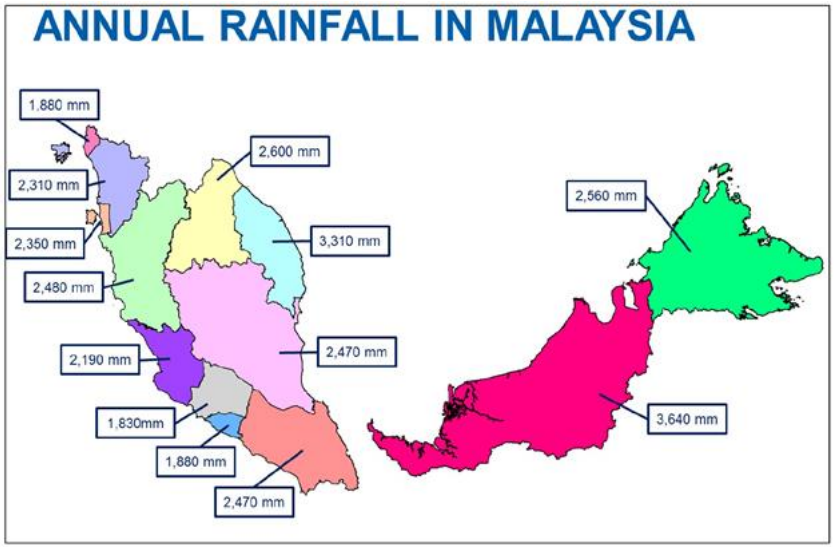

Figure 2: Annual rainfall distribution in Malaysia (The Malaysian National Water Resources study, 2010)

Based on the rainfall depths and recipient land surface areas, there is an annual rainfall volume of roughly 990 billion m3. We can retain and store the surface or river runoff at the downstream or nearshore by utilizing a river reservoir or by constructing the reservoir at the nearshore, as shown in Figure 3. Locating the reservoir close to the demand centre downstream captures a more significant portion of catchment runoff. It alleviates the need for regulating environmental flow from a dam or to other river intakes. In contrast to conventional downstream river intakes, a downstream or coastal reservoir is also protected from salinity intrusion by virtue of its containing structure

and can be selective about receiving a flow of suitable water quality (Teh & Lim, 2017).

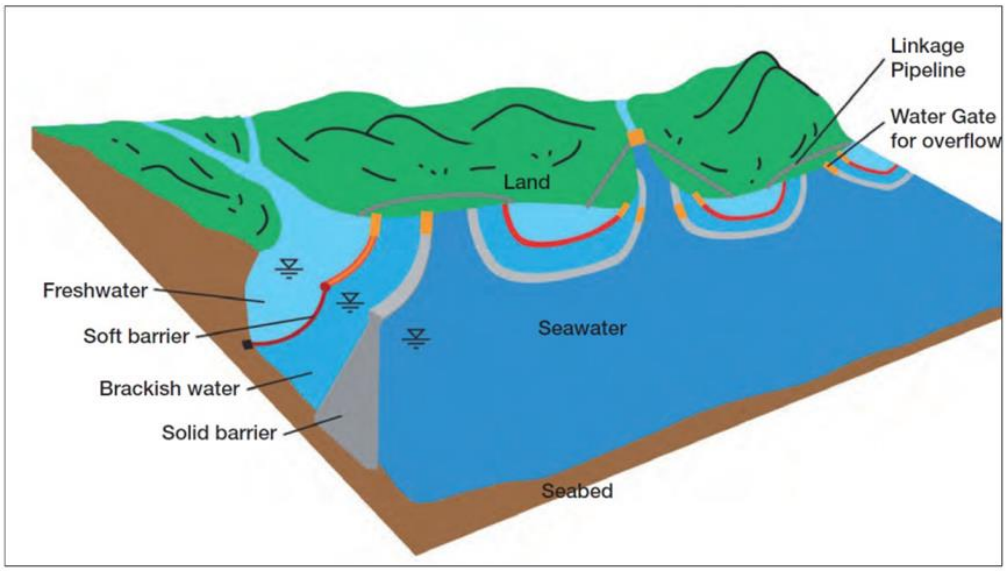

Figure 3: Coastal reservoir concept (Teh & Lim, 2017)

The coastal reservoir also takes advantage of the monsoon pattern in Malaysia, which dominates rainfall patterns and monthly distribution. Storage of excess flood water during wet seasons allows for distribution during the next dry spell. Sizing of the storage required can be estimated by assuming zero inflow into the reservoir during drought (Teh & Lim, 2017), and the actual storage requirements may require detailed design and reservoir storage simulations (Yang, 2016; Yang & Lin, 2011; Yang et al., 2013). Coastal reservoirs can be designed to absorb the flood water shocks and release 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. They are designed with gates so that the excess flood water that is more than the reservoir's capacity can be discharged into the sea. Even inlets and outlets are controlled so that only good-quality water enters the reservoir with very little water stagnation. One can adopt very innovative designs with smart sensor networks to operate the coastal reservoirs efficiently (Sitharam, 2017). A detailed study is needed, even considering salt water intrusion through estuaries, bays and gulfs.

The coastal reservoir can be constructed of concrete, earth or other materials depending on the soil condition and consists of a primary and secondary barrier. The primary barrier should be high enough to avoid tidal flux and significant wave height and withstand the forces imparted on the wall by wave and tidal actions. The secondary barrier is typically a floating barrier with a suspended skirting that extends to the reservoir floor and can be weighted with ballast to fix it in place. This allows a buffer

zone that can be varied in volume to maintain and separate contaminated water from uncontaminated freshwater as shown in Figure 4 (Yang et Al., 2005).

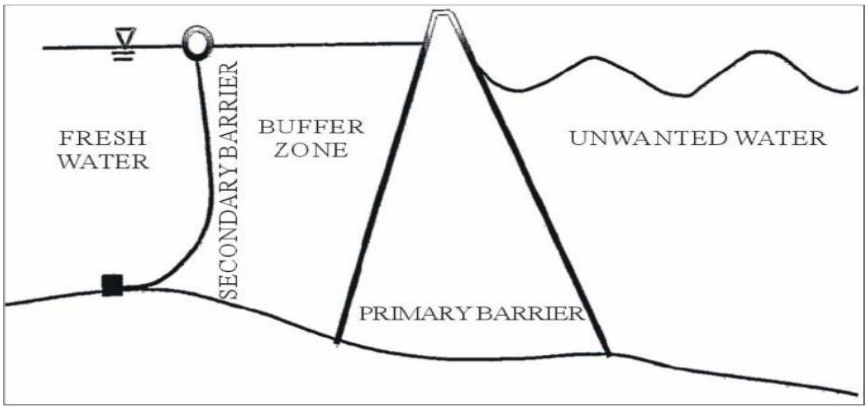

Figure 4: Illustration of buffer zone created by primary and secondary barriers

The sidewalls consist of impermeable sea dikes at one side and the coast bound on the other side (Yang, 2015). These sea dikes with suitable modifications can create coastal reservoirs within the shallow waters of the coast. Sea dikes are classified as a hard engineering shore-based structure used to provide protection and lessen coastal erosion. Sea dikes may also be constructed from various materials, most commonly: geosynthetic tubes, geo-cells, reinforced concrete, boulders, steel, or gabions. Sea dikes are primarily used at exposed coasts, but they are also used at moderately exposed coasts. Commonly, use of sea dikes is presented for the separation of ocean saltwater from the floodwater from rivers stored in coastal reservoirs (Sitharam, 2017; Parthasarathy et al., 2018). A sea dike is an embankment widely used to protect low-lying areas against inundation and acts as a backwater to prevent erosion of the coast and encroachment of the sea. The purpose of a sea dike is to protect areas of human habitation like towns & villages and conservation and leisure activities from the action of tides and waves (Parthasarathy et al., 2018).

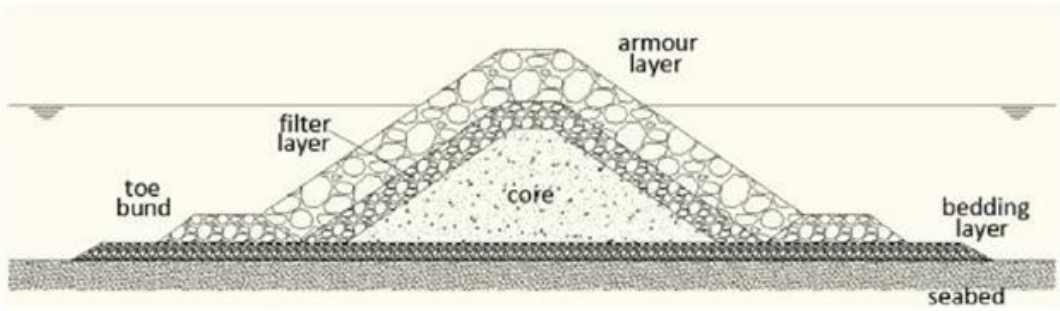

Figure 5: Typical features of sea dike

Further, it prevents coastline erosion and creates calm water in the coastal reservoir area for many activities. Most important function of the dike, in this case, is to separate salt water and freshwater in the coastal reservoir. The dock also allows freshwater fishing and other activities in calm water conditions and it can also provide dock or quay facilities along with support of floating solar panels for energy production (Parthasarathy et al., 2018).

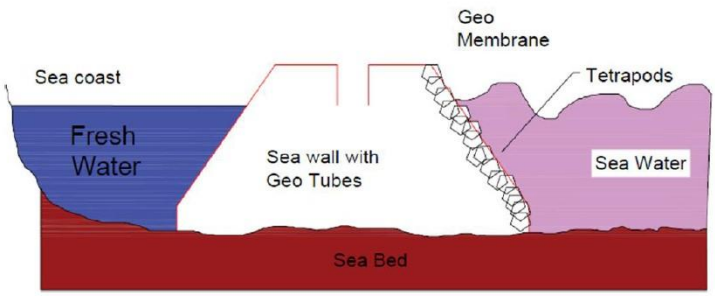

Figure 6: A typical impermeable sea dike for coastal reservoir (Parthasarathy et al., 2018)

Review of the available geotechnical information helped in deriving a generalized geological model as a useful preliminary design profile for a quick check on stability and settlement of the proposed coastal reservoir, which is good enough for the feasibility study stage. However, a site-specific detailed integrated site survey is warranted during detailed project report stage. A detailed integrated site survey comprising of geophysical investigation (bathymetry, side-scan sonar & sub-bottom profile) and geotechnical investigation (boring, in situ testing & laboratory testing) shall be planned to be undertaken to derive the geological model appropriate for the location demarked for the coastal reservoir.

Conclusion

Improving water resources management by adopting the new and innovative approach of a coastal reservoir can potentially increase the utilization of raw water resources. This potentially resolves the water shortage problem during drought by storing the excess water during wet seasons. Overall, the coastal reservoir is a cost-effective, environmentally friendly, green and sustainable solution for raw water resources development in Malaysia.

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