Journal of Civil Engineering, Science and Technology
Volume 8 Issue 1 April 2017

COASTAL AND ESTUARY RESERVOIR: CASE STUDIES FOR JOHOR RIVER BASIN

H.H.Heng[1], W.F.Pan[2], F.L. Siaw[3] and C.P.Hii[4]
[1]Associate Director, SMHB Sdn Bhd.
[2,3]Faculty of Engineering and the Built Environment, SEGi University
[4]Jurutera Adda Sdn Bhd

Date received: 06/01/2017, Date accepted: 13/3/2017
Corresponding author's email: hiicp@adda.com.my

Abstract –This paper presents an alternative water storage concept at lower sea-river interface vis-à-vis the conventional dam/reservoir storage scheme in the upper headwater region of a river basin. Two (2) estuary or coastal reservoir schemes are proposed to meet the future water demand of Johor Bahru and its vicinity. The low flow yields of a 98% reliability (or design 1:50-year return period) for both river schemes are also presented. A hydrological assessment is carried out to correlate the hydrometric variables, i.e. rainfall and streamflow. A long term 54-year streamflow record is adopted as input to the yield calculation. The reliable yields of 98% reliability criteria are in turn estimated based on a water balance or mass conservation. This new paradigmatic shift of reservoir storage location from headwater region to lower estuary/coastal interface can harness sufficient yield to meet the future demand of Johor Bahru and vicinity.

Keywords: coastal reservoir schemes, low flow yields, 98% reliability criteria

---

1.0 INTRODUCTION

Johor river basin is currently the one of the largest southern region raw water sources to various demand centers in Johor and vicinity (see *Figure 1*). It also contributes to some 40% of Singapore water supply under an international agreement until 2061 (1157 Mld or 250 MGD is delivered via pipeline across the Malaysia-Singapore causeway). In the upper Johor river headwater region, Linggiu dam (CA= 208 km^2) is currently in operation to regulate low flow regime at the downstream Johor River Water Works (JRWW, nominal capacity of 1157 Mld) intake and various water treatment plant (WTP) schemes at the upper reach, such as Semangar 1&2, Sungai Johor phase 1, 2, & 3, and other minor run-of-river (ROF) abstraction along the upstream tributaries of Johor River, such as Sayong, Bandar Tenggara, and FELDA schemes. The existing yield available under present hydrological regime is currently assessed at about 1837 Mld. However the existing capacity and abstraction is about 2028 Mld. Thus, a deficit of 191 Mld has to be augmented by exploring new sources.

In addition another source works development on a smaller left bank tributary of Johor river, Seluyut river, was implemented recently with a 76 MCM capacity low height zoned earthfill dam to supply a maximum of 520 Mld to Pegirang Industrial and Petrochemical Complex (PIPC). The scheme is currently in operation at about 260 Mld under first phase development. Another scheme on Layang River comprises both upper and lower Layang dams that can produce about 318 Mld with supplementary transfer from the Johor River scheme upstream under the Johor River 2 scheme. On the left bank of Johor River a smaller Lebam dam scheme could provide 44 Mld under a direct supply reservoir operation to mainly localized townships around Desaru and vicinities. This scheme is the smallest in capacity.

Figure 1 Location map of Johor River basin: subcatchment and tributaries [1]

Despite a total of about 1837 Mld available under Johor, Layang and Lebam schemes (excluding Seluyut which is solely for industrial usage), existing and future demand cannot be met. With ambitious plans in a large scale multipurpose land development in Johor Bahru and the new burgeoning city of Iskandar Puteri, it is imperative to be able to meet future water demand (total of 3030 Mld by 2060) [1] by planning new untapped sources within the river basin before looking further into raw water transfer from other river basins in the long run.

One option is to investigate the possibility of alternative untapped higher flow regime resources which are available in abundance during the Northeastern monsoon where torrential flood waters from upland are flushing down to the estuary en route to the sea. To capture the flows that otherwise go to waste by flowing into the sea, storage of some sort is required. This is normally achieved by the implementation of additional storage facilities other than the upland dams/reservoirs within the river basin. Off-river storage (ORS) facilities are one such option. In fact ORSs now form integrated parts of total water resources planning with many schemes currently in operation. The other option to be considered in the future is coastal and estuary storage [6, 9, 10]. The coastal storage concept appears to be flexible in locating a suitable site. The reclaimed freshwater lake can be formed along the coastline by embankment enclosure.

Estuary and coastal reservoirs can be created by river/tidal gates and barrages preferably at the lower boundary of the watershed especially near the coastal region. These are barriers between saline and fresh water environments in the coastal or river mouth. In both tidal hydropower and water supply functions, they primarily raise the hydraulic head for ease of diversion to the main intake structure at the side of the river bank. There are many water intakes in conjunction with barrage operation at the middle reach of river basins in Malaysia. The main purpose of the barrages or river gates is to limit tidal and saline intrusion to the water intake upstream during an extreme drought season. There are many such schemes throughout Malaysia. Some of the major barrage schemes for providing freshwater water supply and halting saline propagation upstream are located in MUDA river irrigation region, Kuantan waterworks, Sarawak barrage and ship lock, Selangor water supply intake and the Melaka river in Langkawi to mention a few. However, due to their locations in the middle reaches of the river basin, the storages impounded by many of these barrages are relatively insignificant unless they are located in a wider river mouths near the river-sea interface.
There are also navigation barrages/gates for safe and smooth navigable passage of ships and boats, such as the scenic promenade along the Melaka River near the historical town of Malacca. In Chini Lake, a

low head lock was constructed for facilitating smooth boat traffic and navigation to the natural lake upstream.

River or tidal gates at the river mouth interface are more often than not associated with renewable energy by harnessing tidal power. By taking into daily fluctuation in water levels during tide and ebb cycle, and a suitable site for adequate storage facilities in the tidal region, hydropower can be generated almost daily by storage during high tidal intrusion and release during recessing ebb tide [4,5]. However, water supply and hydropower schemes appear to be mutually exclusive since the former requires storage of freshwater and the latter seawater.

For some environmental concerns, some water supply tidal barrages might be able to operate during normal and average runoff regime by allowing limited saline intrusion. This is done so that critical and vulnerable existing fauna habitats experience minimum disturbance due to the imminent operation of the tidal barrage. The anomaly fatefully reaches its apex during the severe drought season where the gates are needed to be fully closed. This essentially cut off the free fauna movement that mimics a pre project/barrage environment. This closure of barrage gates would be operated in order to facilitate smooth diversion of freshwaters into the respectively intake chamber and at the same time, to exclude the diurnal saline intrusion.

1.1 DESCRIPTION OF JOHOR RIVER SYSTEM

The Johor River basin comprises a catchement area of about 2700 km^2 that drains southward to the Straits of Johor. The northern headwater region rises up to the northeast toward the township of Keluang. The upper region of Blument Mountain Range forms the basin boundary to the Endau River basin in the northeast direction. At the upper headwater range two major tributaries, the Sayong and Linggiu Rivers, are located to the west and east respectively. Both tributaries join downstream near Bandar Tenggara before meandering southeast toward the Straits of Johor. Major tributaries, such as Lebam, Layang, Ulu Tiram, Sayong, Linggiu, Seluyut, etc. contribute flows to the basin outlet at the estuary near Tanjung Langat. Less than 1 km southward lies the international boundary demarcation line with Singapore near Tekong Island.

There are currently four (4) reservoir systems in the Johor River basin: (a) Linggiu dam; (b) Lebam dam; (c) upper and lower Layang dams; and (d) Seluyut dam.

1.1.2 LINGGIU DAM (CA= 208 km^2)

The existing Linggiu dam (CA= 208 km$^{\mathbf{2}}$) was built in the middle of 1990's to augment low flow regimes at the downstream Johor River Water Works (JRWW: 1157 Mld capacity) by PUB Singapore and Malaysia Water Department in an international agreement scheme (Ewing and Domondon, 2016). The upstream of the reservoir catchment has a rugged terrain and topography with sharp crest and steeper slopes. The area is above 100 m LSD with the higher mountain ranges reaching about 440 m LSD next to the Endau river basin in the north. The reservoir storage
A low main dam with a full supply level (FSL) of 51 m LSD was constructed across a wider river valley on the main stem of Linggiu River. Four (4) saddle dams were also constructed concurrently on the left abutments of the main dam.
The upland catchment is a designated water catchment area and thus remains mostly untouched by the incessant expansions of oil palm plantations. It is predominantly covered by pristine primary forest. As such the threat of soil erosion and subsequent reservoir sedimentation that plague most of the existing reservoir schemes is minimal.

1.1.3 LEBAM DAM (CA= 20 km^2)

Lebam dam (CA= 20 km^2) is located on the main stem of Lebam River in the upper headwater region of the river basin. It is located in the southeast tip of the State of Johor. It drains 20 km^2 at the dam catchment. The dam was originally constructed in 1979 as a 15 m high zoned earthfill embankment with a slanted clay core to facilitate future raising. Sheet pile cutoff was installed throughout the alluvial layer so that the seepage could be further prolonged. In the 1990's, the dam was raised by 2.5 m to increase the storage to 13.8 MCM from the original 3.3 MCM. The dam raising was originally to receive excess runoff by pump storage scheme in the neighboring Papan river basin. However this was not carried out until recently when the 2015-2016 El Nino event almost drew the reservoir down to its dead storage zone.

1.1.4 LAYANG DAM (CA=31 km^2, upper, and CA= 25 km^2 residual area, lower)

A 20-m high earth fill dam (known as upper Layang dam, CA= 31 km^2) has been constructed across the upper Layang River in the earlier 1980's. The purpose was to provide a storage capacity of about 45 MCM but the arrangement of the ancillary drawoff facility only can draw up to 26 MCM. This was not considered a major operating issue as the bottom outlet can be used to release downstream and in turn the raw waters can then be pumped to the WTP. Associated facilities such as pumps and pipelines/penstocks were provided to deliver raw waters from the dam directly to the WTP immediately downstream. On the other hand to capture the excess runoff of the residual catchment, a 700-m long and 8-m high earth bund (known as lower Layang dam CA= 25 $km^{2)}$ was also constructed at the same period of time with a residual area below the upper Layang dam. The bund overlaid a thick layer of marine clay formation at the river mouth near the confluence. Doing so added about 15 MCM to the overall storage capacity. During an upgrading exercise in the early 1990's, the upper Layang dam (CA= 31 km^2) was equipped with HYDROPLUS fusegate system to store excess runoff during rainy seasons. By increasing the height by 1 m, an additional 5 MCM could be stored behind the labyrinth spillway structure.

The system yields of both upper and lower Layang scheme can provide about 143 Mld of direct raw waters from the reservoirs to the WTP. An additional 175 Mld direct transfer from the Johor River scheme upstream of JRWW intake further increased the reliable yield to 318 Mld.

1.1.5 SELUYUT DAM (CA= 54 km^2)

Seluyut River is one of the major middle reach tributaries of Johor River. It drains about 110 km^2 at the confluence of the Johor and Seluyut rivers. An earthfill dam was recently constructed to provide sole industrial water supply to Pegirang Industrial and Petrochemical Complex (PIPC) in the southern tip of the east coastal region of Johor. The dam drains about half of the river basin toward Johor River. The water supply scheme encompasses two phases with a total capacity of 520 Mld. The scheme transfers major bulks of unregulated runoff from the neighboring Sedili. The dam operation is a pump storage mode such that higher yield could be accomplished by a regulating and direct supply mode of operation.

The zoned earth fill dam (CA= 56 km^2) is located near a 90° bend of Seluyut River about 2.5 km upstream from Kota Tinggi – Rengit River (Federal Road 92) road at the boundary of oil palm plantations and forest reserve. The valley at the dam site is about 100 m wide and the flat plain is located mainly at the left bank. The upstream of the right abutment and other areas are primarily made up of forest cover. The left abutment up to some distance upstream is covered by small to medium scale oil palm plantations.

Seluyut dam (CA= 56 km^2) is a clay core zoned earthfill embankment of 26 m in height, with a crest length of about 100 m built across a narrow valley in the upper river catchment. The Full Supply Level (FSL) and Embankment Crest Level (ECL) are 26.0 m LSD and 30.0 m LSD respectively. The spillway is a chute channel type of 40 m wide and tapering to 20 m further downslope. The corresponding gross storage and inundated surface area at FSL are 72.86 MCM and 9.9 km^2 respectively.

1.2 PROBLEM STATEMENT

The increasing water demand for Johor Bahru and burgeoning townships nearby in the near future requires immediate measures to look beyond conventional approaches in planning feasible source work development within the Johor river basin.

A back-of-the-envelope calculation on water resources availability has suggested maximum limit has been reached in the Johor river basin. Based on an annual average runoff depth of about 1000 mm/year at the JRWW (CA=1561 km^2), the available annual average flow (AAF) is estimated at about 4377 Mld. Based on past studies and experience, the 1:50-year reliable yield that could be inferred is about 50 to 60% of the AAF, translating to some 2138 to 2566 Mld. The existing yields estimated in various past studies were about the same order of magnitude of about 1900 Mld [1, 8]. Therefore, this seems to suggest that the water resources are being fully tapped by conventional means, i.e. regulating reservoir mode. A pump storage transfer scheme was also planned at the same time during the implementation of Linggiu dam (CA= 208 km^2) and JRWW intake scheme. In the original study, the reliable yield can be enhanced from 400 to 500 Mld by a bigger wet weather pumping scheme (2000 Mld in capacity) from one of the neighboring intra river basins.

Notwithstanding, without opting to the original pump refilling scheme, the current shortfall of about 200 Mld (based on a 1:50-year yield reliability estimation) could also be augmented by inter basin transfer scheme according to recent studies [1, 7, 8]. This transfers are proposed from neighboring basins, such as Sedili and/or Endau river basin in the northeast.

The reliable yield of Linggiu dam (CA= 208 km^2) and JRWW was assessed in the earliest studies at about 1850 to 1900 Mld [1, 7, 8]. After taking into account of excess releases that are required for preventing saline intrusion at the JRWW intake (CA= 1561 km^2), the net yield available is reduced to about 1325 Mld.

Other water intakes are located along Johor river reach in between Linggiu dam (CA= 208 km^2) to the downstream JRWW intake (CA= 1561 km^2). These include larger Semangar 1 & 2, and Johor River 1, 2, and 3 schemes, and other minor schemes. Together with the largest supply to Singapore, they add up to a total plant capacity or reliable yield of 2038 Mld. Without the implementation of the JRWW barrage scheme (CA= 1561 km^2) and future schemes, the existing water resources system will be plunged into a much wider water deficit, and shortfalls will be encountered frequently.

Recently, a 90-m long estuary barrage was finally constructed across the Johor River at the JRWW premise primarily for combating saline intrusion during low flow regime. With this in operation, excess compensation releases would not be required for pushing the saline wedge further away from the water intake during drought period. As such, this saving in compensation flows is 400 Mld (100 Mld for compensation past the estuary barrage) and hence is added to the surplus water balance record. Nevertheless, approximately 200 Mld is further required to balance the existing current water deficit of the Johor river system. In addition, it remains inadequate to meet the future increasing water demand in Johor Bahru and vicinity.

This leads to the conventional approach described earlier to augment the deficit by a pump storage operation to Linggiu dam (CA= 208 km^2) from the adjacent Sayong river basin. To take advantage of larger reserve capacity (400 out of 760 MCM), the pump capacity required is about four times, i.e. 2000 Mld of the designated yield to harness an excess of 400 to 500 Mld reliable yield.

Unfortunately, this transfer plan will not be able to proceed to implementation stage in the near future, primarily due to the uncertain status of the potential intake site in Sayong basin. Undoubtedly, the pump refilling scheme that was planned earlier in the master water resources plan [1] is urgently required. However the implementation is expected to meet vehement opposition from various stakeholders. Coupled with the uncertainty in the status of current and future land uses, the chance of development will be bleak at best. Besides, after many years of lack of insight and prudence, the once pristine Sayong river basin is now being transformed into major oil palm plantation and suburban community such that the intake and dam site earmarked earlier are no longer available. In addition, the hydrological regime may have also been altered due to the conversion of land use since the 1990's.

Many options and alternatives are being proposed to enhance the incremental yield of the Johor river system by tapping the unregulated flows in the neighboring Sedili river basin. However, there is no definite roadmap and time line to allow this interbasin transfer of raw waters to materialize in time to meet the increasing water demand in Johor Bahru. Therefore, recourse was taken to investigate other possible solutions.

1.3 COASTAL AND ESTUARY BARRAGE AND RESERVOIR

Recently both coastal and estuary barrages and reservoirs [6, 10], which in effect are a variant of off river storage (ORS), have been gaining popularity in water resources planning communities in Malaysia. They are being considered as a new paradigmatic approach vis-a-vis the conventional upland dam/reservoir options. The latter approach is now far more difficult to bring to full and timely implementation due to various negative environmental issues and fierce opposition from various interest groups and concerned stakeholders. Both forms of estuary and reservoir storage facilities are differentiable distinctly from the conventional upland reservoir that is formed by damming the river valley and then conveying water by gravity via river channel network to WTPs and intakes downstream.

In Malaysia, there are about sixty-five (65) dams/reservoirs of various storage capacities serving mostly domestic and irrigation water supply, hydropower generation, and to a lesser extent, navigation and recreation lake facilities (Prang Besar Dam in the PutraJaya Federal Territories). Monolithic dam structures that are mostly behemoth structures made of concrete, rockfill and earthfill are dominating the upper head water region landscape since the early 20th century. The construction of storage facilities is a necessity rather than choice, by buffering the time domain fluctuation of the hydrometric variables in Malaysia.

1.4 OBJECTIVES AND AIMS

The objectives of this study are twofold; firstly to address the issue of water deficit in the Johor river basin, and secondly to investigate the feasibility of alternative storage facilities vis-à-vis conventional upland storage.

The specific tasks are to firstly confirm the reliable yield of the existing Linggiu dam (CA= 208 km^2) and JRWW scheme. This is vital before proceeding to the next course of activity for securing incremental reliable yields to meet the future demand.

Secondly, reliable yields of estuary barrage schemes are estimated based on the conventional approach of a 98% reliability criteria. Two (2) schemes are tentatively proposed at the river mouths of Johor River and Lebam River respectively (*Figure 2*). The former encompasses almost the entire 2700 km^2 of the Johor river basin. The latter is a smaller tributary draining about 200 km^2 of the residual catchment downstream of the existing Lebam dam (CA= 20 km^2). The residual catchment areas for Johor and Lebam rivers alone can contribute significantly to the reliable water yield if suitable storage space can be found. Additional storage could supply and guarantee adequate yield during periods of drought and also take advantage of excess runoff generated during high flow regimes especially the Northeast monsoon season of November to February. Like artificial lakes created behind estuary barrages, coastal reservoirs can be reclaimed readily. Relative storage volume and surface area of a coastal barrage could be several times larger than both Johor and Lebam river barrages.

Figure 2: Johor River and Lebam River estuary barrage location [1]

2.0 METHODOLOGY

2.1 HYDROLOGICAL ANALYSIS

BAKAJ carried out a comprehensive hydrological analysis to derive monthly inflows of various major river basins [1]. The long-term augmented monthly streamflow records of Johor River at Rantau Panjang streamflow station (CA= 1130 km^2) was used in this study. Co-relationship of rainfall and runoff by a multiple lag-1 regression based on monthly interval was also carried out. The aim of this exercise was to demonstrate that a close co-relationship could be established and subsequent augmentation and extension of the streamflow records using proxy rainfall records could be carried out confidently in the future. Rainfall records are available in abundance and with relatively good quality assurance. A geographically proximate and representative rainfall station at Kota Tinggi was selected to provide a check on the homogeneity and consistency of the streamflow records. More than 50 years of records were available for this analysis.

The concurrent monthly rainfall and runoff records (see *Figure 3*) was divided into both calibration (1963 to 1983) and validation (1983 to 2009) periods. During the calibration periods, precautions were also taken to ensure reasonable low flow regimes are captured. Both observed and predicted flows had consistent statistical properties, such as mean, standard deviation, and skewness. The root mean square of errors (RMSE) for both calibration and validation periods are relatively small, at about 9 and 12 mm/month respectively. The summaries are presented in *Table 5.1* below.

Extending the streamflow records beyond 2009 in the future endeavor could be carried out using the same regression parametric approach as appropriate. *Figure 4* shows the results and comparison of both calibration and validation of rainfall runoff model.

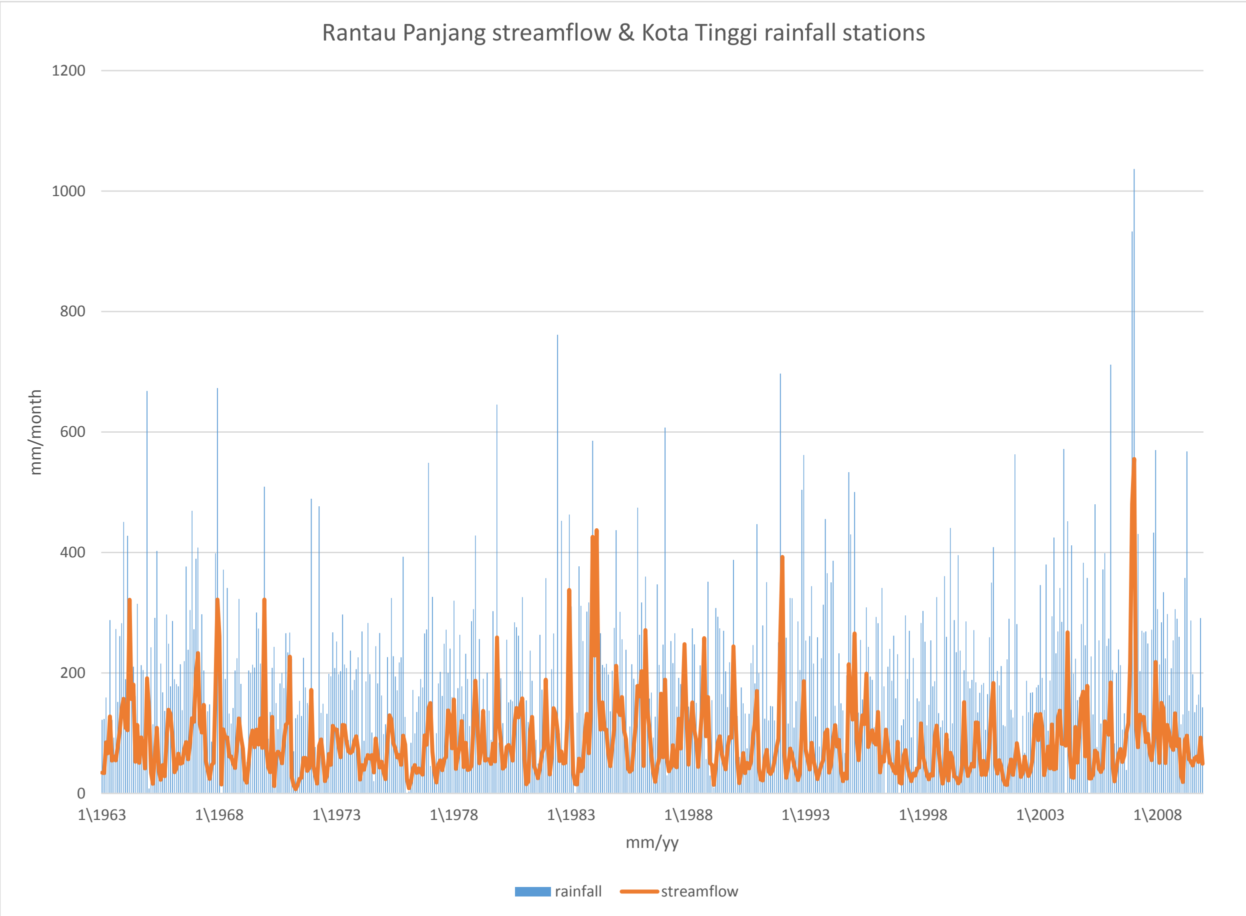


Figure 3: Rainfall and runoff long term record: Rantau Panjang and Kota Tinggi stations

Table 5.1: Statistical properties and comparison during calibration and validation periods

Period of Record	Statistic Parameter	Observed Monthly Flow mm/month	Predicted Monthly Flow mm/month
Calibration 1963 to 1983	MEAN	81	82
	SD	55	41
	SKEW	1.91	0.92
Validation 1984 to 2009	MEAN	86	93
	SD	71	50
	SKEW	2.88	2.22

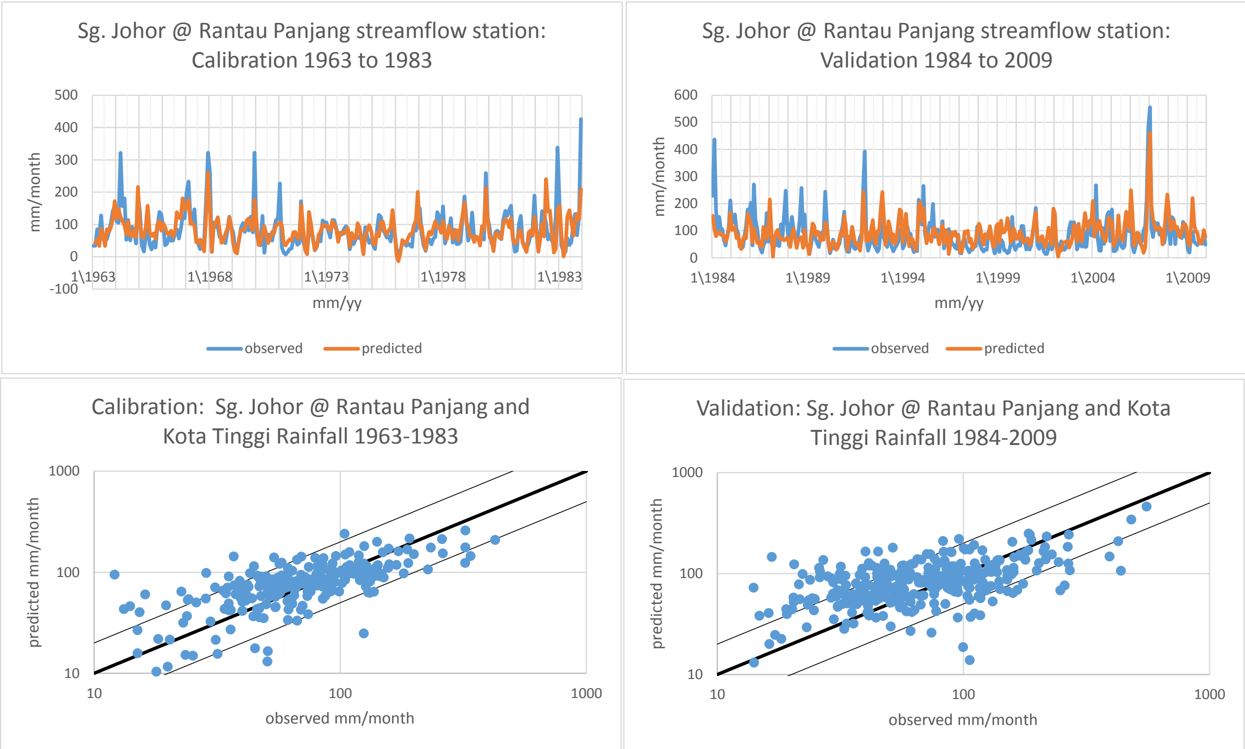


Figure 4: Rainfall runoff calibration and validation: Johor River at Rantau Panjang streamflow station and Kota Tinggi rainfall
(LEFT: Calibration period 1963 to 1983; Right: Validation period 1984 to 2009)

2.2 YIELD ANALYSIS

The prerequisite of a water resources assessment undertaking is to select an appropriate design low flow (magnitude and duration in the form of a representative flow sequence of the most severe drought) in the river basin for a prior assigned probability of occurrence or in short, return period or average recurrence interval (ARI). In essence, both terms are synonymous in water resources engineering. The water resource analysis and methodology adopted in the yield estimation is based on hydrological assessment of the prevailing low flow regime in a river basin.

The techniques utilize probability and/or statistics to infer the lowest possible flow regime in a river basin. Among the numerous probability distribution functions (PDFs), only a few are commonly used. These probability distributions are Extreme value family (EV), Gamma, and Normal, and their respective transformations and variants by logarithmic means.

Prior to this, the updated historical hydrometric information is collated, processed, and translated quantitatively into a series of estimated discharges (design flow) that are presumably to be representative of the low flow regime of a pre-determined probability of non-exceedance. The available design flow should be able to sustain a flow continuously throughout the drought period of a given probability of occurrence or return period.

This represents a 2% chance of failure (opposite of 98% reliability) to meet the target supply by a probability analysis of hydrometric records and water balance calculation. This is the industrial standard in Malaysia's water sector. In turn, this probable magnitude of low flow will be available and subsequently adopted in the estimation of reliable yield and its corresponding storage requirement in a reservoir analysis by scrutinizing the behavior of the reservoir drawdown curves.

The term *Yield* has been loosely defined in Malaysia. In the context of this study, "yield" is defined as the steady supply of water that is withdrawn and/or diverted and/or abstracted directly from rivers/lakes without the provision of some form of storage facility. Further, run-of-river yield is abstracted directly from the reservoir and delivered to the water treatment plant by a long haul pipeline system, in the case of a direct supply reservoir system, and is transferred by pumping/diversion at the intakes downstream or other river basins nearby normally via pipeline/penstock system, and, in case of shortfall, the remaining water sources are then augmented partially by the reservoir releases to make up the deficit, in the case of a regulating reservoir and pump storage system. These two conventional modes of operation assume that the reservoir releases are made by gravity since the dam/reservoirs are constructed in the high elevation headwater region of the river basin.

The final stage of reservoir development is the pump storage scheme by refilling the reservoir using inter or intra-basin water during higher flow regimes similar to ORS schemes. Under a specific design configuration, yield can be increased tremendously at a tradeoff of higher pump cost and other incurring appurtenance capital investment.

The continuous supply of raw waters to the respective WTPs could be maintained throughout the design drought period i.e. 1:50-year drought or 2% drought that is normally adopted in Malaysia. This conventional approach of yield assessment based on Twort's text [2] has been the design standard for water resources planning activities in the earlier years of independence circa 1960's. By analogy, a similar approach could be used in the estimation of reliable yield for the proposed estuary barrage scheme.

2.3 YIELD CALCULATION AND ASSESSMENT

A conventional water balance calculation was carried out using the estuary or coastal storage as control volume unit. All inflows and outflows are accounted for in the mass balance calculation. The outflows are the useful withdrawal analogous to yield, and evaporation from the surface water. Other losses such as seepage is assumed negligible, since a diligently filter engineering design is able to cut off underwater embankment seepage. It is also anticipated that there will be no releases from the proposed estuarine or coastal reservoir with the exception of overspills during significant storm events. The freeboard and the spillway capacity shall be adequate to buffer a design risk of a 100-year return period or higher as deemed appropriate. Higher surface water evaporation is also expected, so a constant 6 mm/day of evaporation rate is allowed in the water balance calculation. On the other hand, the inflows into the estuary and coastal reservoir water body are abundant especially during monsoon months. By intercepting excess runoff generated during these intervening months, the reliable yield can be estimated according to the water balance calculation.

The yield estimation calculation also assumes that the existing upstream water resources system, such as Linggiu dam JRWW scheme, Upper and Lower Layang dam scheme, Seluyut-Sedili Besar intake scheme (PIPC) are excluded from this calculation. The design reliability criterion is based on 98% probability of occurrence of hydrological regime that can satisfactorily fulfill the water demand. The percentage of the success to supply adequate water for the specific demand is tabulated and expressed as a percentage of the total months of the simulation period, i.e. 564 months. The long term streamflow record of Rantau Panjang streamflow station is adopted. It is assumed that the reservoir is full at the beginning of the calculation time step.

3.0 RESULTS AND ANALYSIS

3.1 EXISTING LINGGIU AND JRWW INTAKE

The earlier yield estimation was carried out during the feasibility study in early 1985 under a joint Singapore and Johor Development Committee on Johor River Water Resources. Subsequently, studies using longer hydrometric information confirmed the reliable yield on the same order of magnitude [1, 7]. Linggiu dam (CA= 208 km^2) and related appurtenances such as an intake gallery were built to harness some gross yield of about 1837 Mld, including 512 Mld required to be released during severe low flow events. Over the years new assessment using latest hydrometric information reported about the same order of magnitude in yield. This study basically concurs with the yield calculation by earlier studies. The reliable yield of 1902 Mls with a corresponding storage of 370 MCM out of 760 MCM at FSL could be harnessed under a 98% reliability criterion. Similar to past studies, it would take about 5 to 6 years once the reservoir is drawn down to its bottom. This suggests overstressing of the reservoir system without augmentation by pump storage scheme from Sayong basin. *Figure 5* shows the reservoir drawdown curve with longer recovery period for Linggiu dam-JRWW regulation system.

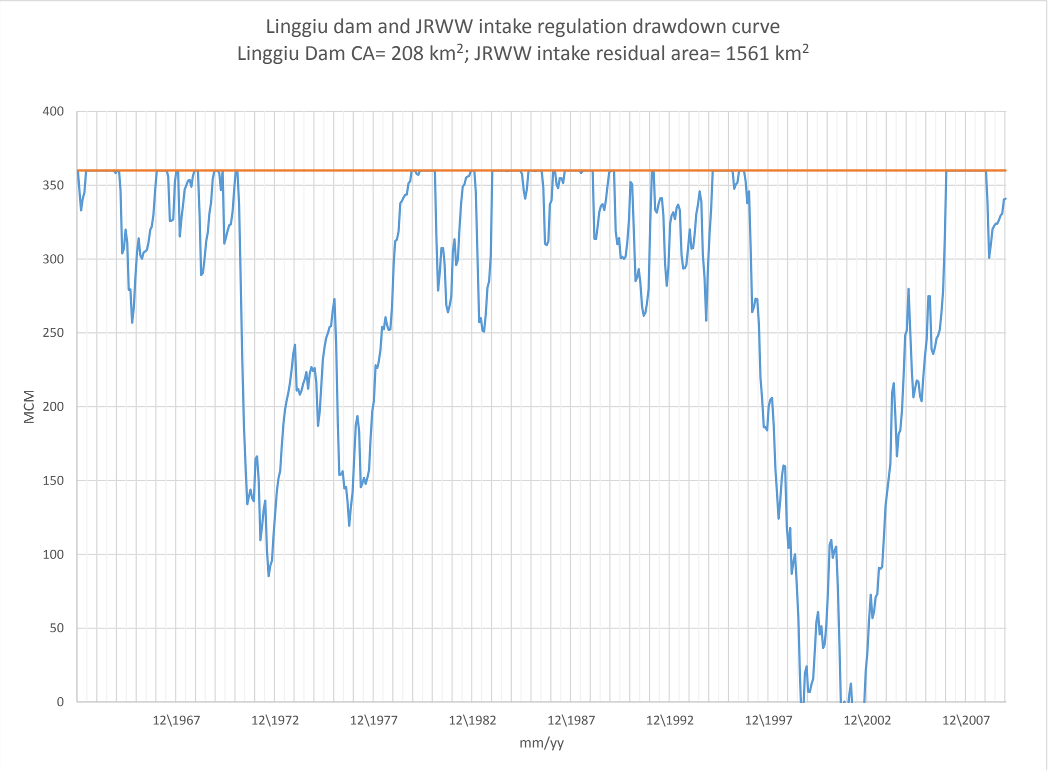


Figure 5: Reservoir drawdown curve: Linggiu dam 1963 to 2009

3.2 LEBAM ESTUARY

The proposed barrage is located at the river month of the confluence. The residual catchment area at this node is about 200 km^2. There is a sizable residual catchment area downstream of the existing Lebam dam (CA= 20 km^2). The lake surface area as measured by planimeter is about 7 km^2. An average of 2m depth could result in massive storage of about 14 MCM. By intuition and past experience, a 1005 mm/year of average runoff depth can contribute about 550 Mld of average flow or 1:2-year return period. By extrapolating to 1:50-year return period, it can readily translate into 250 Mld of gross yield with a sizable estuarine storage capacity of about 35 MCM.

This calculation assumes exclusion of the Lebam dam (CA= 20 km^2) system that continues to operate in a direct supply reservoir mode. Therefore the potential yield that could be harnessed by the estuary reservoir is considered as incremental yield. The existing Lebam dam (CA= 20 km^2) scheme can harness about 44 Mld with a pump refilling operation from an intake located on Papan river nearby.

The enclosure of the Lebam estuary is about 7 km^2 in surface area with a depth of about 5 m on average [5]. As such a maximum of 35 MCM can be deduced. The lake area evaporation is relatively higher due to its shallow water body. In the yield calculation, 6 mm/day of net evaporation is assumed as loss in the water balance calculation.

The Lebam estuary barrage reservoir drawdown shows a relatively short critical period whereby the reservoir is experiencing continuous drawdown but with a shorter recovery period. *Figure 6* shows the results of long term reservoir drawdown behavior for 25 MCM storage capacity with a corresponding yield of about 223 Mld. Several scenario runs using variable estuary storage were carried out for preparation of yield storage relationship.

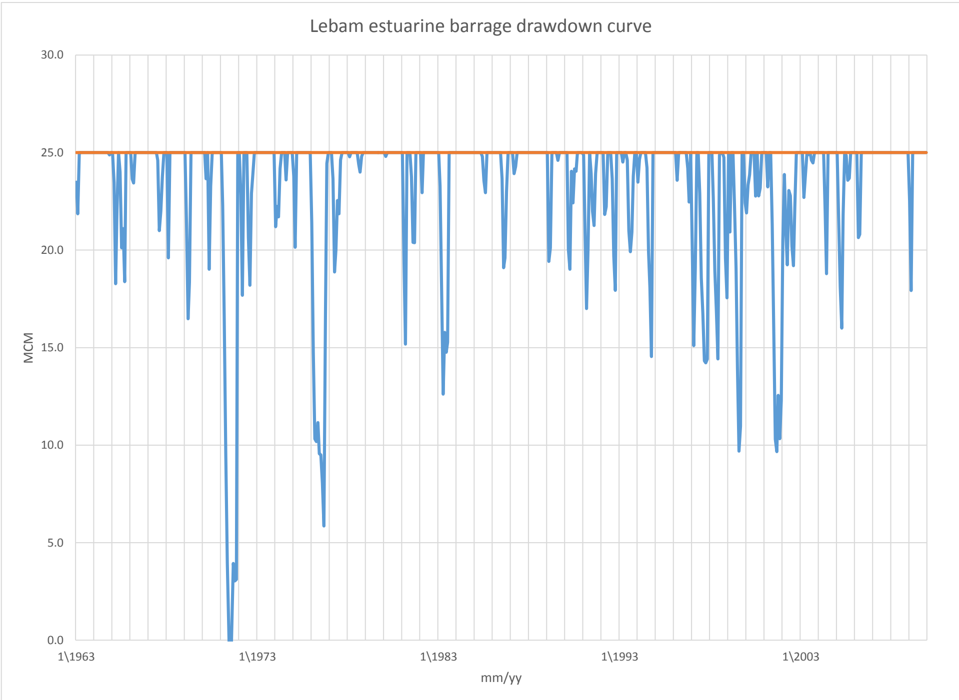


Figure 6 Proposed Lebam estuary barrage drawdown curve

7.3 JOHOR ESTUARY

Compared to Lebam estuary, Johor River at the edge of river month outlet is much bigger in both area and depth. The total catchment area draining at the outlet is about 2700 km^2, with a potential lake surface of about 60 km^2. A sizable residual catchment area downstream of JRWW, i.e. 1039 km^2, can be a major contributory area for runoff into the estuary reservoir. Depending on the size of the estuary storage available the net yield that could be harnessed ranges from 721 Mld to 1180 Mld. Thus the incremental yield in *Figure 7* shows the results of the long term reservoir drawdown behavior of 40 MCM storage volume.

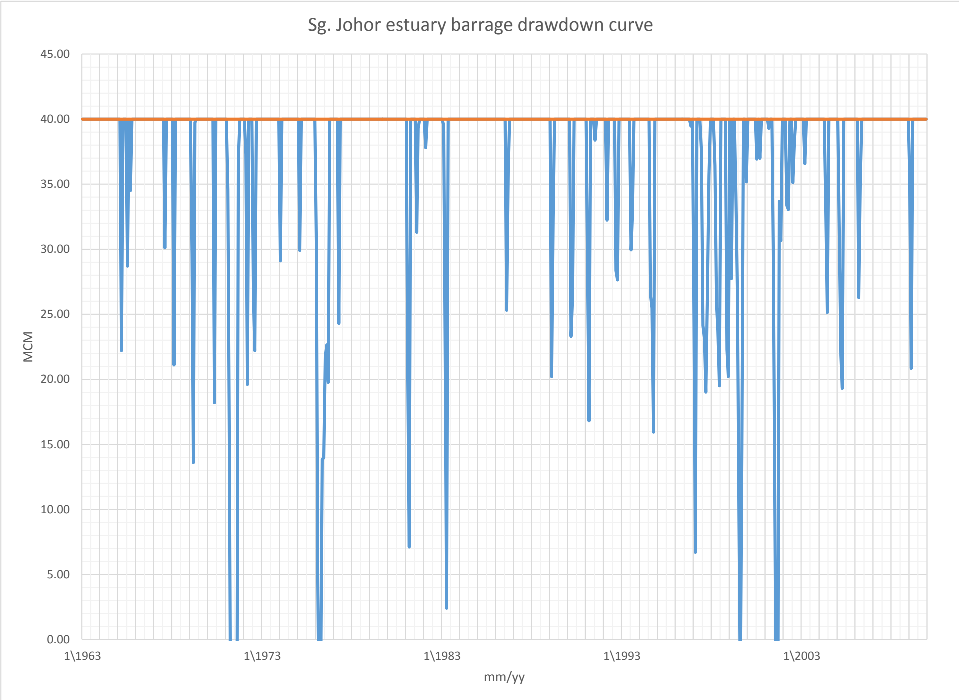


Figure 7 Proposed Johor River estuary barrage drawdown curve

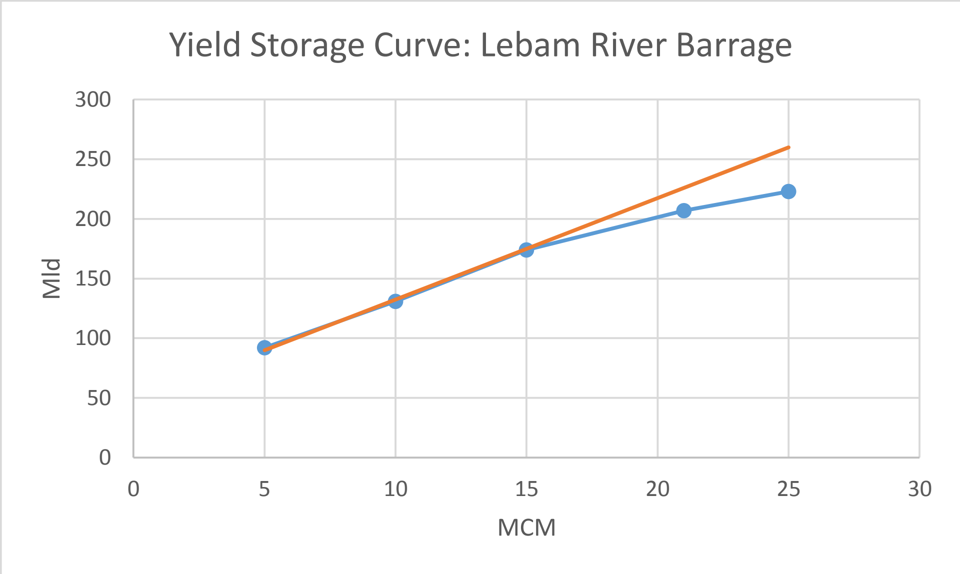
7.4 SUMMARY OF YIELD STORAGE RELATIONSHIP

Yield storage relationships were prepared for both Lebam and Johor estuary barrage schemes. The purpose of these yield storage curves is to ascertain the hydrological limit of the estuary barrage scheme by identifying the maximum upper marginal return. This alludes to the fact that further increasing the storage capacity may not necessarily result in an equivalent increment in reliable yield. In other words, the catchment runoff has reached its maximum discharge limit. It would be futile to increase the storage capacity for sole purpose of yield enhancement and maximization. In addition, it is reckoned that the maximum yield is dependent crucially on the supply side or the runoff that could be generated by the residual downstream catchment area. Beyond this critical point, any bigger incremental storage capacity of both schemes would not result in significant linear yield as can be observed in the plateaus in both respective curves for Lebam and Johor river barrage scheme (see *Figure 8*). *Table 7.1* shows the results of yields and corresponding storage capacities required.

Table 7.1: Yield storage relationship: Johor River and Lebam River barrages

Johor River Barrage		Lebam River Barrage	
MCM	Yield Mld	MCM	Yield Mld
40	721	5	92
60	918	10	131
80	1016	15	174
100	1115	21	207
120	1180	25	223

The limits of development that can be deduced for both Lebam and Johor reservoir barrage are at 15 MCM and 60 MCM respectively. These correspond to about 174 Mld and 918 Mld.



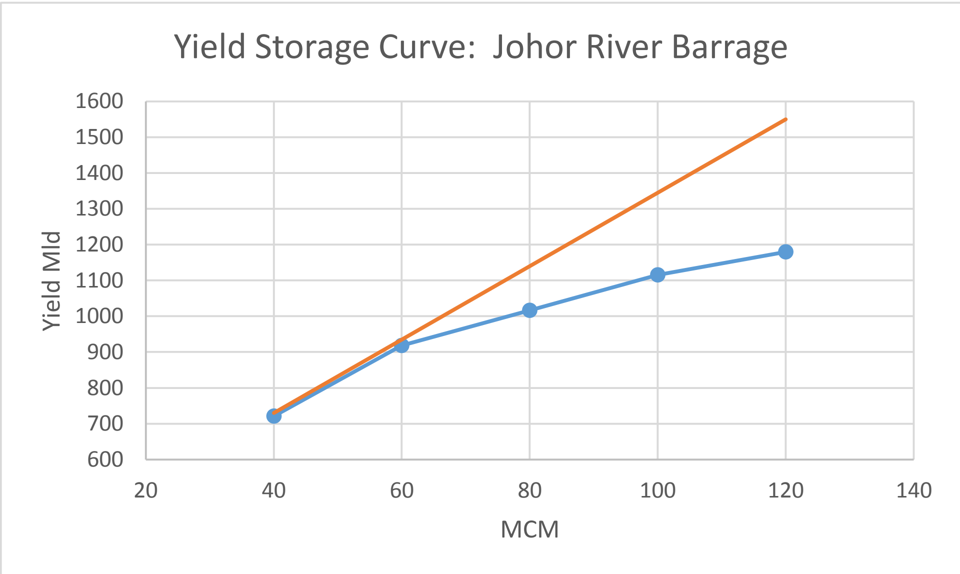


Figure 8 Yield storage curves: Johor River barrage and Lebam River barrage

4.0 CONCLUSION

Due to varying spatial and temporal domains/patterns in the hydrometric parameter distribution of rainfall and runoff in the state of Johor, storage facilities in the form of dam/reservoir schemes and of recent, off river storage (ORS) are required. They are vital for harnessing extra reliable yield of 1:50-year return period or to secure 98% reliability for the existing water resources system.

The reliable yield obtained by Lebam estuary reservoir scheme alone is approximately in the range of about 200 Mld with an effective storage ranging from 21 to 25 MCM. This extra yield enables the deficit augmentation of the existing Linggiu dam-JRWW scheme, but still fell short to meet the growing water needs of Johor and its vicinity in the near future. The second case study is to move the estuary barrage further down to the Johor River.

By relocating the barrage further downstream to the river mouth of Johor river near the international boundary, the incremental yields could possibly be increased four- or five-fold due to a relatively larger residual river catchment downstream of Linggiu dam (CA= 208 km^2). Moreover, the estimated yields range from 721 Mld to 1180 Mld, depending on the storage capacity of the estuary barrage. These maximum yields are constrained by the hydrological limit, as well as geographical and hydrological factors.

In conclusion, this new paradigmatic shift of the reservoir storage location from the headwaters to the lower estuary/coastal interfaces can equally serve the purpose of harnessing sufficient yield to meet the future demand of Johor Bahru and vicinity. The limits of development that can be deduced for both Lebam and Johor reservoir barrage are at 15 MCM and 60 MCM respectively. These correspond to about 174 Mld and 918 Mld.

REFERENCES

[1] BAKAJ (2016). *Johor Water Resources Study 2010-2060*. BAKAJ (Water Regulating Authority, Johor), Government of Johor, Malaysia.

[2] Brandt, MJ., KM. Johnson, AJ. Elphinston, and DD. Ratnayaka (2016). *Twort's Water Supply*. 7th edition, Elsevier, Netherland, (2016).

[3] Ewing, J. and K. Domondon (2016). *Drought, Pollution and Johor's Growing Water Needs.* ISEAS Yusof Ishak Institute: Pespectives, 47, 1-10 (2016).

[4] Lee, KS. and LY. Seng (2009). *Simulation Studies on the Electrical Power Potential Harnessed by Tidal Current Turbines*. J. Energy and Environment, 1(1), pp 18-23 (2009).

[5] Lee, WK. and Nur Hidayah AZ (2015). *Lagrangian Investigation on the Compound Effects of Reclamation and Proposed Tidal Barrage to the Environmental Flow.* J. Kejuruteraan, 27, 71-80 (2015).

[6] Liu. JL, SQ. Yang, and CB. Jiang (2013). *Coastal Reservoirs Strategy for Water Resources Development: A Review of Future Trend*. J. Water Resource Protection. 5, 336-342 (2013).

[7] NWRS (2011). *National Water Resources Review 2000 to 2050.* Jabatan Pengairan and Saliran, and Economic Planning Unit, Government of Malaysia.

[8] SAJ (1994). *Study on Comprehensive Water Resources Planning and Development in the State of Johor*, Final Report, Economic Planning Unit, Government of Malaysia.

[9] Sidani, A. and M. Youssef (2016). *Potential Freshwater Supply in Developing Countries*. Int. I. Adv. Agriculture Environ. Eng. 3(1) 20-27 (2016).

[10] Yang SQ (2015), *Coastal Reservoir: A Technology that may Dominate Future Water Supply*. J. Water Resource Hydraulic Eng. 4, 388-397.

APPENDIX: ABBREVIATIONS

CA, Catchment Area
MCM, Million Cubic Meter
ROF, Run-of-River
Mld, Million Liter per Day
MGD, Million Gallon per Day
LSD, Land Survey Datum
FSL, Full Supply Level
ECL, Embankment Crest Level
PDF, Probable Density Function
ARI, Average Recurrence Interval
AAF, Annual Average Flow
EV, Extreme Value Distribution
WTP, Water Treatment Plant
JRWW, Johor River Water Works
NWRS, National Water Resources Study
JWRS, Johor Water Resources Study
PIPC, Pegirang Industrial and Petrochemical Complex
ORS, Off River Storage
RMSE, Root Mean Square of Error