*Proceedings of the 1st International Conference on Civil Engineering for Sustainable Development (ICCESD-2012), 23~24 March 2012, KUET, Khulna, Bangladesh (ISBN: 978-984-33-4247-8)*

# A SCENARIO-BASED HOLISTIC APPROACH FOR MULTIPURPOSE RESERVOIR OPERATION CONSIDERING EFR, IRRIGATION AND HYDROPOWER DEMAND: A CASE STUDY

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## ABSTRACT

*This study presents the detailed outline of a holistic methodology for the operation of a multipurpose reservoir located in the Hari Rod River basin of Afghanistan by taking account of all the existing water demands (e.g. environmental flow requirement (EFR) by the riverine ecosystem, irrigation and hydropower generation) in the basin. At first, environmental flows required for healthy ecosystem in the Hari Rod River have been assessed for establishing suitable assessment techniques to be applicable for basin-wide management of the aquatic flora and fauna. Available historical data and information forms the basis of this study. Four well-established hydrologic-based approaches (e.g. Tessman method, 7Q10 method, Flow Duration Curve method, Indicators of Hydrologic Alteration method) and one hydraulic-based approach (e.g. Wetted Perimeter method) are applied to quantify the required environmental flows by the wholesome riverine environment. For proper allocation of environmental flows along with the water requirements from other existing demands (i.e. irrigation and hydropower generation) in the Hari Rod River basin, a reservoir simulation model for the planned Salma dam reservoir in the basin is developed within the modeling framework of HEC-ResSim software. In the developed reservoir model, water demand from irrigation sector and hydropower generation followed by the estimated additional EFR demand is incorporated in the priority rule of water allocation. Three different alternative scenarios are generated from the developed reservoir model to determine the potential impacts of allocating water for existing demands along with additional demand by EFR. At the same time, different mitigation options are suggested to alleviate those impacts completely. Using simulation technique, a new conservation zone rule curve was developed to decrease the water shortages for irrigation caused by the estimated additional demand due to water allocation for EFR in the Hari Rod River. However, irrigation water requirement is calculated by using the CropWat software. This study estimates that the water shortages can be considerably alleviated by improving the existing irrigation efficiency in the basin. This study finally provides another impact mitigation solution, by which water shortages can be reduced substantially by a little improvement of the existing irrigation efficiency in the basin.*

**Keywords:** *Afghanistan, CropWat, EFR, Hari Rod River Basin, HEC-ResSim, Salma Dam Reservoir*

## 1. INTRODUCTION

Worldwide, increasing concerns over environmental sustainability and preserving ecosystems and their associated functions in rivers persuade the water managers to recognize the requirement of allocating specific amount of flow in the rivers with an acceptable level of quality which is often regarded as the environmental flow requirement (EFR) (Song et al., 2007; Tharme, 2003). EFR is the amount of water from the original river flow regime that needs to flow all the way to the outlet into the sea in order to maintain the specified valued features of the river ecosystem in a desirable condition (Pal et al., 2009; Song et al., 2007; Gordon et al., 2004; Smakhtin et al., 2004). Through mimicking the natural flow regime, EFR ensures the provisions of ecosystem goods and services that rivers provide on which humanity rely in numerous ways. Therefore, such flow is recommended in all the regulated rivers across the world to preserve the ecosystems integrity to a certain desired level (Mullick et al., 2010). Hari Rod River basin in Afghanistan has unstable environment where the ecological flora and fauna have been affected due to the years of civil war, severe drought, growing pressure on available water by irrigation sector within the catchments, and lack of attention to environmental impacts. The primary focus of water resources development projects in Afghanistan particularly in the Hari Rod River basin are irrigation and hydropower. Until now, less attention was paid on low flow and EFR downstream of these developments. However, with increasing consciousness and approbation for maintaining environmental sustainability, the apprehension to minimize adverse environmental impacts of such plans is getting much more attention nowadays. Legislation in Afghanistan emphasizes that its water resources management plan should reserve satisfactory amount of water to be required for environmental purposes in all its river basins. It is also highlighted in the water sector strategy of the country's national development plan. However, little is known about the existing environmental and natural circumstances of the river basins in Afghanistan except few reports identifying the possible management plans and development options (Qureshi, 2002). This has led to the recognition that environmental flow (EF) in each of the river basins in Afghanistan along with the potential impacts need to be quantified.

The available discharge in the Hari Rod River, which is mainly used for irrigation purpose within the basin, is deficit in the summer and excess in the spring. Accordingly, water user groups in the basin have adjusted their agricultural and irrigation water supplies to natural flow regime available in the river. However, there is a lack of distribution efficiency in the major sub-branches of the river caused by corrupted canal diversions, alignments and devastated bifurcations (Qureshi, 2002). Considering the present state of water management, establishment of environmental water requirement for the river is regarded as an essential part prior to any water resources development projects in the Hari Rod River basin of Afghanistan. The primary intention of EF management in the basin must be the anticipation of further degradation that may arise from flow regulation intensification, particularly loss of high flood flows, reduced base flows and further alteration in the seasonal inflows. Aiming to contribute to the research gap, this paper presents detailed outline of a holistic methodology for the operation of a multipurpose reservoir (proposed Salma dam) located in the Hari Rod River basin of Afghanistan, where natural flora and fauna have been affected due to the years of civil war, severe drought and growing pressure on the available water resources due to growing water demands by different competing sectors. Appropriate allocation and sustainable exploitation of the water resources while preserving riverine ecosystem integrity are essential in all the river basins of Afghanistan. Therefore, the present study attempts to estimate EFR required for the healthy ecosystem and quantify holistically the potential impacts of EFR allocation along with other water demands for irrigation and hydropower production on the proposed Salma dam reservoir operation and the irrigation water management policy in the Hari Rod River basin of Afghanistan.

## 2. MATERIALS AND METHODS

### 2.1 Description of the Hari Rod River Basin

Hari Rod River basin is located in the western part of Afghanistan (Figure 1), which is relatively more developed than other basins in that area of the country. Upper part of the basin is located in the Ghor province with an altitude of 4000 m above mean sea level (MSL), and lower part is in the Herat province having an altitude of 750 m above MSL. The basin area covers about 3.9 Mha with a population of 0.46 million. Hari Rod River has narrow valley with gravely bed in the upper reach, in the middle reach the river valley becomes wide, flat and meanders greatly below the village Obeh. In the lower reaches, the river forms part of the international boundary between Afghanistan and Iran, and finally flow into Turkmenistan where it disappears into the sand in downstream. The basin is characterized by distinguished climate with cold winters with snowfall and rainfall increasing with rising altitude. Usually, the rainfall occurs in spring and the mean annual precipitation is 236 mm with uneven spatial distribution. Runoff comes from snowmelt, which is the major source of surface water and groundwater of the basin spanning over only two months (February/March to April). High flood flows from March to June, and very low flows from August to February are observed in the Hari Rod River. Discharge from the river is mainly used for irrigation purpose in the basin and farmers have adapted their agricultural activities to this flow regime. In addition, groundwater is used as a supplement to satisfy the irrigation demand throughout the year. The proposed Salma dam reservoir is located near the Chisht-e-Sharif in Herat province, which is planned as a multi-purpose reservoir to support the irrigation activities and power generation. Now the project is under active construction that is to be utilized in the upcoming years. Significant lacking is observed in the consideration of environmental and ecological aspects as an important issue for this water resources development project (proposed Salma dam reservoir) in the basin. The reservoir should meet the current irrigation demand of 42,000 ha, and generate an installed capacity of 42 MW early after construction, and expected to meet the future irrigation demand for 74,859 ha after the development of full irrigation facilities in the basin. Considering the present status of demand and reservoir storage, no shortage is observed for irrigation when reservoir is operating only for hydropower generation. Even the EFR is satisfied in this base condition (Atef, 2009). Thus, the present study attempts to evaluate the future impacts, when the irrigation demand is expected to be very high, and the reservoir will be operated in the interest of both irrigation and hydropower demand along with the EFR demand.

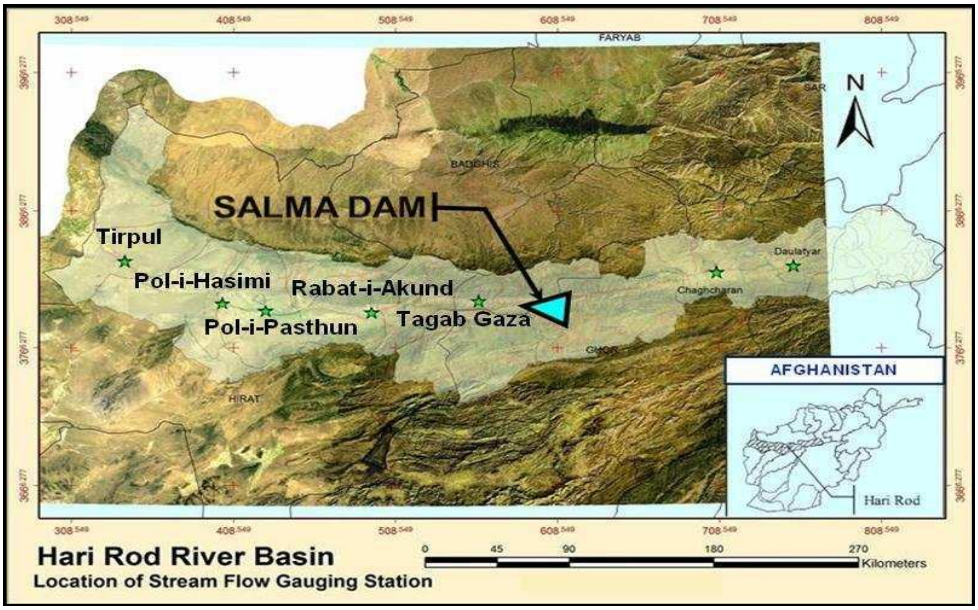


Figure 1: The Hari Rod River basin in Afghanistan

## 2.2 Estimation of EFR in the Hari Rod River

The framework of methodology (Figure 2) mainly consists of two subsets of activities: quantifying EFR and establishing reservoir operation policy by applying simulation technique to mitigate the impacts of incorporating EFR on other demands. The methodology followed in this study is largely based on observed data and information in the field. Recent (2001-2008) and past (1961-1980) available daily discharge and river cross-section data at Tagab Gaza monitoring station (located immediately downstream of the reservoir) in the Hari Rod river were collected. However, there has not been any observation made during 1981 to 2000 due to several years of conflict. The primary hydrological data (river cross-section) is collected from field survey at different points of the Hari Rod River and the secondary hydrological data is taken from irrigation department and FAO-EIRP office in Herat city of Afghanistan. Simple approaches have been adopted to analyze the available hydrological data. Well-known hydrological methods (e.g. Tessman or modified Tennant method, Flow duration curve (FDC) method, 7Q10 method, Indicators of hydrologic alteration (IHA) method considering Range of Variability Analysis (RVA) technique) and hydraulic method (e.g. Wetted perimeter method) were applied to quantify EFR. A detail review of all these approaches can be found in Smakhtin and Anputhas (2006).

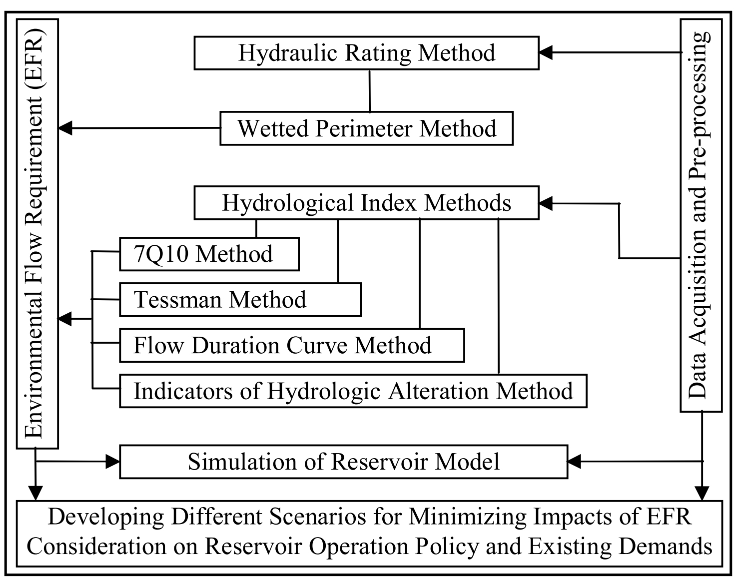


Figure 2: The methodological framework followed in the present study

### 2.3 Simulation of the Reservoir System

HEC-ResSim, a public domain model for reservoir system simulation developed by U.S. Army Corps of Engineers (USACE), is used for simulating the reservoir (proposed Salma dam reservoir) operation in the Hari Rod River basin. It utilizes reservoir inflow hydrographs, river networks and physical properties of the dam including reservoir characteristics and rule curves as necessary input data. Reservoir release, storage, spillway flow and downstream hydrographs are the model output (USACE, 2007). In the developed reservoir model, water is firstly allocated only for irrigation and hydropower demand and then EFR demand is considered along with them in sequence on a priority basis. The reservoir should meet the current irrigation demand of 42000 ha, and generate an installed capacity of 42 MW early after construction, and expected to meet the future irrigation demand for 74859 ha after development of irrigation facilities. Considering the present status of demand and storage behind the Salma dam, no shortage of water is observed for irrigation when reservoir is operating only for hydropower generation. Even EFR is also satisfied in this base condition. Thus, the present study attempts to evaluate the future impact when irrigation demand is expected to be very high, and reservoir will be operated in the interest of both irrigation and hydropower demand along with EFR demand. Twenty years daily time series data is used in the reservoir model for the simulation. Another publicly available decision support tool for computing crop water and irrigation water requirements, CropWat model, which is developed by the Food and Agricultural Organization (FAO) of the United Nations (UN), is used to estimate irrigation water requirement (IWR) for each crop (FAO, 1999) in the Herat province located downstream of reservoir. Mean monthly temperature, rainfall, evaporation and soil data are used to estimate net irrigation depth for each crop. Finally, three different scenarios are generated to evaluate the potential impacts of allocating EFR on the irrigation and hydropower demands and possible solutions are suggested to mitigate those impacts in the Hari Rod River basin of Afghanistan.

## 3. RESULTS AND DISCUSSIONS

### 3.1 EFR in the Hari Rod River

Major tributaries of the Hari Rod River are located in the lower part of the Hari Rod River basin. Thus, the present study considered the monitoring stations for the EFR assessment, which are located in the lower part of the basin. Tagab Gaza and Tirpul station is located in the middle and lower part of the basin respectively along with three more gauging stations (Pol-i-Pashtun, Pol-i-Hashimi and Rabat-i-Akhund) along the river between these two stations (Figure 1). Since the Tagab Gaza monitoring station is located immediately downstream of the Salma dam reservoir, EFR estimation in that station is more justified to be incorporated into the reservoir simulation. Estimated EFR in the Tagab Gaza monitoring station is presented in Figure 3.

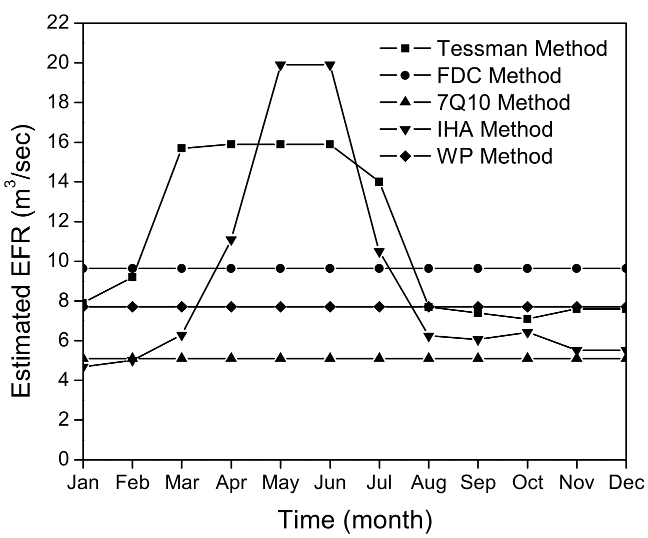


Figure 3: Estimated EFR in the Tagab Gaza monitoring station in the Hari Rod River

Tessman method (also called modified Tennant) uses a percentage of the average annual flow (AAF) for a monthly basis rather than two season (six months period) basis (Tennant method) to estimate EFR, which refers that this method considers seasonal variability. For selecting monthly minimum flow (MMF), this method applies the criteria such as: if average monthly flows (AMF) < 40% of average annual flow (AAF), then MMF equals the AMF, if AMF > 40% of AAF, then MMF equals 40% of AAF, and if 40% of AMF > 40% of AAF, then MMF equals 40% of AAF respectively. In FDC method, generally $Q_{95}$ (% of time when a specified river discharge is equalled or exceeded 95% during the period of calculating EFR) and $Q_{90}$ (% of time when a specified river discharge is equalled or exceeded 90% during the period of calculating EFR) indexes are used to define EFR, which indicate the extreme low flow conditions to protect the riverine ecosystem integrity. 7-day low flow with a 10-year return period is calculated to quantify EFR in 7Q10 method using 20 years daily discharge data. This method depicts that the resulted minimum stream flow should be maintained to protect river water quality. IHA method quantifies the hydrologic sequential variability of flow regime into 32 biological parameters based on statistical evaluation. These parameters were calculated from 20 years daily flow records (1961-1980) at Tagab Gaza station by considering single period analysis with nonparametric statistics using IHA (Indicators of Hydrologic Alteration) public domain software released by Nature Conservancy, USA. The result shows that there is an alteration between the recent (1971-1980) time and pre-settlement (1962-1970) time periods. The monthly low flow median in pre-impact period is 6.4 $m^3/s$, which is decreased to 5.3 $m^3/s$ in the post-impact period. There is significant variation in April and May median flows of post-impact period compared to pre-impact period. The results from IHA analysis are used for range of variability analysis (RVA) technique and the management targets are identified. First, the management rules are developed based on the estimated ecological information needed to accomplish the target flows on annual basis. Then, biological goals are identified to achieve through generated flow regime. The nonparametric monthly low flow analysis for Tagab Gaza monitoring station indicates that the post-impact period peak discharge and volume increased by 4% compared to pre-impact period. The positive and negative changes in water conditions are increased from the pre-impact period than the post-impact period. In the wetted perimeter method, EFR is estimated as 7.71 $m^3/s$. Since it is difficult to estimate the point of maximum curvature in the wetted perimeter to discharge relationship, EFR is obtained based on the breaks in slope of wetted perimeter verses discharge diagram.

Tessman method generally provides good results at initial level of analysis. However, most often it gives unexpected under or over estimated results due to seasonal condition. EFR by this method is considerably higher than other methods for dry season. Estimated EFR by 7Q10, wetted perimeter and FDC approach are lower than that estimated by Tessman method. FDC method concise the entire flow distributions and shows the range of extreme low flow conditions in the river and can be used for primary screening of the complete series of river discharges from low flow to flood events. However, when the question of seasonal variability arises, 7Q10, FDC and wetted perimeter methods cannot fully include EFR in the management level. It is recognized that intra and inter-annual variability of hydrologic regimes are needed to maintain and restore the natural forms and functions of the aquatic ecosystems. Thus, IHA considering RVA is the most sophisticated form of hydrological index approaches to quantify EFR in a basin. It generally considers the magnitude, duration and frequency of the flow regime. Therefore, the estimated EFR using IHA method is incorporated into the reservoir simulation model to define its EFR demand during simulation of the developed reservoir model and evaluating the impacts of EFR on the other existing demands.

### 3.2 Scenario-based Simulation of the Salma Dam Reservoir

The proposed multi-purpose Salma dam reservoir is under construction in the Hari Rod River basin of Afghanistan, which is to be used for water supply and power generation. The hydrological characteristics of Salma dam reservoir is given below:

- Reservoir gross capacity is 633 $Mm^3$
- Live storage capacity is 514 $Mm^3$
- Average annual inflow to the river is 1217 $Mm^3$
- Existing average annual irrigation demand for 42000 ha of land is estimated as 246.57 $Mm^3$
- Average annual irrigation demand in future for 75000 ha of land is estimated as 587.62 $Mm^3$
- Average annual evaporation is estimated as 12.2 $Mm^3$
- Average annual gross EFR demand is calculated as 277.73 $Mm^3$
- Specific EFR demand (four months) is found as 45.67 $Mm^3$

In the proposed project, EFR demand has not been considered which is essential for the riverine ecosystem integrity and its long run sustainability. Therefore, there must be shortages of water for the existing irrigation and hydropower demand, if allocation for EFR demand is ensured in the basin. Thus, different alternative scenarios based on with or without EFR demand following the existing or proposed guide curve, were generated to evaluate the possible impacts of incorporating EFR into the reservoir operation policy as well as on the other existing (i.e. irrigation and hydropower) demands. All the scenarios from the simulation are described step-by-step in the following sections.

### *3.2.1 Scenario I: Simulation of Reservoir System without Considering EFR*

The intention of developing this scenario at base conditions is to elaborate the dam status immediately after construction as the reservoir is being designed to operate for both the irrigation and hydropower demand. The simulation shows that there are about 18 fully satisfied years for irrigation within 20 years of analysis. The irrigation shortage is observed in only two dry years in specific months of dry season. Available water in the reservoir is very less in the year 1966 and from 1970 to 1971. Thus, these two periods are highlighted in this study. The shortage of water due to the irrigation demand from August to November in 1971 is presented in Figure 4 and in that year total annual inflow is 281 $Mm^3$. However, the average annual irrigation demand and average annual inflow (AAI) to the river are found as 584 $Mm^3$ and 1217 $Mm^3$, respectively. This implies that there is no shortage of irrigation demand for the normal and wet years, if the reservoir inflow is equal to or more than the estimated AAI. The result also shows that total reservoir inflow in year 1969 to 1970 was almost same as year 1971, but there was no shortage observed. This is due to the reservoir storage during 1968 to 1969 period when the reservoir inflow is more than the estimated average inflow. Thus, besides meeting the demands, much water was stored in the reservoir and released in the year 1970 and no shortage was observed in that specific year. Observation shows that annual inflow in 1971 was extremely low which is almost equal to one-fifth of AAI. Although there was less inflow into the reservoir, simulation result shows that a total of 8 months (January to end of July) was fully satisfied. However, irrigation demand was 20% satisfied in August and 45% in September and October, assuming that there is no irrigation demand in December. The average energy simulated is reasonably more than the proposed capacity (186.13 MWh). This is because the release for both hydropower and irrigation is from the hydropower gate in order to optimize both demands. It is considered as a key reference to compare with the other scenarios.

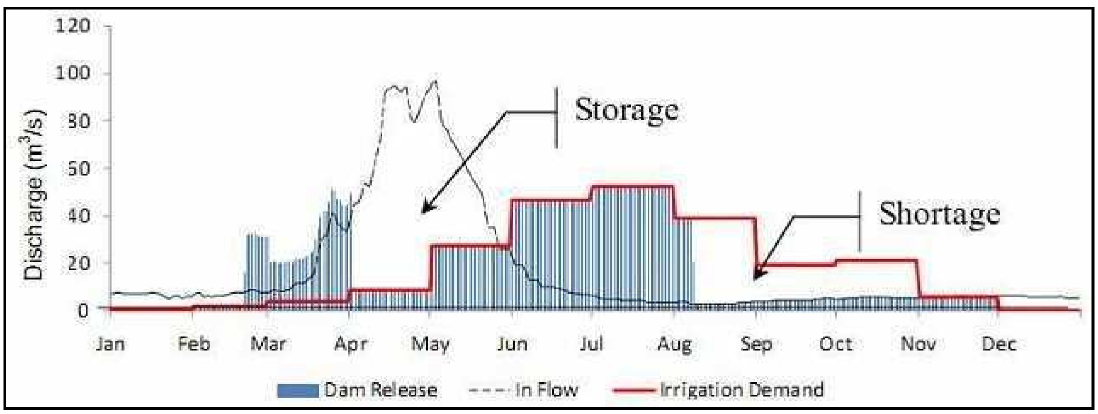


Figure 4: Dam release without considering EFR to satisfy irrigation demand in 1971

### *3.2.2 Scenario II: Simulation of Reservoir System by Considering EFR*

This scenario evaluates the impacts of incorporating the EFR demand into reservoir operation policy on the other existing demands. The simulation shows that there will be more stress on the irrigation demand in the specific dry years and this is presented in Figure 5.

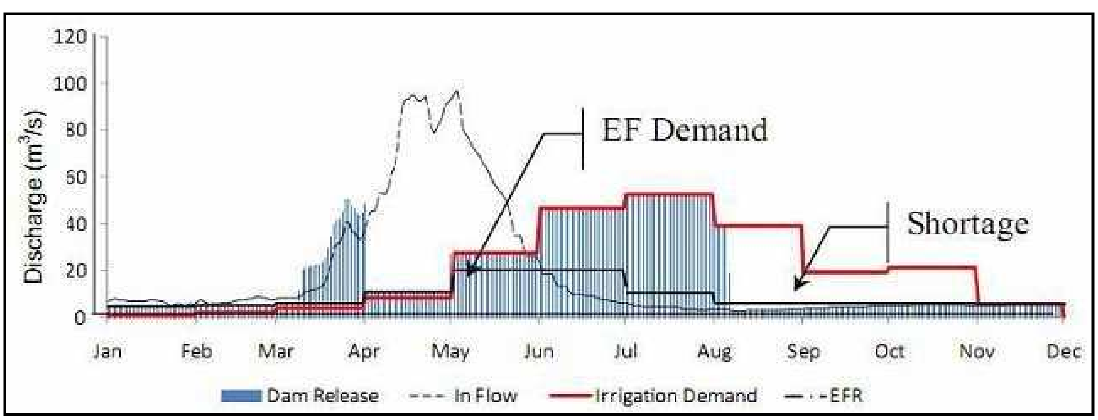


Figure 5: Shortage of irrigation demand in 1971 by considering EFR into reservoir operation

The release decision to satisfy EFR was defined as a minimum reservoir supply on monthly basis. This decision is made in reservoir hydropower gate and then EFR is evaluated downstream of the river at Tirpul station. River routing is carried out to calibrate the estimated EFR downstream of the river. Table 1 presents the impacts of EFR consideration into reservoir operation policy on irrigation demand. The shortage is observed from August to October of 1966, 1970 and 1971 out of 19 years of simulation. In addition, severe shortage is noticed in 1971, where reservoir is meeting almost 22% of the irrigation demand. However, much difference is not observed in average energy produced after adding EFR demand in reservoir simulation model.

Table 1: Shortage to satisfy irrigation demand due to EFR consideration for scenario II

| Description | Aug-66 | Sep-66 | Oct-66 | Sep-70 | Oct-70 | Aug-71 | Sep-71 | Oct-71 |
|---|---|---|---|---|---|---|---|---|
| Release ($Mm^3$) | 59.0 | 14.2 | 16.5 | 37.7 | 19.2 | 24.3 | 10.9 | 13.9 |
| Irrig. Demand ($Mm^3$) | 101.0 | 49.8 | 54.8 | 49.8 | 54.8 | 101.0 | 49.8 | 54.8 |
| % Satisfied | 58 | 29 | 30 | 76 | 35 | 24 | 22 | 25 |

### *3.2.3 Scenario III: Developing Proposed Guide Curve for Reservoir Operation*

The simulation result shows that the reservoir starts to storing water from April to end of June, and releases water from July to next April. This release decision is applicable for the normal and wet years, where the dam inflow is almost equal to AAI. It may also help to decrease the possibility of flooding while meeting the irrigation demand and generating the hydropower energy. However, during drought period, when the dam inflow is almost one-fifth of AAI, the existing conservation zone will not fully meet the irrigation, hydropower and EFR demands. Thus, a new conservation zone is developed based on dry year circumstances to meet all three demands during dry years. The result also shows that no shortage will be observed after applying the new rule curve of conservation zone, which is presented in Figure 6.

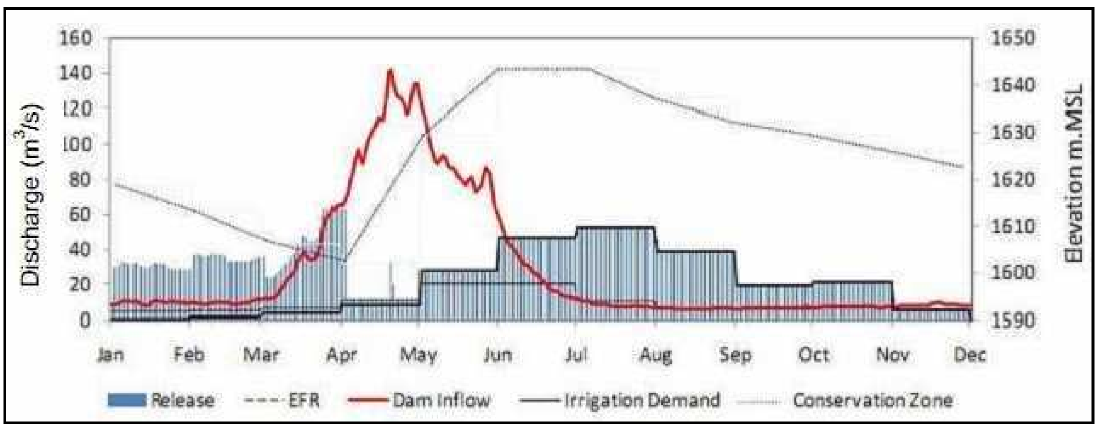


Figure 6: Proposed guide curve of conservation zone for reservoir operation

Results obtained by all scenarios are summarized to evaluate the impacts of EFR consideration on the irrigation and hydropower demand (Table 2). It shows that when reservoir releases for only irrigation and hydropower, there is shortage for years 1966 and 1971. However, after EFR inclusion into the reservoir operation policy along with other demands, shortage is noticed for the years 1966, 1970 and 1971. Afterwards, by applying the proposed new conservation rule curve estimated in scenario III simulation, it can be shown that there is no shortage for irrigation, hydropower and EFR demand. At the same time, the energy generated for those specific years for scenario III is more then that for scenarios I and II.

Table 2: Comparison of the results obtained by all three scenarios

| Description | Unit | Scenario I Irrig.+Pwr/Existing Conservation Zone | | Scenario II Irrig.+Pwr+EFR/Existing Conservation Zone | | | Scenario III Irrig.+Pwr+EFR/Newly Proposed Conservation Zone | |
|---|---|---|---|---|---|---|---|---|
| Irrigation Shortage | Years | 1966 | 1971 | 1966 | 1970 | 1971 | 1966 | 1971 |
| | $Mm^3$ | 114 | 155 | 116 | 86 | 157 | 0 | 0 |
| | % | 54 | 73 | 56 | 54 | 76 | 0 | 0 |
| Power Gen. | MWh | 154.5 | 121.6 | 156 | - | 120 | 197.4 | 140.9 |

### 3.3 Scenario-IV: Impact Mitigation by Improving the Irrigation Efficiency (IE)

Improving the current irrigation practices could be another potential solution for minimizing the irrigation shortage. Before the conflict period, total cultivated area was about 97000 ha, which has been drastically decreased to 42,141 ha. Thus, there is a potential scope of expanding the current irrigation scheme in future. Scenario II shows that there will be shortage of water in dry years for 74859 ha irrigable areas if EFR demand is considered into reservoir operation policy. Therefore, improving IE can be a good option to mitigate this impact. For this, average IWR per ha was estimated to find the total demand from the future irrigable area.

Table 3: Improving irrigation efficiency (%) for mitigating impact for the whole cultivable area

| Description | Unit | IE | Wet Season | Dry Season | Total |
|---|---|---|---|---|---|
| Total cultivated area | ha | - | 52402.00 | 22458.00 | 74859 |
| Estimated avg. CWR per ha | L/s/ha | - | 2.42 | 4.13 | - |
| Total irrigation water supply (winter) | $Mm^3$ | - | 361.01 | **226.00** | 587.01 |
| Existing IWR (winter) | $Mm^3$ | 35% | 328.44 | 240.26 | 568.70 |
| IE increased by 5% IWR (winter) | $Mm^3$ | 40% | 317.24 | **225.09** | 542.33 |
| IE increased by 10% IWR (winter) | $Mm^3$ | 45% | 309.59 | 221.09 | 530.68 |
| IE increased by 15% IWR (winter) | $Mm^3$ | 50% | 303.11 | 211.54 | 514.65 |

Table 3 demonstrates that improvement of IE only by 5%, there will not be any shortages of water for irrigation hydropower and EFR demands. During dry season, total supply and demand from the reservoir is simulated as 226 $Mm^3$ and 240.26 $Mm^3$, respectively. However, the demand is more than the supply, which means that there is shortage having 35% existing IE. The result also shows that the irrigation demand is decreased almost about 15 $Mm^3$ for improving IE only by 5%, and hence the supply is meeting the full irrigation demand. Besides, further options will be created for cultivating more irrigable area during wet years with the surplus water.

## 4. CONCLUSIONS

This study was an attempt for establishing a framework to estimate EFR in the Hari Rod River basin of Afghanistan by using different well-known hydrological and hydraulic methods. After estimating EFR, a reservoir simulation model was developed for the proposed reservoir (Salma dam reservoir) system applying the HEC-ResSim model to estimate the impact of incorporating EFR into the reservoir operation policy as well as on the irrigation management. It was found that the hydrological based methods were suitable to establish EFR in the Hari Rod River basin of Afghanistan. Estimated EFR using the IHA method considering the RVA approach was preferred for simulating the reservoir model, as it considers natural flow variability, magnitude, frequency and duration of flow during EFR estimation. The study concludes that there will be shortage of water during dry years if the Salma dam reservoir operates for meeting all the three demands such as irrigation, EFR and hydropower production. Impact of EFR consideration on the reservoir operation policy can be mitigated by applying the developed conservation zone for dry years. This can save about 2000 ha land that was supposed to be affected. The present study conclusively proves that impacts of water shortages can be minimized significantly by a little improvement of the existing irrigation efficiency in the Hari Rod River basin of Afghanistan.

## ACKNOWLEDGEMENTS

This research was conducted at the Water Engineering and Management field of study in the Asian Institute of Technology (AIT), Thailand with the financial assistance from the Government of the Netherlands through a fellowship grant. The authors are thankful to the Government of Netherlands for providing the financial supports as well as to AIT for providing the technical and educational supports during the study.

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