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RESERVOIR OPERATION CONSIDERING ENVIRONMENTAL FLOW REQUIREMENTS IN THE HARI ROD RIVER BASIN, AFGHANISTAN

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ABSTRACT

Growing pressure on the available water in the Hari Rod River basin of Afghanistan requires a better understanding of the river flow systems for effective allocation of the available resources considering water requirement by the riverine ecosystem. This study attempts to quantify environmental flows required for healthy ecosystem as well as to establish appropriate assessment techniques to be applied for basin-wide management in the major basins in Afghanistan. The study is based on collected data and information regarding the Hari Rod River basin in Afghanistan. Indicators of Hydrologic Alteration method considering Range of Variability Analysis were applied for quantifying the environmental flow requirements and compared with other hydrological based approaches (e.g. Tennant Method, Flow duration curve analysis and 7Q10 method) and hydraulic based approaches (e.g. wetted perimeter method). It is found that hydrological based approaches are appropriate to estimate environmental flow requirements in the basin. Maintaining environmental flows of a river means the reducing of water demand from one or more sectors. Keeping this in mind, reservoir simulation technique was applied to operate the proposed reservoir (Salma Dam) in the Hari Rod River basin of Afghanistan. HEC-ResSim model was used for simulating the reservoir operation (proposed Salma Dam) and different alternative scenarios were generated to evaluate the possible impacts of allocating environmental flows on the other demands (e.g. irrigation and hydropower). Different mitigation options were suggested at the same time to reduce the impacts. A new conservation zone rule curve was developed to decrease the water shortages for irrigation caused by the additional demand due to the allocations of the environmental flows. This study estimates that the water shortages can be alleviated substantially by improving existing irrigation efficiency in the basin. The result also shows that there will be no water shortages by irrigation, hydropower and environmental flow demand for a 5% improvement of irrigation efficiency.

Key Words: Afghanistan, Environmental Flow Requirement (EFR), Hari Rod River Basin, HEC-ResSim, Irrigation Efficiency, Reservoir Operation, Salma Dam

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1. INTRODUCTION

Increasing water demands are the main cause of degrading river and other aquatic ecosystems in countries across the world. Many of these countries acknowledge that environmental protection must be a component of their management of aquatic resources, but have limited data and understanding of their systems with which to achieve this. Nowhere is the problem more urgent than in developing countries in semi-arid climates, where fast-growing populations are dependent on the very limited water resources [3,12]. This has led the protection of the aquatic environment to take the top position on the world's water resources agenda. Thus, it is recognized that there is a high requirement to allocate water for the rivers itself to meet the ecological demand for preserving the riverine ecosystems and its associated functions. 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 is known as the environmental flow requirement (EFR) [2,5,8,10,11]. The concept of the river EFR is emerged from the requirement to establish the level to which the flow regime of a river can be altered from the natural condition while preserving the sustainability of the riverine ecosystem [11,12]. Such requirements are determined by means of environmental flows assessment (EFA), which attempt to determine the amount of water that must remain during different times of the year in a regulated river system to maintain the aquatic ecosystem and resources at desirable level [1,9]. The objective of environmental water requirement and its ecological values signify the necessity of EFA in a basin. Such objectives attempt to maintain or improve flora and fauna in a desired status; the higher this status, the more flow regime will need to be allocated for protection of riverine ecosystem [2,8].

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 catchment and lack of attention to environmental impacts. Civil war and years of conflict has created a situation in the country where local people and government officials do not percept the value of endangered species in contrast to pre-conflict period. Dust storms, water pollution and loss of biodiversity are rapidly increasing because of high poverty and high population growth. The available discharge in the Hari Rod River to be used for irrigation purpose is deficit in the summer and excess in the spring. Accordingly, water user groups have adjusted their agricultural and irrigation water supplies to natural regime. But the distribution efficiency is degraded on the main and major sub branches of the Hari Rod River caused by corrupted canal diversions, alignment and devastated bifurcations. The primary focus of water resources development projects in Afghanistan particularly in Hari Rod River Basin has been the irrigation and hydropower aspects. Until now, EFR downstream of these developments have not been considered an important concern. However, the apprehension to minimize the adverse social and environmental consequences of such plans is getting much attention. Therefore, establishment of environmental flows is regarded an essential part of Hari Rod River basin management prior to any water resources developments projects. The primary intention of environmental flow (EF) management for the Hari Rod River 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. Legislation in Afghanistan depicts that its water resources management plan should reserve that much amount of water to be required for environmental purposes in all its river basins. This issue is also highlighted in the water sector strategy of the country's national development strategy [4,6]. 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 [6]. This has led to the recognition that environmental flows in each of the river basins in Afghanistan need to be quantified. But there has not been any established guideline yet for this purpose which suggests in developing a slate of methodology to be adaptable for the river basins in Afghanistan. Thus, the present study attempts to assess the environmentally acceptable flow regime for the Hari Rod River basin, which is expected to assist in developing an appropriate operating policy for proposed Salma dam in the basin with a consideration of estimated environmental flows. It is also expected that this study would contribute to the efforts required for managing properly the riverine ecosystem in the Hari Rod River basin of Afghanistan.

2. DESCRIPTION OF STUDY AREA

Hari Rod River basin is located in the western part of Afghanistan (Fig 1), which is relatively more developed than other basins in that location. The upper part of the basin is located in Ghor province with an altitude of 4000m above mean sea level (MSL). The location of lower part is in the Herat province with an altitude of 750m above MSL. The basin covers a total area of 3,901,722 hectare having a population of 460,000. Upper reach of the Hari Rod River has narrow valley with gravelly bed, 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 enter into Turkmenistan where it disappears in the sand. Climate is distinguished by cold winters with snow and rainfall increasing with rising altitude. Usually rainfall occurs in spring and the mean annual precipitation is estimated as 236 mm with uneven spatial distribution. Runoff comes from snowmelt which is the major source of surface and ground water of the basin spanning over two months (February/March to April). The river has high flood flows from March to June and very low flows from August to February. Hence, there is sufficient flow in the river from end of February to middle of June or sometimes end of July. Farmers within the basin have adapted their agricultural and irrigation practices to this flow regime. Thus, the river water is mainly used for irrigation purpose. However, groundwater is used as supplement for irrigation throughout the year. Salma Dam is located near the Chisht-e-Sharif in Herat province and was planned as a multi-purpose project to afford both irrigation and power benefits. Presently, it is under active construction which 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) in the basin [4]. Thus, there is a requirement for better understanding of the EF in the Hari Rod River in order to establish and allocate water for ecological processes of the riverine ecosystem of the basin.

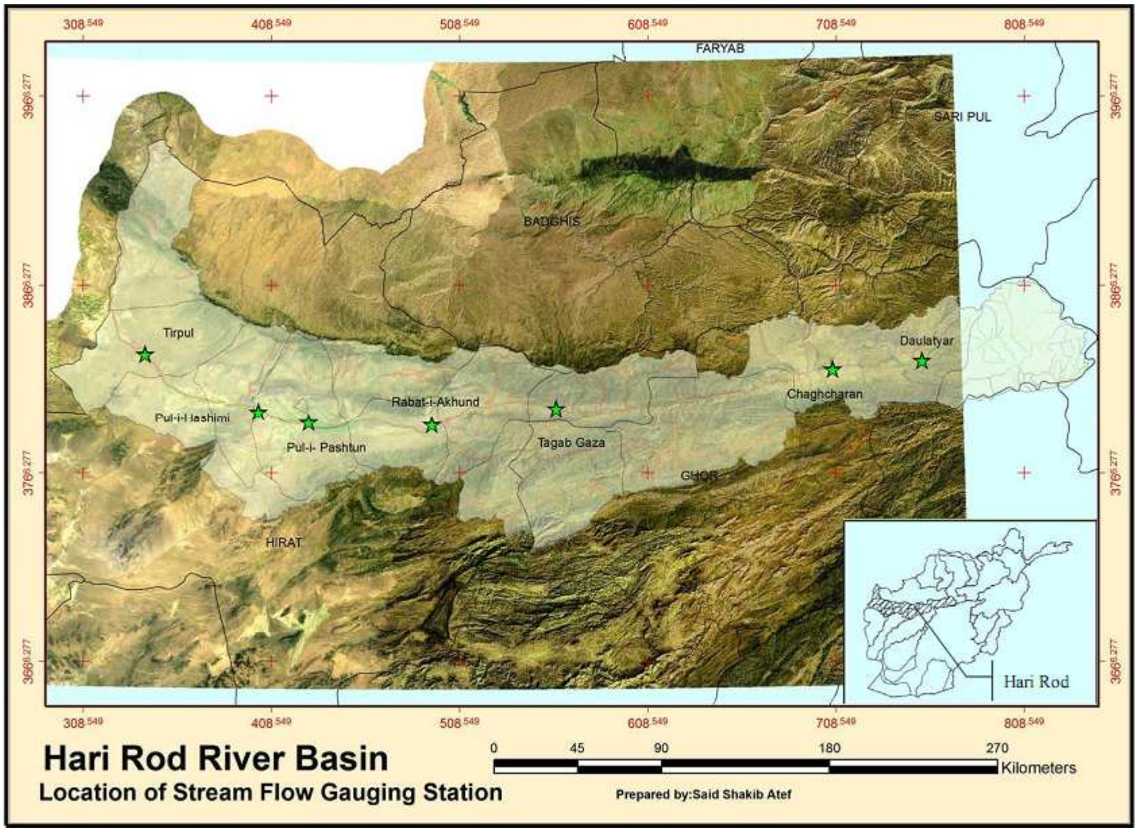

Fig 1: Location Map of the Hari Rod River Basin in Afghanistan

3. METHODOLOGY

The methodology for establishing reservoir operation considering environmental flows in the study area is based largely on the observed data and information in the field. Simple approaches have been adopted to use commonly available hydrological data. The framework of methodology mainly consists of two subsets of activities: estimation of environmental flow requirements and establishment of a reservoir operation policy applying simulation technique. Well-known hydrological (e.g. Tessman method, Flow Duration Curve analysis, and 7Q10 method, Indicators of Hydrologic Alteration method, Range of Variability analysis) and hydraulic method (e.g. Wetted Perimeter method) for estimating environmental flows are used [1,2,5,8,11,12] to estimate environmental flows. HEC-ResSim, a model for reservoir system simulation [7], was used for simulating the reservoir (proposed Salma dam) operation. Three alternative scenarios were generated to evaluate the possible impacts of allocating environmental flows on the other (e.g. irrigation and hydropower) demands.

4. RESULTS

4.1. Estimation of Environmental Flow Requirement (EFR)

Major tributaries of Hari Rod River is located in the lower part of the basin, where there is an impact on EF due to growing pressure on the available water by irrigation demand. Thus, the present study considered the gauging stations which are located in the lower part of the basin for EFR assessment. 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 (Fig 1).

4.1.1. Tessman Method

Tessman (modified Tennant) method uses a percentage of the average annual flow (AAF) for a monthly basis rather than two season (six months period) basis (Tennant Method). In this method, EFR is estimated for all stations using 20 years daily flow data considering seasonal variability which is presented in Table 1. As a representative example for Tagab Gaza station, it is observed that the AAF is less than average monthly flows (AMF) from March to end of June, then EFR is equal to 40% of AAF and for the rest of the year, EFR is equal to AAF where AAF is more than AMF. Maximum EFR (15.9 m^3/s) is obtained at Tagab Gaza station, which is located very near the reservoir (proposed Salma dam) location.

4.1.2. Flow Duration Curve (FDC) Analysis

This method uses daily discharge data to develop FDC. Then, the percentage of time that values of a specified river discharge is equalled or exceeded 90% during a period of interest was considered as standard for EFR. Usually, Q_{95} and Q_{90} index are used, which indicate the extreme low flow conditions to protect the riverine ecosystem integrity. Table 2 presents the EFR (Q_{90}) in various gauging stations, which shows that the estimated EFR for Tagab Gaza stations is tolerable. But for other three stations, it is very less. This is due to increased demand of available water by irrigation in upstream of these stations. The result also shows that there is sufficient flow in the river during spring season due to less irrigation demand. But in summer season, the river discharge doesn't meet the irrigation requirement since the demand is high. So, the groundwater sustains the irrigation and aquatic biota is not protected. Therefore, Q_{50} is estimated, which is used as indicator of aquatic biota protection (Table 2).

4.1.3. The 7Q10 Flow Methodology

This method can be interpreted as the 7-day low flow with a 10-year return period using daily discharge data. At least 10 years observed data is needed to start the analysis and consecutive 7-day average flow for each year as well as frequency of return interval is calculated. This method depicts that the resulted minimum stream flow should be maintained to protect river water quality. The estimated EFR by this method (Table 2) for Tirpul station is very less. This is because that the river flow disappears into sand in the downstream part of the basin.

4.1.4. Indicators of Hydrological Alteration (IHA) Method

IHA method quantifies the hydrologic sequential variability of flow regime into 32 biological parameters based on statistical evaluation. In this method, these parameters were calculated from 20 years daily record (1961 to 1980) at Tagab Gaza station by considering single period analysis with nonparametric statistics. The result shows that there is alteration between recent and pre-settlement period. For specific months the monthly low flow is drastically decreased in the recent period. The monthly low flow median in pre-impact period is 6.4m^3/s which is decreased to 5.3m^3/s in post-impact period. The tabulated view of median flow variation is presented in Table 3. There is a significant variation in April and May median flows of post-impact period compared to pre-impact period.

Table 1: Results of EFR by Tessman method for stations in lower Hari Rod River basin

Month	Tagab Gaza EFR (m^3/s)	Pol-i-Pashtun EFR (m^3/s)	Pol-i-Hashimi EFR (m^3/s)	Tirpul EFR (m^3/s)
Jan	7.9	6.99	10.62	12.44
Feb	9.2	11.2	11.48	12.48
Mar	15.7	15.6	12.49	12.48
Apr	15.9	15.31	12.49	12.48
May	15.9	15.31	12.49	12.48
Jun	15.9	14.75	8.96	12.48
Jul	14	0.44	1.36	0.79
Aug	7.7	0.29	0.92	0.1
Sep	7.4	0.35	1.02	0.08
Oct	7.1	0.6	1.76	0.16
Nov	7.6	1.37	3.72	2.35
Dec	7.6	2.04	7.15	5.21

Table 2: Results of estimated EFR by FDC and 7Q10 methods

Code	Name	Elevation (m)	EFR by FDC Method		EFR by 7Q10 Method
			Q_{90} (m^3/s)	Q_{50} (m^3/s)	(m^3/s)
93	Tagab Gaza	1460	5.61	9.64	5.10
89	Pol-i-Pashtun	940	0.18	1.15	0.38
88	Pol-i-Hashimi	850	0.86	8.31	0.90
86	Tirpul	760	0.04	2.4	0.085

Table 3: Results of monthly median flow alteration by IHA method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pre-Impact	4.3	5.6	10.9	67.6	151.0	37.5	10.5	5.7	6.1	6.4	5.5	5.0
Post-Impact	5.0	5.8	9.0	113.5	141.0	38.9	8.7	5.0	5.4	5.3	5.4	5.2

4.1.5. Range of Variability Analysis (RVA) Method

The results from IHA analysis are used for RVA approach 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 analyze for Tagab Gaza station shows that the post-impact period peak discharge and volume is increased by 4% compared to pre-impact period (Fig 2). The positive and negative changes in water conditions are increased from pre-impacted period than post-impact period.

4.1.6. Wetted Perimeter Method

The Tagab Gaza site is selected based on the availability of daily flow data and surveyed cross-sections. The intention is to compare the estimated EFR with other methods. Since it is difficult to estimate the point of maximum curvature in the wetted perimeter to discharge relation, so EFR are estimated based on the breaks in the slope of wetted perimeter verses the discharge diagram and it is about 7.71m^3/s.

4.2 Comparison of EFR Methodology

Tessman methodology usually provides good results at initial level of analysis. But it is found that most often this method under or over estimates and gives unexpected results due to seasonal condition. The result by this method is considerable higher than other methods for dry season. However, FDC results are much lower than Tessman method. FDC method concise the entire flow distribution and shows the range of extreme low flow conditions but they do not reveal the detail of the seasonal impacts. Since it is highly necessary to maintain variability for the entire year, this method can be used for primary screening of the complete series of river discharge from low flow to flood events. Therefore the single, minimum, threshold flow can't represent the entire EFR of a river (Fig 3). Results obtained using 7Q10 method is very less in terms of magnitude compared to other methods. But when the question of seasonal variability arises, 7Q10, FDC and wetted perimeter method can't fully include EFR in management level. It is recognised that intra and inter-annual variability of hydrologic regimes are needed to maintain and restore the natural form and function of aquatic ecosystems. That range of variability is the most sophisticated form of hydrological index methodologies. IHA method generally considers the magnitude, duration and frequency of flow regime. Therefore, the estimated EF of IHA method is considered to simulate the reservoir and evaluate the impact of EFR on other demands.

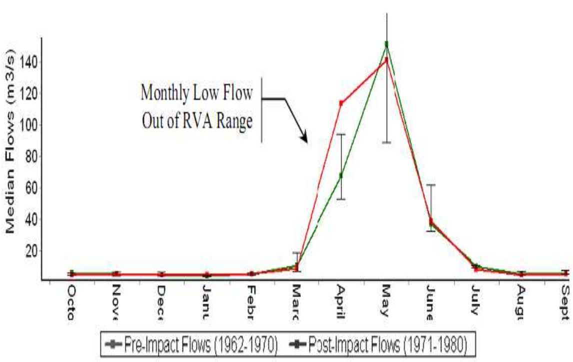

Fig 2: Monthly flow alteration with RVA boundaries in Tagab Gaza station

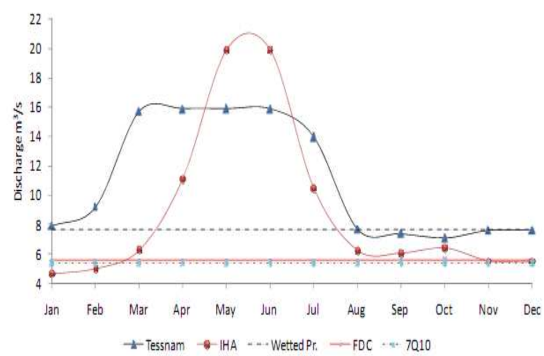

Fig 3: Comparisons of EFR obtained by Different EFR Methodology

4.3. Simulation of Reservoir System

During simulation of reservoir system, irrigation and hydropower demands are considered initially. The reservoir (proposed Salma dam) should meet the current irrigation demand of 42000ha and generate an installed capacity of 42MW early after construction and expected to mee the future irrigation demand for 75000ha after development of irrigation facilities. Considering the storage behind Salma dam, there is not shortage for irrigation when reservoir is operating only for hydropower and unintentionally environmental flow is also meet; hence this study evaluates the future impact, when irrigation demand is high and reservoir will be operated in the interest of both irrigation and hydropower including EFR. HEC-ResSim model was used to simulate the reservoir (Proposed Salma dam) operation with 20 year daily time series data. Three different scenarios were developed in order to evaluate the impact of

EFR consideration on irrigation and hydropower demands which are described in subsequent sections.

4.3.1. Scenario I: Reservoir Simulation without Considering EFR

Since Salma dam is designed to operate irrigation and hydropower demand, for this reason, the intention of developing this scenario was to elaborate dam status after construction. The evaluation shows that there are about 18 fully satisfied years for irrigation within 20 years analysis period. The simulated time series of the reservoir shows that the irrigation shortage was observed in two dry years in specific moths (dry season). It also shows that the available water from 1970 to 1971 is very less, the same happens in year 1966, therefore both of these years were highlighted in this study. Fig 4 shows the irrigation shortage from August to November in 1971, where the total annual inflow in that specific year was 281Mm^3, this is while the average annual irrigation demand and average annual inflow to the river is 584Mm^3 and 1217Mm^3 respectively. This implies that there is no shortage for irrigation for normal and wet years, if the reservoir inflow is equal or more then estimated average annual inflow. Besides observation shows that total reservoir inflow in year 1969 to 1970 was almost same as year 1971, but there was no shortage observed, this is because of reservoir storage in 1968 to 1969, the reservoir inflow is more then estimated average inflow, therefore, beside meeting the demands, much of the water was stored and were released in year 1970, thus there was no shortage on that specific years. It can be conclude that, reservoir operation policy can meet both irrigation and hydropower demand if the available water is more then average reservoir inflow in addition the storage behind dam is also meeting the next dry year demand. Observation shows that the annual inflow in 1971 was extremely low; it was almost 1/5 of average annual flow. Though there was less inflow to the dam, simulation shows that totally 8 month (Jan to end of Jul) was fully satisfied, but irrigation demand was 20% satisfied in Aug and 45% in Sep and Oct, bearing in mind that there is no irrigation demand on Dec. The resulted average energy generated is reasonably more than the proposed capacity (186.13 MWh). This is because the release for both hydropower and irrigation is from hydropower gate in order to optimize both irrigation and power demand. It is considered as key reference to compare with other scenarios.

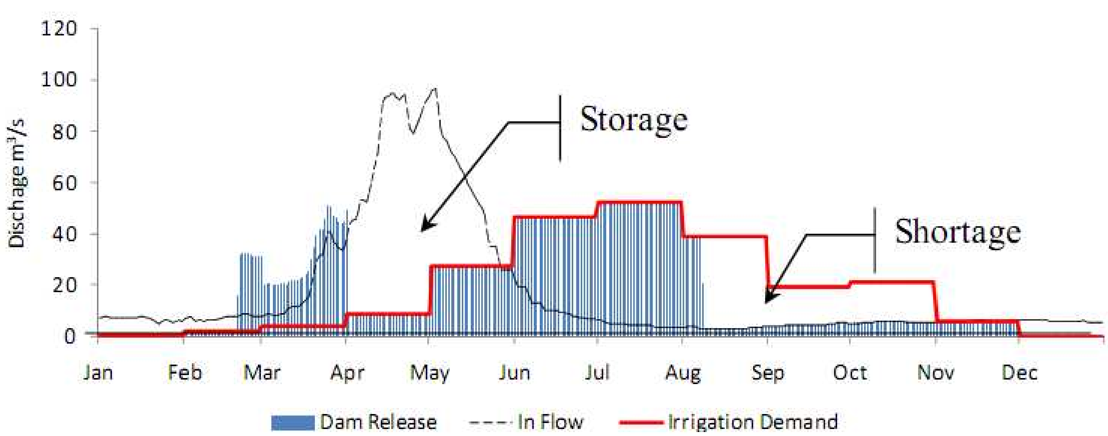

Figure 4: Dam release vs. irrigation demand for the year 1971 without EFR.

Table 4: Irrigation shortage due to EFR consideration (Scenario II)

Date	Release (10^6 m^3)	Irrigation Demand (10^6 m^3)	Percent of Satisfied
Aug-66	59.0	101.0	58%
Sep-66	14.2	49.8	29%
Oct-66	16.5	54.8	30%
Sep-70	37.7	49.8	76%
Oct-70	19.2	54.8	35%
Aug-71	24.3	101.0	24%
Sep-71	10.9	49.8	22%
Oct-71	13.9	54.8	25%

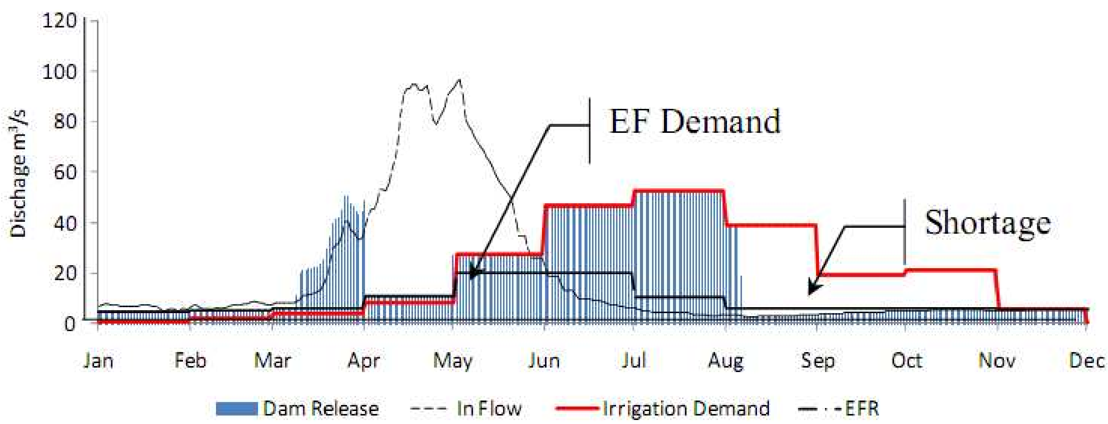

Fig 5: Shortage of Irrigation Demand due to EFR Consideration for the Year 1971

4.3.2. Scenario II: Reservoir Simulation Considering EFR

This scenario evaluates the influence of EF consideration on other demands. The simulated result shows that after inclusion of EF in reservoir operating policy, there will be more stress on irrigation demand in the specific dry years (Fig 5). The EF release decision was defined as a minimum reservoir supply on monthly basis. This decision is made in reservoir hydropower gate and then EF is evaluated downstream at Tirpul Station. River routing was carried out to calibrate the estimated EFR downstream of the river. Table 4 presents the EF consideration impact on irrigation demand. The shortage has been noticed from Aug to Oct of 1966, 1970 and 1971 out of 19 years simulation period and sever shortage was noticed in year 1971, where reservoir is meeting almost 22% of the demand. There was not much difference in average energy generated after adding EFR demand in reservoir simulation model.

4.3.3. Scenario III: Developing Guide Curve for Reservoir Operation

Evaluation shows that reservoir starts to storing water from April to end of Jun and releases from July to next April. This release decision is applicable in normal and wet years where the dam inflow is almost equal to average annual inflow. This may also help to decrease the level of flooding while meeting the irrigation demand and generating more energy. But during the drought period, when the dam inflow is almost one fifth of the average annual inflow, the existing conservation zone will not fully meet the irrigation, hydropower and environmental demands (Fig 6). So, a new conservation zone is developed based on dry year circumstances to meet irrigation, hydropower and EFR during dry years. The simulation result shows that there will be no shortage for both irrigation and EF after applying the new conservation zone. It is observed that reservoir release is meeting the total demand of irrigation and EFR. Different results are obtained for each scenario (Table 5) and compared to evaluate the impact of EF consideration on the irrigation and hydropower demand. It shows that when reservoir releases for only Irrigation and hydropower, there is shortage for years 1966 and 1971, but when EF is included to reservoir operation in addition to other demands, there is shortage for years 1966, 1970 and 1971. But after applying scenario III, simulation result shows that there is no shortage for irrigation, hydropower and EF demand. In addition, the energy generated for those specific years of scenario III is more then scenario I and II.

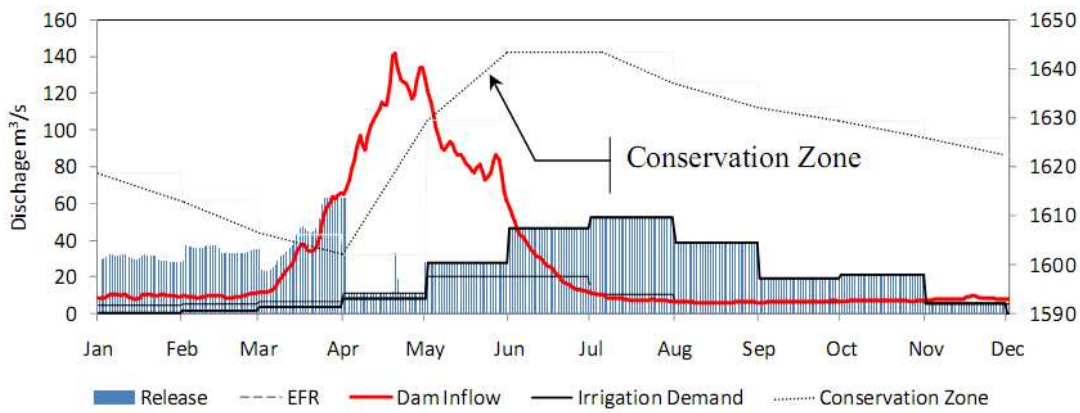

Fig 6: Reservoir release decision when existing conservation zone is applied (1977)

Table 5: Comparison of scenarios I, II and II

<table>
<tr><th>Demand</th><th>Unit</th><th colspan="2">Scenario I</th><th colspan="3">Scenario II</th><th colspan="2">Scenario III</th></tr>
<tr><td rowspan="3">Irrigation Shortage</td><td>Years</td><td>1966</td><td>1971</td><td>1966</td><td>1970</td><td>1971</td><td colspan="2">0</td></tr>
<tr><td>Magnitude(MCM)</td><td>114</td><td>155</td><td>116</td><td>86</td><td>15</td><td colspan="2">0</td></tr>
<tr><td>Percentage (%)</td><td>54</td><td>73</td><td>56</td><td>54</td><td>76</td><td colspan="2">0</td></tr>
<tr><td>Average.</td><td>(MWh)</td><td>154.5</td><td>121.6</td><td>156</td><td>-</td><td>12</td><td>197.4</td><td>140.9</td></tr>
</table>

4.3.4. Scenario IV: Improvement of Irrigation Efficiency

Improving the current irrigation efficiency could be another possible solution for minimizing the irrigation shortage. It is reported that currently the overall irrigation efficiency in Hari Rod River basin is 35%. Data analysis shows that there was about 970000 ha cultivated area under the basin before the conflict period. As a result, it has been drastically decreased to almost 42000ha. Consequently, there is a potential and available source to expand current cultivation. Irrigation water requirement (IWR) for each crop was estimated using CropWat model developed by FAO, for Herat province. Mean monthly temperature, rainfall, evaporation, and soil data were used to estimate net depth of irrigation for each crop.

Scenario II shows that there will be shortage in dry years for 75000 irrigable areas if EF demand is considered in Dam operation policy. Therefore improving irrigation efficiency can mitigate this issue. For this purpose, average IWR per ha was estimated to find total demand of future irrigable area. Table 6 shows that by improving 5% of irrigation efficiency, there will not be any shortage for irrigation demands. In dry season, total dam supply is simulated 226 x 10^6 m^3 and in that specific season the demand is 240.26 x 10^6 m^3, the demand is more then maximum supply it means there is shortage having 35% irrigation efficiency, by improving 5% of irrigation efficiency, the demand will decrease by almost 15 x 10^6 m^3, thus the supply is meeting the demand. Besides, additional area can be irrigated during wet years. Usually it is expensive and time consuming issue to improve irrigation distribution efficiency this can be done by canal lining, and constructing the broken bifurcations and canal diversions. In case of the distribution efficiency is not improved then almost 2000 ha out of 75000 ha of land will be impacted.

Table 6: Improving irrigation efficiency to meet demand of 75000ha cultivated area

No	Description	Wet Season	Dry Season	Total
1	Total Cultivated Area (ha)	52402.00	22458.00	74859
2	Estimated Av. CWR per he (l/s/ha)	2.42	4.13	-
3	Total Irri. Water Supply. Winter (10^6 m^3)	361.01	226.00	587.01
4	IWR Winter (10^6 m^3), 35% efficiency	328.44	240.26	568.70
5	IWR Winter (10^6 m^3), 40% efficiency	317.24	225.09	542.33
6	IWR Winter (10^6 m^3), 45% efficiency	309.59	221.09	530.68
7	IWR Winter (10^6 m^3), 50% efficiency	303.11	211.54	514.65

5. CONCLUSION

This study attempts to establish EFR in the Hari Rod River basin of Afghanistan using different hydrological and hydraulic methods. It also simulates a proposed reservoir (Salma da) system applying HEC-ResSim model to estimate the impact of EFR inclusion in the reservoir operation policy. It is found that the hydrological based methods are suitable to establish EFR in the Hari Rod River basin which are appropriate for initial reconnaissance level of assessment. Estimated EF using IHA method is preferred as it considers natural flow variability, magnitude, frequency and duration of flow for estimating EFR. Salma Dam is in the process of establishment and this study concludes that there is no severe impact on other demands with the inclusion of EFR in reservoir operation policy. The reservoir simulation result shows that there will be in shortage of water by irrigation demand during dry years if Salma dam operates to satisfy all irrigation, power and EFR demand. Impact of EFR inclusion in the reservoir operation can be reduced by applying proposed conservation zone for dry years. This can save about 2000 ha land which was supposed to be affected. The simulation result also demonstrates that there will be no shortage of water for irrigation, hydropower and EF for 5% improvement of irrigation efficiency in the Hari Rod River basin of Afghanistan.

6. ACKNOWLEDGEMENT

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