Assessment of Existing Irrigation Head Work to Hydropower Development:Kuraz Irrigation Development Project, Ethiopia

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Abstract

Integrated development of water resources is a high priority consideration in the economic development of most of the developing countries, as food and energy continue to be among the most pressing needs and help to control flood, check soil erosion, provide water for irrigation and drinking purposes, generate electricity for industries.Kuraz sugar development project was planned and built only for irrigation water requirement, even though there are large amount of excess inflow exceeding normal inflow of irrigation requirements. An effort was made to identify possible power plant site by topomap for existing headwork for alternatives, the result indicates that it is possible at left side spillway for intake level of 480 m.a.m.s.l to 465 m.a.m.s.l at tail water level resulting gross head of 15m. Design discharge giving maximum benefit considering dimension of the project and site condition, subtraction of irrigation and environmental flow from average available flow 92m$^{3/}$s selected. Reservoir Simulation Model(HEC-ResSim) was performed to evaluate the performance of different water uses, time distribution of water and power production. The potential power of 11MW can be developed by release of 92m^3/sby integrating existing infrastructure without affecting the project benefit and surrounding environment of Kuraz Irrigation headwork.

Key words: Food, Energy, Integration, Multipurpose, Modification

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1. Introduction

Integrated development of water resources is a high priority consideration in the economic development of most of the developing countries, as food and energy continue to be among the most pressing needs and help to control flood, check soil erosion, provide water for irrigation and drinking purposes, generate electricity for industries. Ethiopia is endowed with abundant water resources in twelve river basins which carry quite a big amount of water annually with river basins being very steep at the upstream and gentle in the downstream, are quite suitable both for hydropower development and Irrigated agriculture. The Omo-Gibe basin is one of the major river basins in Ethiopia which is situated in the southern part of the country. It has a total catchment area of about 79 000 km^2 and it has a catchment area of 48520km^2 at the Kuraz development diversion site. The project has an overflow weir to raise water on the side of a barrier (coffer dam) that spans the cross section of a river at diversion site selected at the outlet of Omo River to flood plain and it is intended to divert irrigation water to150000 ha of land on both sides of the river for Sugar cane development. For the estimation of flow at the headwork two scenarios were considered; i.e., flow at the diversion site with and without Gibe III dam. Finally the design was based on second scenario i.e. flow at the diversion site both residual area and power release of Gibe III hydropower in order to minimize flow during deficit months from the residual area only. However, there is flow exceeding the irrigation demand spills every month at flood control spill channel thought the saddle. As per the water balance study the inflow of water to the diversion weir is in the range of 17.9 billion m^3, while the gross amount of diverted water that can be utilized for irrigation is about 29 % of the incoming flows based to the study of [1].Hence**,** objective of the research is integration of food and energy by modification of existing irrigation headwork of Kuraz sugar development project for multi-purpose.

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2. Materials and Methodology

2.1 Description of the Study Area

Kuraz sugar development headwork site is situated on the Omo river at a location of 6^0 17’ 03”N-N and 36^0 2’ 35”E-E with an elevation of 475m.a.s.l. The omo River up to the headwork site has a catchment area of 48,520 km^2, which comprises of 61% the total omo river drainage area. The site is located about 240 km far from Gibe III dam.

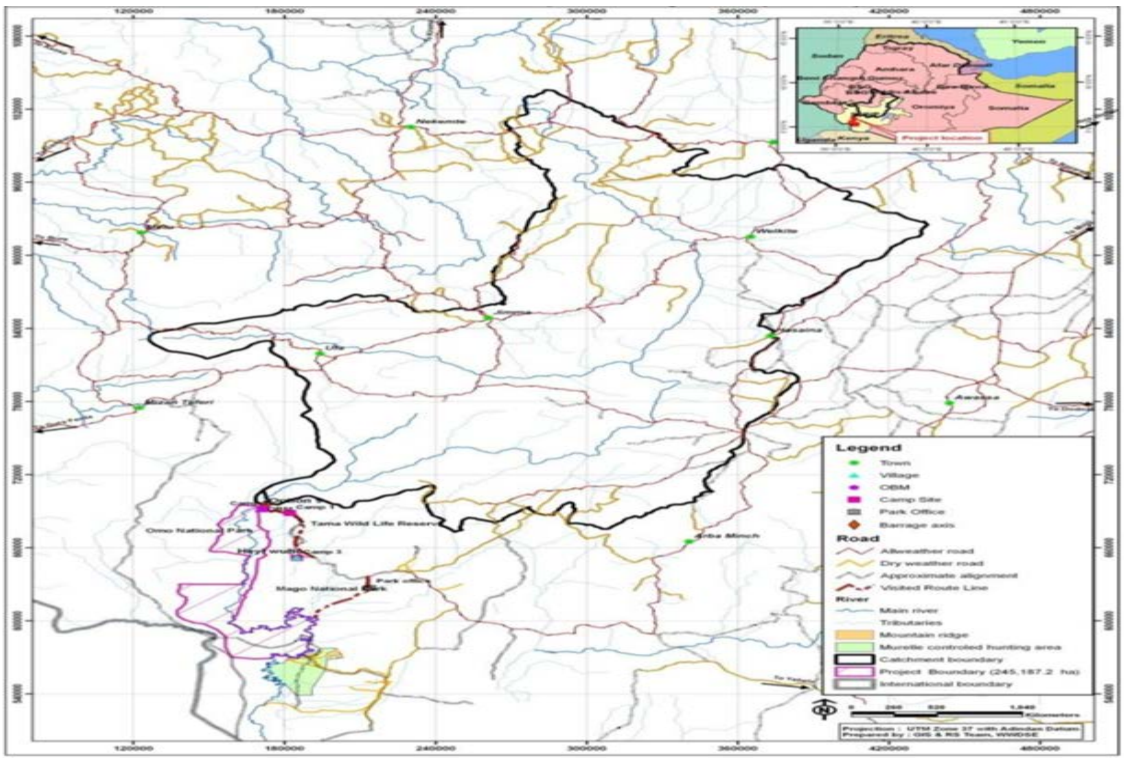

Figure 1: Location of thestudy Area

2.2 Methodology

The methodology of estimating firm hydropower from existing kuraz irrigation head work from excess discharge pass downstream is as follows:

2.2.1 Location and Layout

According to [2] defined the multipurpose systems as those in which electricity generation is not their primary priority, but the second. This implies the integration of the power plant in the existing infrastructure while guaranteeing its both primary (Irrigation) and secondary (hydoloelectric power generation) function. Assessment of the site is a prerequisite in any hydropower development according to [3] .The key parameters during the assessment are the pressure head, the flow rate of the given river, and wire to water efficiency of the overall system. This parameter can be easily found through measurement and manufacturer specification. The upper value of net power capable of being developed technically is computed from potential water power by introducing reduction factors to account for losses in conveyance and in energy conversion. According to [4] the factor to be about 0.75 to 0.80.

$$P_m = (0.75\ to\ 0.8)\gamma Q_m H \quad (1)$$

Where Q_m is arithmetic mean discharge

P_m is potential power

For Kuraz irrigation development for integration of power plant, it was tried to identify suitable power plant layout from three alternatives.

Alternative 1: It was aligned at left spillway for excess dependable flow with gross head of 14m to power plant at 465ma.m.s.l. distance of 1.2km.

Alternative 2: It was aligned considering both excess dependable flow and left irrigation demand at gross head of 4.4m on the left spillway to power plant at 474.6ma.m.s.l distance of 550meters.This alternative eliminated due to less head difference of power generation.

Alternative 3: It was aligned considering both excess dependable flow and left irrigation demand at gross head of 4m on the right spillway to power plant at 474ma.m.s.l distance 640meters.At this case there is accessibility problem during installation and construction in addition to less head difference of power system

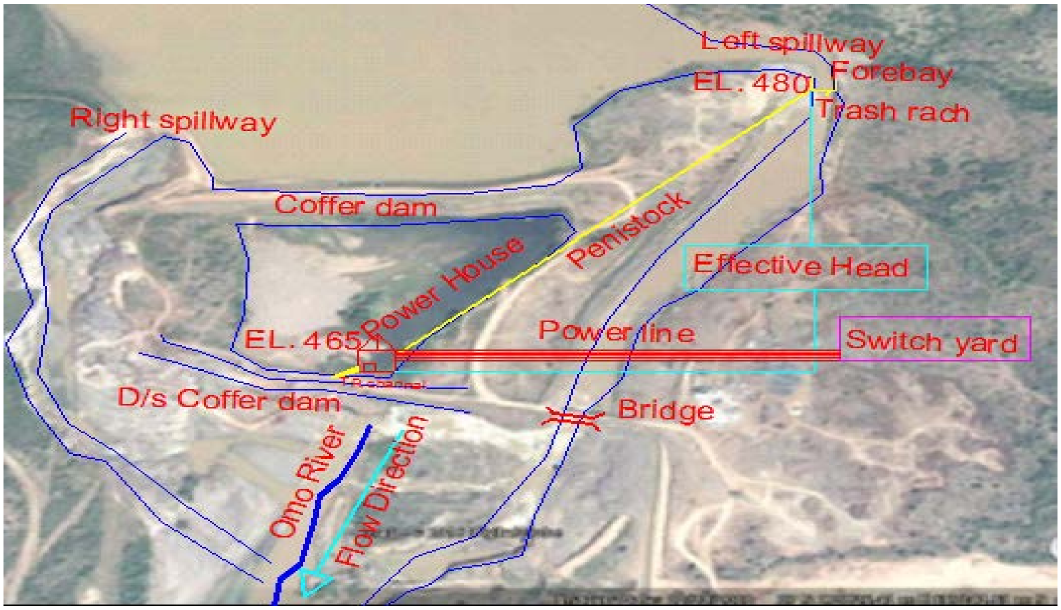

Figure2 Location and layout to karaz hydropower option

2.2.2 Discharge

In order to adequately assess the minimum continuous power output to be expected from the diversion with storage system, the minimum quantity of water available throughout the year must be determined. For this study stream flow to weir site obtained from[1]. Adequate length of the stream flow (1964-2001) data developed was obtained for the study.

Table 1 Mean discharge from each year

Year	Qmean	Year	Qmean	Year	Qmean	Year	Qmean
1964	337.167	1978	331.833	1992	341.667	2006	297.333
1965	319.167	1979	298.500	1993	351.000	2007	305.833
1966	292.000	1980	302.750	1994	314.500	2008	296.667
1967	312.333	1981	242.583	1995	288.417	2009	295.333
1968	295.333	1982	303.000	1996	343.083	2010	298.750
1969	311.000	1983	277.333	1997	381.167	2011	298.833
1970	310.000	1984	275.083	1998	373.250	2012	288.250
1971	306.417	1985	238.083	1999	314.333	2013	311.000
1972	272.750	1986	239.833	2000	340.500	2014	344.583
1973	291.167	1987	217.000	2001	345.000	2015	316.167
1974	305.417	1988	277.583	2002	298.250	2016	303.333
1975	275.917	1989	272.917	2003	311.333		
1976	273.917	1990	317.250	2004	309.917		
1977	294.417	1991	312.500	2005	298.917		

2.2.3 Flow Duration Curve (FDC)

A single value of the flow has no significance in designing a hydroelectric power plant due to fact that flow rate fluctuates considerably in a year, even in a single season. If these fluctuations would not considered in the design process that plant will only efficiently work for a short period of time, and result in a largely uneconomical investment**.** Therefore, it is mandatory to know the flow regime, commonly represented by the Flow Duration Curve (FDC) of 12 months. Thus the availability of power from a hydro plant can also be represented by a power duration curve exactly on the lines as flow-duration curve.

P= (m/N+1)*100 (2)

Where, m=is the order of discharge

Po=percentage probability of the flow magnitude being equaled or exceeded.

N=number of data points that are used in the listing

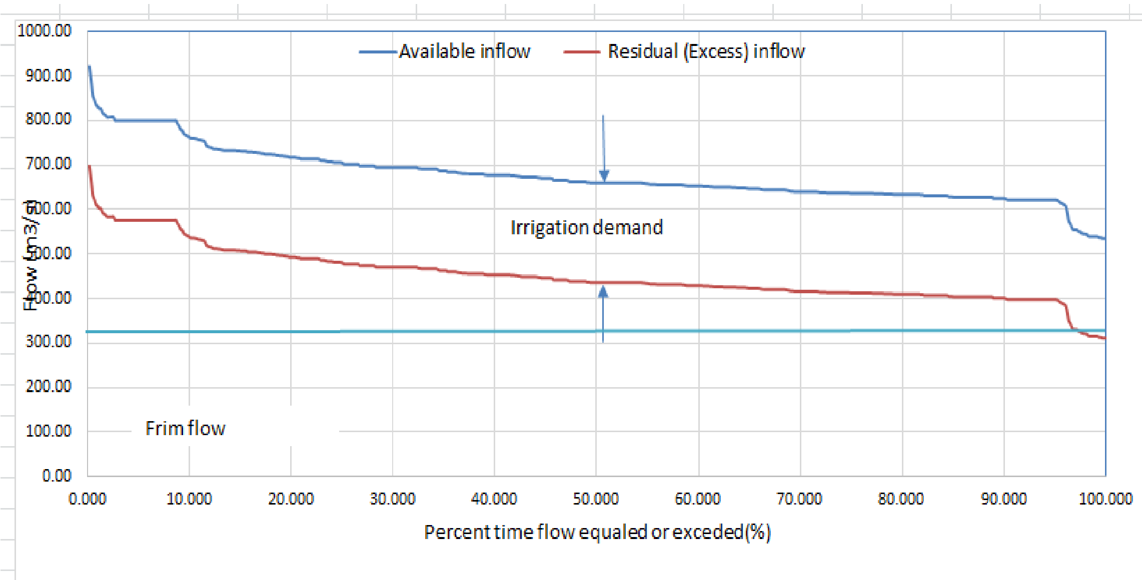

Figure3 Flow duration curve

Residual flow

Residual flow that must be left in the river through the year in excess of the irrigation demand and spilled .This flow is obtained by subtraction of irrigation water consumption from the flow duration curve for plant capacity of multi-purpose. If a high design discharge is selected, the amount of electricity that can be generated in a year will be more. However, as the design discharge increases, dimensions of the project components such as hydro turbines or water conveyance systems also increase, resulting in increased costs in addition to higher risk of not having the required discharge in the river. Usually the design flow is assumed to be the difference between the mean annual flow and the residual (http://www.microhydropwer.net/.).

$$Q_{design} = Q_{mean} - Q_{residual}$$

(3)

The flow duration Curve (FDC) provides means of selecting the right design discharge by taking into account reserved (residual) flow for environmental, losses and aquatic life purpose. This is specified by the user and it is assumed to 25m^3/s which is taken from (WWDES, 2013) for this study. But for this study electricity generation is not their primary priority, but the second. This implies the integration of the power plant in the existing infrastructure while guaranteeing its primary function.Thererfore Design discharge for secondary power considered residual of the firm discharge (95%) available flow from flow duration curve.

$$Q_{Design} = Q_{f\ rim} - Q_{env} - Q_{i\ rrigation}$$

(4)

$$Qdesign = 341 - 25 - 224 = 92m^3 / s$$

2.2.3 Hydropower optimization [HEC-ResSim]

This simulation program [HEC-ResSim 3.1] is developed by the American Us army of Hydrologic Engineering Center [5].In real-time reservoir operation the released water from a reservoir in each period is a function of variables such as reservoir storage volume at the beginning of the current period or the end of pervious period, the reservoir inflow during the current period, and downstream requirement during the current period.By applying simulation model (HEC-ResSim) to Headwork for kuraz irrigation in order to evaluate and determine the amount of water in excess of irrigation demand for power assessment for existing headwork infrastructure, the following reservoir simulation relation based.

$$S_{t+1} = S_t + I_t - Q_s - Q_I - loss \quad (5)$$

Where, S_{t+1} =Final storage capacity at any given period t (Mm^3),
S_t =Initial storage capacity at any given period, t (Mm^3), I_t = monthly inflow into the headwork (Mm^3), Q_S =monthly spill= demand to generate power (Mm^3), Q_I =Monthly irrigation demand (Mm^3) and losses were assumed.

1. Model Setup

HEC-ResSim 3.1 simulation program is developed by the American Us army of Hydrologic Engineering Center. Simulate the reservoir inflow and outflow given the required information on dam characteristics, spillway outflow characteristics and downstream demand. The program is organized in to three modules namely watershed setup, reservoir networkand simulation. The watershed setup module helps the simulator to define the various elements of the river system including the streamlines, the dams and the diversion structures. The reservoir network module is where the reaches are defined and the physical characteristics related to the dam, its reservoir and the outlet works are inputted.

2. Watershed Setup

The watershed setup is where every component of the model is defined. Here the simulator defines the streamlines, the reservoir, the diversion works along with their relative positions and arrangements. In watershed setup, the arrangement river does not need to be dereferenced neither it exact shape be drawn. The software only requires the physical information pertaining to each component (the dam, reservoir, spillway, outlet works etc…) be defined. That is the only way the system recognizes the components. The model setup used in the Kuraz coffer dam simulations is shown below in Figure 4.

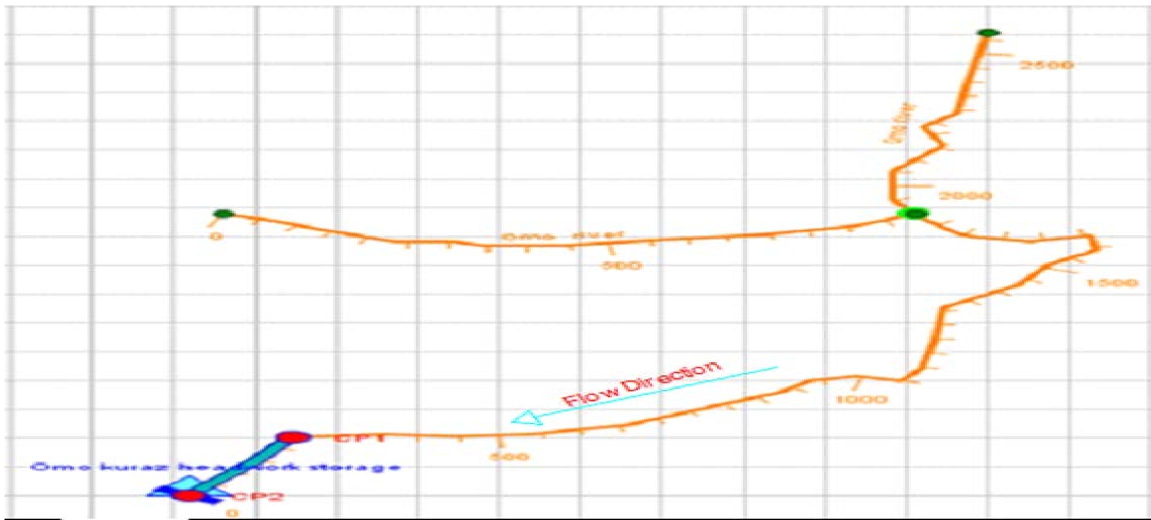

Figure 4 Watershed setup

3. Reservoir Setup

This module mainly deals with defining the physical parameters associated with the various elements of the irrigation system defined in the watershed setup. A typical interface for feeding in these parameters is shown in Figure5, the interface lets the user define various elements associated with the reservoir and the dam. In this simulation, an element like evaporation, irrigation release and spillway release are defined .The next procedure in the reservoir setup is defining the various regions of the reservoir namely the dead storage, the conservation and the flood zones.

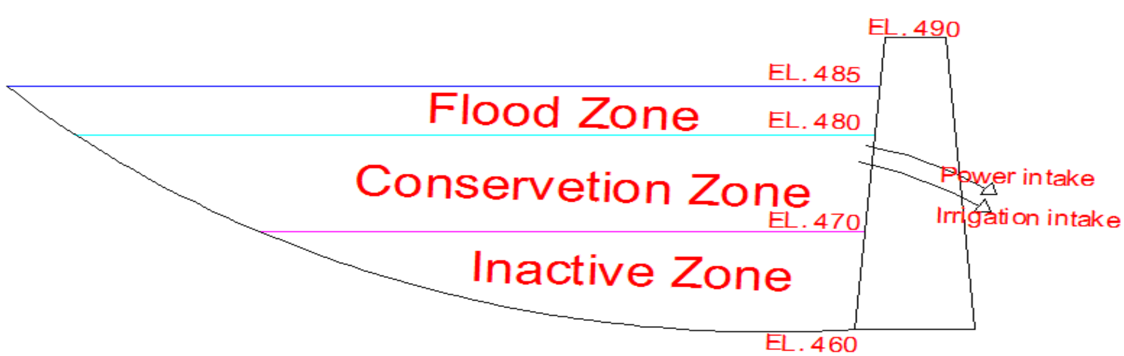

Figure 5 Operation zone of the headwork

3. Results and Discussions

3.1 Plant Capacity and Energy Production

The estimation of plant capacity and average annual energy production is related with design flow and net head. The average annual energy production is a function of flow, net head, and total efficiency of a plant, water density, gravity acceleration and number of hours for which the specified flow occurs.TheHec-ResSim model calculates the estimated renewable energy delivered (MWh) based on the design flow, the gross head specified at intake and tail water level and the efficiencies/losses assumed. The result off simulation with designed discharge of 92m^3/s flow, the average power production of 10.95MW as indicated in Table 5

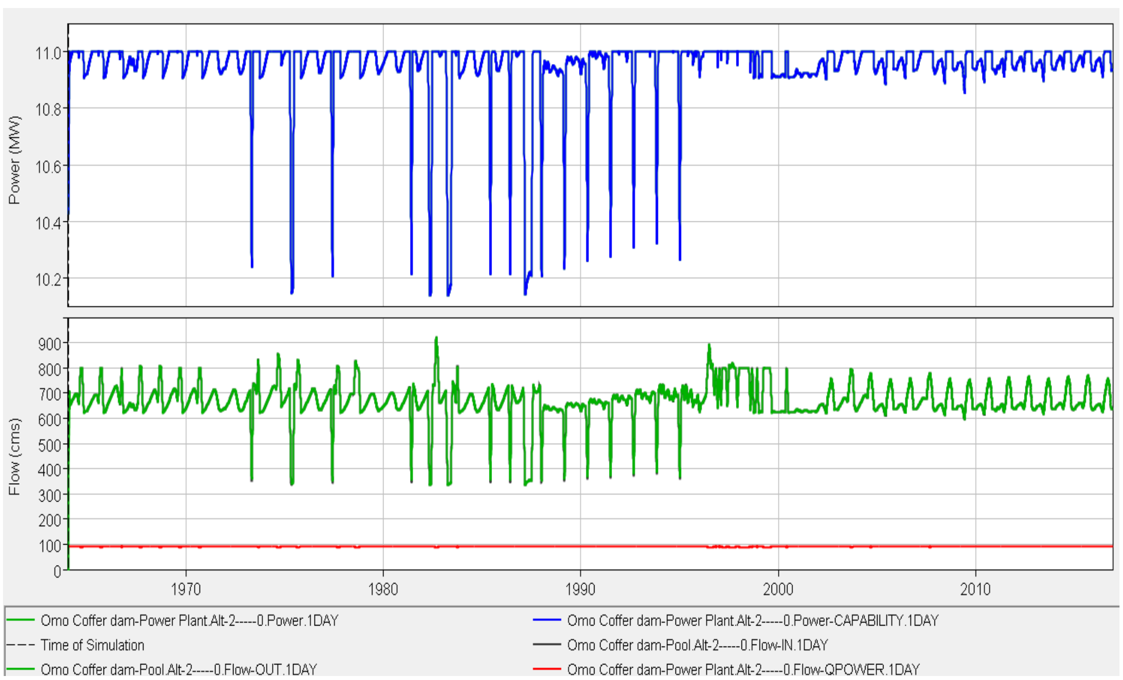

Figure 6Power production pattern of Hec-ResiSm output

Table 2 Hec-ResiSim simulation parameters output

Location parameter	Average	Maximum	Miimum
Omo Coffer dam-power plant			

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Generation efficiency	0.8	0.8	0.8
Power Head(m)	15.23	15.75	14
Hydraulic losses	1.0	1.0	1.0
Power Genertated	10.6	11	10.2
Plant factor	0.45	0.7	0.4
Flow power	90	91	88

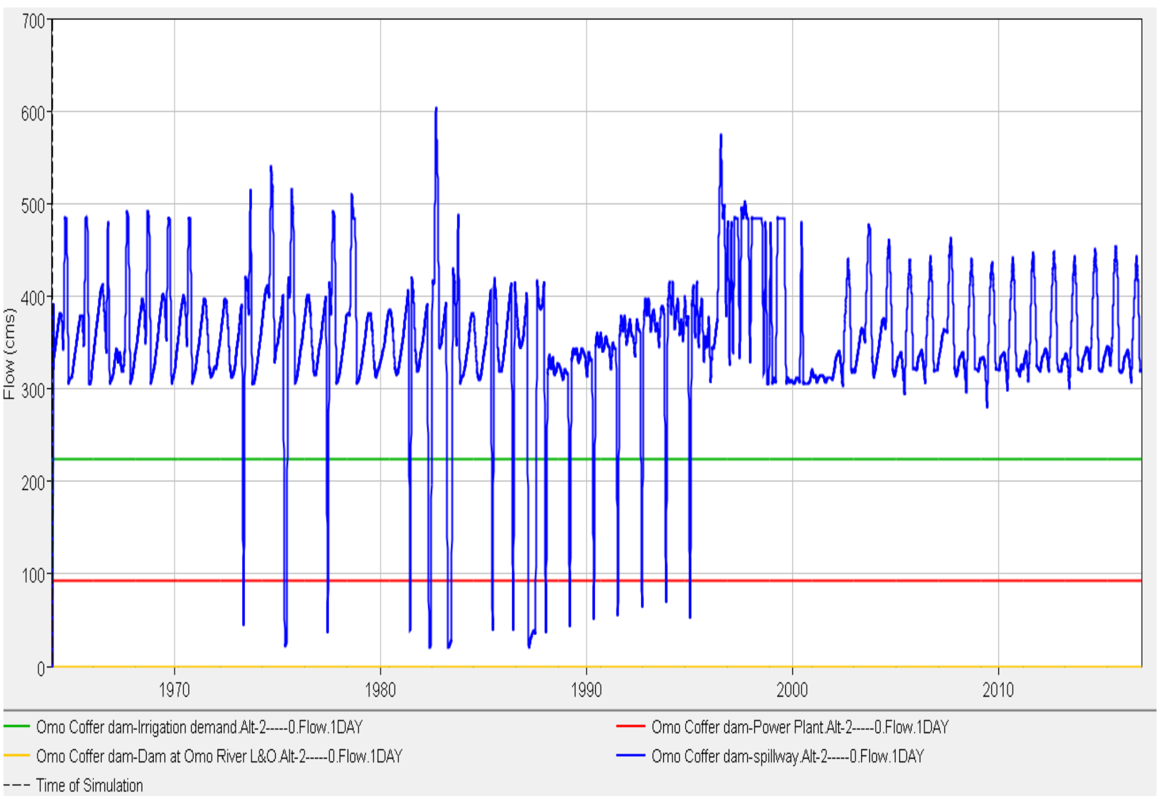

Figure 7 Water use for multi-purpose

The result of power production varation indicates that there is negiligble varation of power production from hydropower system while comparing average, maximum and minimum power simulated as shown in Table 3. This result indicates that there is large volume of water spilled that exceeds even the multi-purpose proposed for this study. Thus Kuraz headwork can be integrated for multi-purpose project meeting both primary and secondary function adequately. Decision making for turbine types and capacities has been solved in considering together with economic issues and some additional objectives such as maximization of the produced energy and the best usage of the water stream potential.

4. CONCLUSION

At the left spillway of the headwork, optimum site was identified intake level of 480m.a.s.l to 465m.m.sl.tail water level resulting gross head of power plant. Flow duration curve developed to identify discharge available for different uses like irrigation, power development and environmental reason. The section of headwork, there is adequate flow capable to secondary power development considering existing irrigation and environmental consideration on headwork infrastructure by some modification. The flow result indicates even $92m^3/s$ considered for power development, excess flow left spilling through the saddle spillway. Power or energy generation simulation was made using HEC-resiSim toflow rate, gross head and efficiency values assumed. The simulation indicates that the time distribution of flow and power production, potential power that can be produced is 11MW. It is possible to integrate hydropower development as secondary power development by using existing headwork that improve the food and energy integration by mult-purpose optimization concept that help to control flooding, soil erosion, agricultural productivity and climate change effect by encouraging water driven energy production.

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