Analysis of Hydrology as Input Parameter for Financial Income Calculation from Hydro Power Plant

Goce Bozinovski [1] and Atanas Iliev[2]

Abstract – **The basic idea of this paper is to provide statistical analysis of the input parameters of hydrology through a series of hydrological inflow data for a long period of years with monthly distribution. The hydrological data is for the last 45 years (from 1970 until 2014) which covers extremely wet and extremely dry hydrological periods. This is important in order to get relevant statistics of expected values with appropriate probabilities of occurrence. The proposed methodology is applied on the real example: HPP Spilje which is part of the hydro power system of Crn Drim river in the Republic of Macedonia.**

Keywords – **Statistical analysis, HPP, probabilities, water inflow, expected values, probabilities of occurrence.**

I. Introduction

Hydroelectric power plants (HPP) are high investment projects that require serious and comprehensive analysis in terms of energy benefits and financial effects of the project. Hydrological data and especially water inflows of the basin are the most important parameters in energy analysis, as well as technical parameters of HPP units. This affects on the expected production of electricity and on the benefits obtaoined from electricity generated in the hydro power plant.

The results from analysis can be applied in determining the expected hydropower production, or appropriate expected revenue of the electricity generated from the HPP.

II. Hydrological analysis of HPP Spilje

The hydro power system of Crn Drim consists of two hydro power plants HPP Globocica and HPP Spilje and three water reservoirs Ohrid lake, Globocica lake and Debar lake. The system is in operation in the last 50 years. The paper is focuses on hydrology data for HPP Spilje, which is on Debar lake with water accumulation of 210 million m^3. The installed turbine flow for each of the 3 units is 36 m^3/s, or the total turbine flow is 3x36 m^3/s = 108 m^3/s. The average gross head is 90 m, and the total installed power of the generators are 3x28MW = 84 MW. Average yearly production of electricity from HPP Spilje is 300 GWh.

Based on the hydrological data for the last 45 years in the Debar Lake which is the reservoir for HPP Spilje, the average annual value of the water inflow is 47,48 m^3/s.

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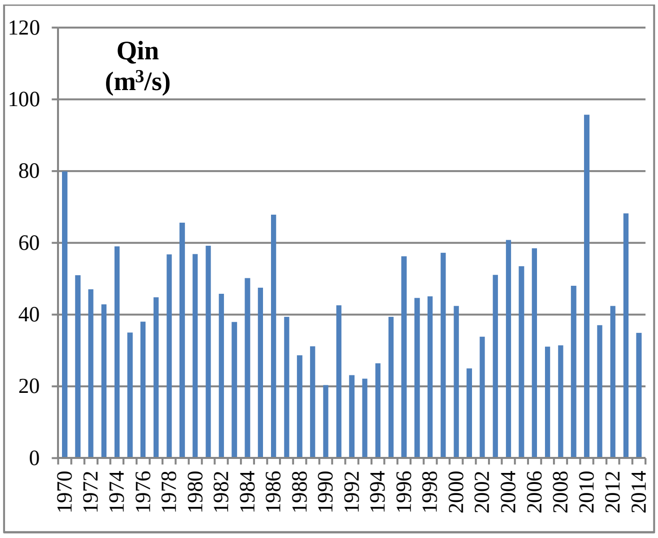


Fig. 1. Average yearly water inflow for the period 1970-2014 in Debar lake

Factor of water inflow is the ratio of average yearly inflow of water and the average inflow for the whole range of years (T).Factor of water inflow for each year (t) is calculated by the relation:

$$K_{in,year}(t) = \frac{Q_{year}(t)}{Q_{year}^{averager}} = \frac{Q_{year}(t)}{\frac{1}{T}\sum_{t=1}^{T} Q_{year}(t)} \quad (1)$$

Factor of generating energy (production factor), is the ratio between the annual production for a year and the average production of a whole range of years (T). Factor of generating energy for each year can be obtained from the relation:

$$K_{gen,year}(t) = \frac{W_{year}(t)}{W_{year}^{average}} = \frac{W_{year}(t)}{\frac{1}{T}\sum_{t=1}^{T} W_{year}(t)} \quad (2)$$

The coefficient of correlation between water inflow factor and production of electricity factor for the period 1970-2014 is 0,974. Therefore, it indicates a strong positive linear correlation between water inflow and electricity production. The average total water inflow in a year is approximately 6,5 times larger than accumulation space of Debar lake. HPP Spilje is the seasonal type of the hydro power plant and presents the indicator for possibility of additional unit(s) for installation of the power house.

III. Probability of Water Inflow and Generation of Electricity

According to the monthly water inflow data for the period of 45 years (1970-2014), as well as from data of HPP operating regime (turbine discharge and electricity generation), we can obtain probabilistic parameters.

The main parameters for analysis are:

– Qin (m^3/s) - water inflow (monthly or in a year)
– Win (GWh) - inflow energy corresponding to the water inflow Qin
– Qtur(m^3/s) - turbine water discharge (monthly or a year)
– Wgen (GWh) - generated energy corresponding to the turbine discharge Qtur

According the data for the parameters of 45 years for each month (45x12=540), the probability of having the expected values in the intervals between minimum and maximum values are shown in Tab.1.

P (Xmin<X<Xmax), where X=(Qin, Win, Qtur, Wgen) (3)

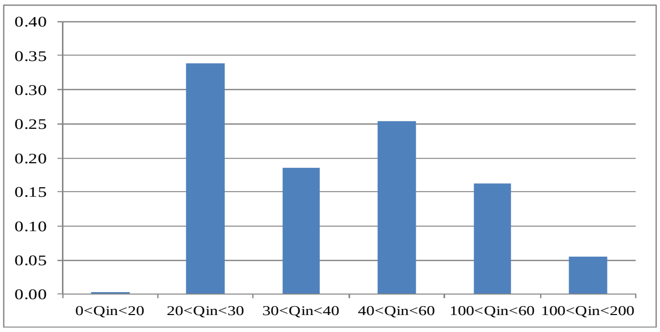
TABLE I
PROBABILITY P(XMIN<X<XMAX) FROM THE DATA FOR THE PERIOD OF 45 YEARS (1970-2014)

Probability of hydrology inflow Water inflow and inflow energy			
0<Qin<20	0.00	0<Win<10	0.13
20<Qin<30	0.34	10<Win<20	0.39
30<Qin<40	0.19	20<Win<30	0.26
40<Qin<60	0.25	30<Win<40	0.09
100<Qin<60	0.16	40<Win<50	0.07
100<Qin<200	0.06	50<Win<120	0.06

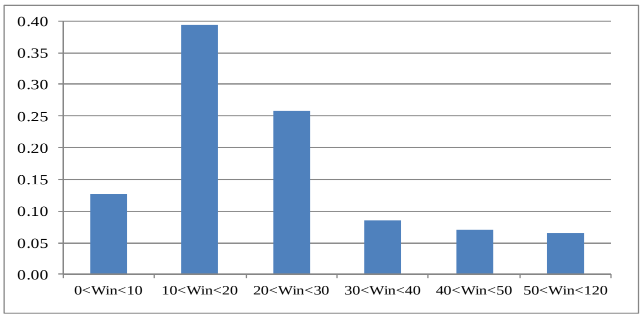
Probability of operation regimes Turbine discharge and generated energy			
0< Qtur <20	0.11	0< Wgen <10	0.12
20< Qtur <30	0.17	10< Wgen <20	0.35
30< Qtur <40	0.21	20< Wgen <30	0.29
40< Qtur <60	0.28	30< Wgen<40	0.13
60< Qtur <80	0.16	40< Wgen <50	0.08
80< Qtur<120	0.07	50< Wgen <100	0.02

The top side of the table shows the probability of inflow parameters as the water inflow and inflow expected energy corresponding to the water inflow. The inflow parameters are the main drive for the operating regimes for each hydro power plant. HPP Spilje can storage some of the water for 3-5 months depending on the hydrology and demand for generation of electricity in the grid. Therefore, on the bottom side of the table the operating parameters show the probability of turbine discharge and generated energy corresponding to turbine discharge. On Fig.2 and Fig.3 are presented the graphical overview of the numerical results from Tab.1.

The results of probability show that the expected inflow water over the turbine installed discharge is near 6% (Fig.2a), which correspond to spilling energy of the HPP Spilje.

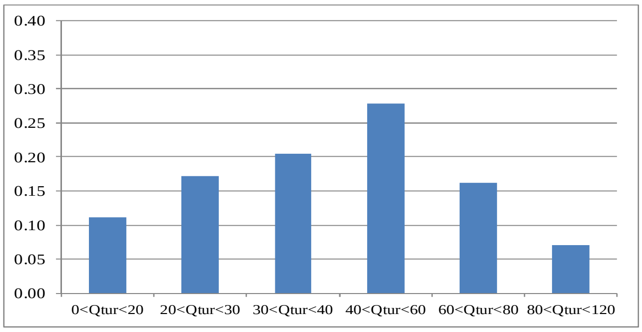


a) Water inflow probability

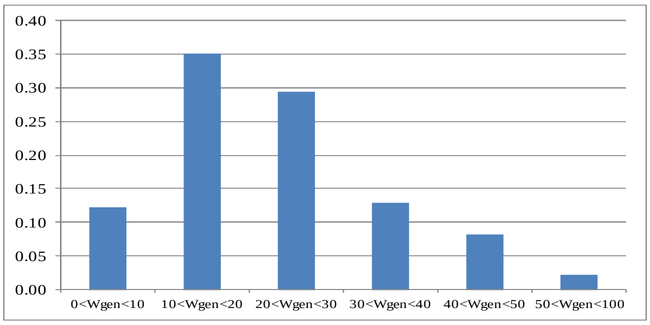


b) Energy inflow probability

Fig. 2. Probability of inflow parameters



a) Turbine discharge probability



b) Generated energy probability

Fig. 3. Probability of operating regimes of the HPP Spilje

The turbine discharge distribution (Fig.3a) shows relatively good matches with normal distribution around the average inflow. The highest probability of generation electricity is around 10-30 GWh in a month (Fig. 3b) which is nearly half of the maximum monthly production (Wmax =56 GWh in a month) for the gross head of 90 m.

IV. Monthly Distribution of the Probability for Inflow Parameters

The same analysis can be done for monthly probability distribution for the inflow parameters (water and energy inflow), as well as for the values of operating regimes for the 45 years of data. The values of probability show the expected energy inflow, and other relevant parameters needed for operating of the HPP. The energy which is generated from the HPP can be divided into three parts, as which are base energy, peak energy and spilling energy.

$$W(t) = W_{base}(t) + W_{peak}(t) + W_{spill}(t) \qquad (3)$$

The expected base load and peak load energy can be approached by the time interval of low tariff (for base load) and high tariff (for peak load) periods of the day. For the Power System from ELEM Macedonia, the low tariff is Tlow=7 hours in a day and the rest Thigh=17 hours is the peak load period. Therefore, the maximum generated monthly energy of HPP Spilje is around Wmax=56GWh.

If the Win<[Thigh/(Tlow+Thigh)]*Wmax, then the HPP can operate in peak regime. For HPP Spilje, if the Win>(17/24)x56 = 40 GWh, then the plant is operating in base load regime (low tariff). Therefore P(40<Win<50) is the probability to have base load energy. Over 50 GWh of inflow energy, or P(50<Win<120) is the probability to have spilling energy.

Tab.2 gives the monthly probability of inflow energy which gives the expected energy inflow for each month, which is very important for the planning point of view.

Table II

Probability of Inflow Energy Win Corresponding to Water Inflow Qin

Probability Win (GWh)	Jan	Feb	Mar	Apr	May	Jun
0<Win<10	0.02	0.13	0.02	0.00	0.00	0.00
10<Win<20	0.42	0.27	0.31	0.04	0.09	0.38
20<Win<30	0.27	0.47	0.36	0.33	0.22	0.33
30<Win<40	0.16	0.04	0.13	0.18	0.13	0.16
40<Win<50	0.09	0.07	0.11	0.22	0.18	0.11
50<Win<120	0.04	0.02	0.07	0.22	0.38	0.02

Probability Win (GWh)	Jul	Aug	Sep	Oct	Nov	Dec
0<Win<10	0.18	0.20	0.33	0.29	0.29	0.07
10<Win<20	0.51	0.71	0.62	0.60	0.40	0.38
20<Win<30	0.31	0.09	0.04	0.07	0.29	0.31
30<Win<40	0.00	0.00	0.00	0.04	0.02	0.16
40<Win<50	0.00	0.00	0.00	0.00	0.00	0.07
50<Win<120	0.00	0.00	0.00	0.00	0.00	0.02

The last two rows have the values of probability to operate in base load (40<Win<50) or to have spilling energy (50< Win<120). These probability values for base load and spilling energy in each month are presented graphically on Fig.4.

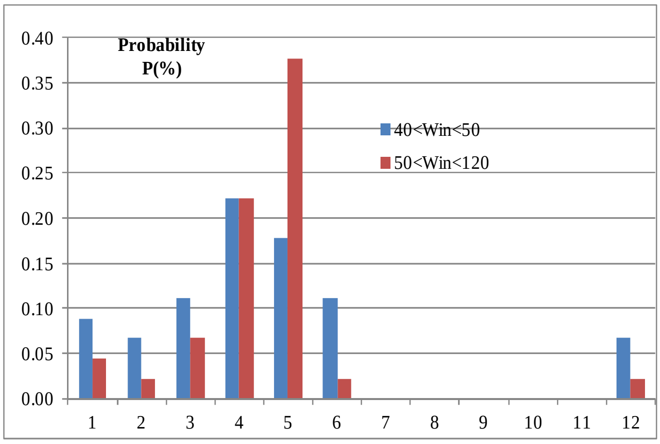
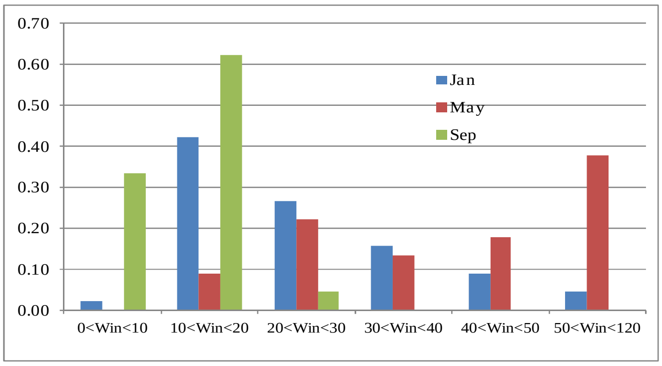
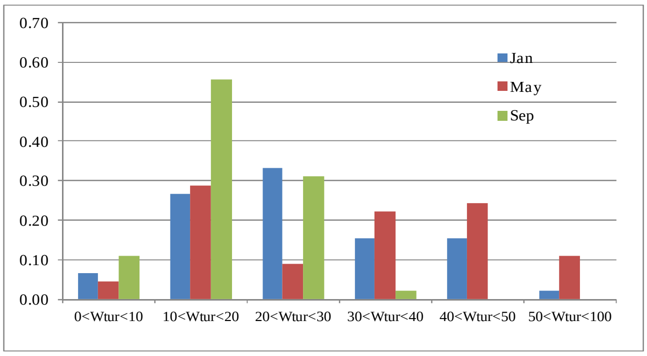


Fig. 4. Probability of operating in base load and spilling energy for each month in the year



a) Expected inflow energy probability



b) Generated energy probability

Fig. 5. Probability of inflow energy and generated energy for HPP Spilje for 3 typical months

The results show high probability to have spilling water and energy in April and May, and also high probability of operating in base load (from January until June).

Fig.5 presents the values of probability for inflow energy and generated energy for 3 selected months (January, May and September). The selected months are typically for winter period (January), spring period with highest inflow (May) and September with lowest inflow.

The results show that the represented months have different probability of operating regimes comparing with the inflow energy. January is typically winter month with middle inflow, and high generated energy which is needs of the request on electricity market. May is typically the period with the highest water inflow, but the requests of generated energy are smaller because of low demand. The high generated energy is mainly for the reason to avoid spilling water. This is the indicator for additional unit(s) in order to have more hours peak load in a day and to avoid spilling. September is typically month with low inflow water and low demand of energy.

V. Influences of Energy Parameters to the Financial Analysis of Hydro Power Project

The financial analysis is based on the economic and technical parameters of the hydropower project, with taking into account indicators such as energy and benefit from the HPP operation. The parameters needed as input variables for the analysis can be divided into 3 groups:

- Technical parameters (installed flow, number of units, head losses, the reservoir volume, the reservoir elevations)
- Energy parameters (installed power, electricity generation, tariff policy, transmission system limitation etc.).
- Economic parameters (investment, repayment period of the loan, construction period, discount rate, operating and maintenance costs, the cost of produced electricity, etc.).

The model can be described as a function of all three sets of input parameters as:

$$FINanalyse\_HPP = f(TEHNp, ENERGp, ECONp) \quad (4)$$

The technical parameters reflect the design of the project with all associated facilities: construction, mechanical and electrical design solutions. Energy parameters are closely related to the technical solution and the inflow water and operation modes of the HPP. Economic parameters as investment costs depend on the technical solution, time of construction, the discount rate and the rate of loans, prices of generated energy and power engaged, and the operation costs. After appropriate processing of the necessary input parameters, follows the financial calculations of economic indicators such as: NPV, B/C, IRR and PBP, which give a clear image for project feasibility.

Required input parameters of the model (technical data, energetic parameters and economic parameters) are:

- Installed capacity of the hydro power plant.
- Investments in power plant unit (includes all investments as material needs, equipment, installation, construction, etc.).
- Expected electricity production or CF-Capacity Factor.
- Economic parameters: time of repayment of the loan in years, a grace period of years, the rate of return of the loan, inflation rate, discount rate for all cash flows etc,.
- Operating life of the plant, number of years of operation for economic profit.
- Price of electricity in high and low tariff
- O&M costs of the plant are divided into fixed costs which do not depend on generated electricity (salary costs of employees and utility costs) and variable costs which are mostly for equipment maintenance and repair and depend on electricity production.
- Additional benefits such as subsidies for environmentally friendly facility (CDM project).

The annual or monthly income depends on electricity production in high and low tariff:

$$Income = \sum_{t=1}^{T} \left(Chigh(t) \cdot W_{HIGH}(t) + Clow(t) \cdot W_{LOW}(t) \right) \quad (5)$$

The data for water inflow and the operating data of energy generation, can give expected probability for certain value of generation electricity corresponding of technical and operating condition of the HPP.

VI. Conclusion

The hydro power plants are complex facilities which require large investment activities, which should certainly make a precise analysis of economic valuation. Taking into account the future uncertainties, the investors face risks of different nature, such as: financial risks, stock risks, political risks, technological risks and others.

Each project individually may have satisfactory financial performance and be appropriate positive and attractive for investment, or on the other side to have unacceptable economic parameters for investment.

The data of inflow parameters can give energy expectations of the HPP, which is necessary for operational modes of the hydro power plant as the followings:

- HPP operating for 24-hour demand in high and low tariff.
- Impact of water inflow or the distribution of electricity production in the long-term period of 30-40 years (various hydrological conditions of extremely dry, average and wet monthly inflows).
- Energy losses because of spilling energy in extremely wet periods.
- Expected lower revenue in extremely dry years.

Therefore, the contribution of the input data for water inflow, as well historical operation data of the hydro power plant is very important in order to calculated expected income from electricity generation. On the other hand, these analysis are very important for improve the technical performances of the HPP in increasing the installed turbine flow in existing units, or to install additional unit(s) in the power plant.

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