A NEW TECHNIQUE FOR HYDROPOWER ENHANCEMENT IN NEW ESNA BARRAGE

By

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Abstract

The annual report of The Ministry of Electricity and Power in Egypt states that about 22% of the total power in Egypt are hydropower. This indicates the importance of studying the different methods of increasing the Hydropower generation out of the fixed amount of water released downstream the major hydraulic structures in Egypt. This study is based on the point of view of the Ministry of Water Resources and Irrigation . However, it considers the data of the Ministry of Electricity. Three trials for identifying the hydro power generation from hydraulic structures such as New Esna Barrage was studied. These different methods consider analyzing the historical data of discharge and water level upstream and downstream the barrage during the period between (1996 – 2000). In addition, they depend on including the actual efficiency factor that is used in the hydro-power stations at this barrage in the general equation relating the electric power with the discharge and net head (difference of water level upstream and downstream barrage). The analysis concludes that the best equation that can be used for generation of electric power based on the discharge where the net water head is approximately constant is a linear type. The collected data during the same period were used for estimating the coefficients of these equations. Also, the calculated Hydropower was compared to the measured one. The statistical comparison showed that the calculated values are very close to the measured ones. This concludes that these linear equations may be used in the future for estimating the best values of the Hydropower that can be generated from this barrage.

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Introduction:

River Nile is the main source of water for Egypt. River Nile is the longest river in the world. Its basin area is estimated to be about 3.0 million square Kilometers. The river's natural flow pattern through Egypt had been characterized by two seasons: flood season, starts by the end of July and arrives its peak around the middle of September, and low flow season for the remainder of the year. This cycle is now controlled since the completion of Aswan High Dam at Aswan in 1968. The biggest consumed water arriving to Egypt are used in irrigation and the rest of consumed water is used for industrial, municipal, and navigation purposes. All these water are used simultaneously in power generation, [2]. Since 22% of the total power in Egypt is hydropower, therefore it is very important to maximizing the electric power generated from hydraulic structures.

Objectives:

1. Developing characteristic curves for the generated electric power related to discharge at different hydraulic structures with normal and critical years (very high flood years), such as year 1998/1999. New Esna Barrage has been taken as a case study in this research.
2. Prediction the value of generated hydropower based on the characteristic equations for every station, future discharges and turbines capacity.

The results of this study could serve the needs of engineers and decision-makers in the formulation and execution of schemes for maximum generation and utilization of electric power out of major hydraulic structures.

New Esna Barrage (NEB):

The new Esna barrage, located 1.2 km to the north of the old one. The main reasons that led to the construction of the new barrage are the followings, [3]:

- The continuous increase in the head difference due to degradation in the river channel downstream the old barrage.
- The need to raise upstream levels to supply the different canals with the required irrigation water
- To make use of the head difference between upstream and downstream to generate electrical power
- To develop the navigation lock to match the draught of the different types of vessel.

Electrical Works of NEB

The power plant structure is connected to the navigation lock on the left bank of the Nile river and its main characteristics are the following, [4]:

Length: 110 m   Width: 60m   Height: 28 m

Equipment: 6 bulb units each one with a generated capacity of 14.28 Mw

The power plant is equipped with six double-regulated low-head turbines called **Bulb Turbines** directly connected to generators. The energy produced by the generators is transferred to the network through a direct 132 K.V. double-cirect overhead line.

Discharge of NEB Hydro-electric Station

Discharge estimation was obtained by measuring flow velocities both upstream and downstream the powerhouse. The discharge at New Esna Barrage fluctuates from maximum value of 175 million.m^3 /day to minimum value of 40 million m^3 /day

Head of NEB Hydro-electric Station

The available net head at a hydropower site is usually equal, the difference between the up-stream water level and the down stream water level. The head fluctuated at New Esna Barrage between a maximum of 7.5 m, and a minimum of 3.5m.

NEB Type of Turbine

Bulb (or Tubular) Turbine: It is a Kaplan turbine, it is employed for very low head and has to be installed below the tailrace level. But with a modified axial flow, watertight assembly of turbine and generator with horizontal axis, submerged in a stream of water. The efficiency of such plants working under very low head is low due to excessive losses at the bends. The advantages of bulb sets are [5]:

1) The Bulb sets can be employed at very low head sites.
2) Maximum turbine efficiency is increased by about 3% due to almost straight flow and straight draft tube.
3) Under equivalent conditions of head, runner diameter and efficiency the bulb units are capable of passing higher discharge than the conventional Kaplan turbine.

Collected Data:

Water Levels Upstream and Downstream Barrages

Daily water levels measurements upstream and downstream the New Esna Barrage, are recorded automatically at the location in especial form. This data was obtained from the records in Esna Barrage. The complete records of water levels upstream and downstream Esna power station were collected for its service life from 1996 to 2000. The records in 1996 were not complete because the station was still in the testing period. Figure (1) represents net water head at NEB power station.

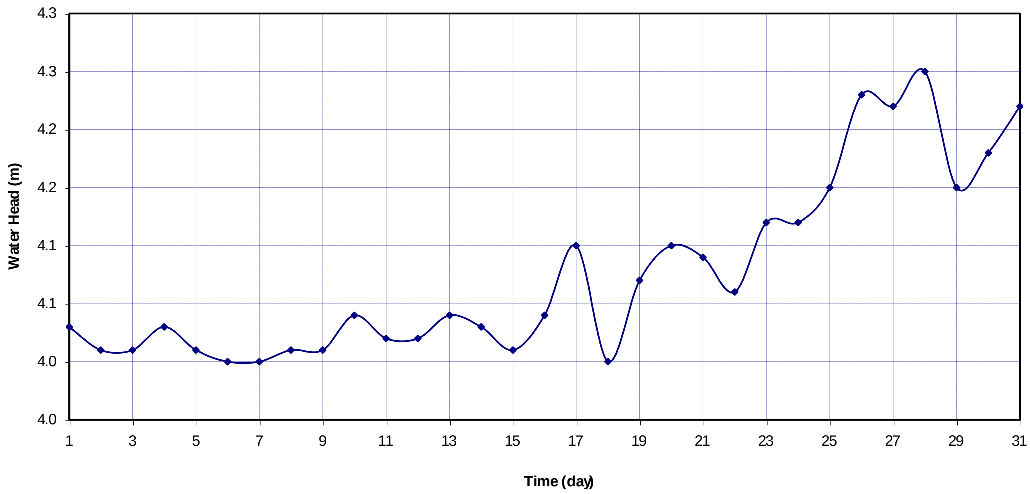

Fig.(1), Net Head & Time (day) at NEB power Station, July, Year 1999/ 2000

Water Discharge

There are two categories of recorded values for water discharge at every hydraulic structure. The first is the turbine discharge, while the second is the spillway discharge in million m^3/day. Where water discharge at turbines is measured by using electronic technique. At AHD the spillway discharge depends on the requirements of irrigation and navigation. If required water is more than the capacity of the turbines, the excess water passes over the spillway. The operation at NEB power station is considered especial case because the priority of operation is devoted to increasing the level of the river downstream of NEB so as to provide the required water for irrigation. Therefore the turbines water discharge sometimes equals zero; this means that no power is generated during that times, and all the water passes over the spillway. This policy occurred in the beginning of service life of the station and sometimes occurs during the maintenance period. Figure (2) indicates the discharges at the turbines of NEB for one-month (July), as an example. This figure shows the daily variation of the turbines water discharges and shows clearly that the discharge is not

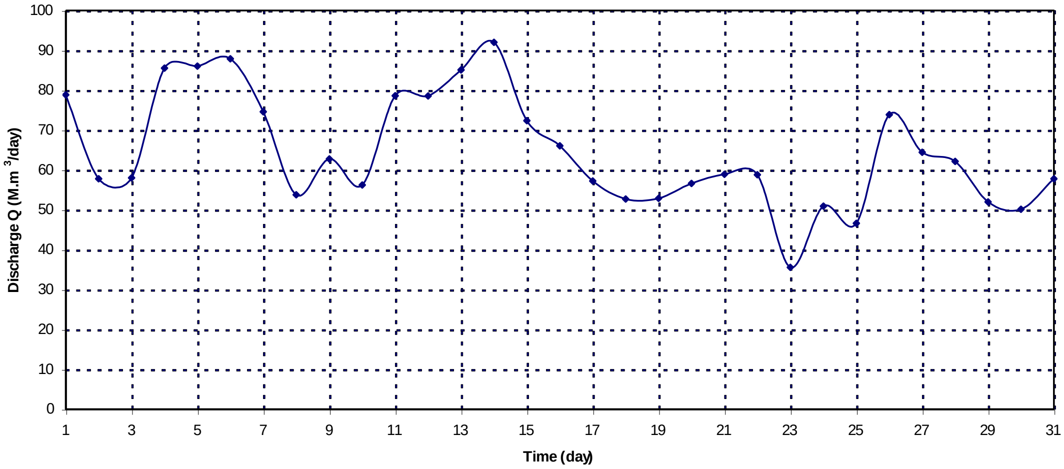

Fig. (2), Turbine Water Discharge & Time at NEB Power Station, July, Year 1999/ 2000

constant even within the same season. In this study, the turbine discharge is used to calculate the generated power at the station.

Efficiency Factor of Power Stations

The efficiency factors were collected from the annual reports of Ministry of Electricity and Energy, and presented in the following table.

Table (1), Historical annual efficiency for hydropower generation at NEB

Year	New Esna Barrage
1996 / 1997	82.7 %
1997 / 1998	82.2 %
1998 / 1999	81.1 %
1999 / 2000	82.0 %

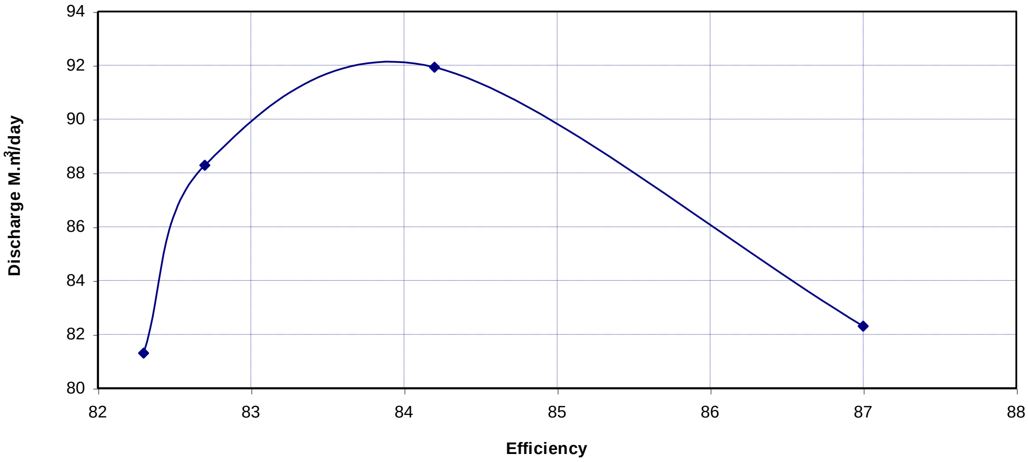

Fig. (3), Disharge & Efficiency Curve for NEB Power station From years 1996 - 2000.

General Equation of Hydro-Power

The generated electric power output of a hydropower plant is given by the following equation:

$$P = \frac{\eta \gamma Q \ H}{1000} \qquad (1)$$

Where

P = generated electric power output in (kW), Q = Water flow through the turbine in, m^3*/sec.*

H = net head of water in (m), *η = Station (turbine & generator) Efficiency factor*

γ = Specific weight of water (9810 N/m^3*).*

To calculate the available energy (E) that can be generated within 24 hours in (GWh), the generated electric power P in (KW) is used:

$$E = \frac{P}{1000 * 1000} * (24) \qquad (2)$$

Calculation of Energy

In this study, the daily measurements for each power station have been collected. The main data that were collected are:-

- Net water head difference (m)
- Daily water discharge (M. m^3/day) through turbines.

From equations (1 & 2), the daily-generated energy from any particular station was calculated using simple spread sheet calculations assuming the following:

i. The net water head is constant throughout the whole day and equals the reported value.

ii. The water discharge in m^3/sec is constant throughout the day and equals

$$\frac{Daily\ water\ discharge\ x10^6}{24\ x\ 60\ x\ 60}$$

iii. The station efficiency is constant throughout the year and equals the values reported in table (1).

Actual Generated Hydropower

The actual hydropower generated monthly, are presented in the annual report of the Ministry of Electricity and Energy for many years. The reported values of the three years 1997 / 1998, 1998 / 1999, and 1999 / 2000 for power station of NEB are used in the comparison with the estimated values of hydropower using the general equation. The actual and calculated values of the generated hydropower at the NEB station is presented in tables (2).

Table (2) Actual and Calculated values of Generated Hydropower at NEB Station (in GWh)

Month / ***Year***	1997/1998			1998/1999			1999/2000		
	Act.	Cal.	(Agr.)	Act.	Cal.	(Agr.)	Act	Cal	(Agr.)
July	25	26.3	1.05	22	23.2	1.05	18	18.2	1.01
August	40	39.9	1.00	20	21.67	1.08	18	19.2	1.07
September	28	36.4	1.3	3	2.87	0.96	8	10.5	1.3
October	40	39.8	1.00	-	-	-	26	23.7	0.91
November	22	16.8	0.76	17	18.46	1.09	26	23.9	0.92
December	28	29.2	1.04	37	34.2	0.92	40	37.2	0.93
January	36	35.3	0.98	38	37.87	1.00	48	40.5	0.84
February	40	46	1.00	28	30.56	1.09	46	49.7	1.08
March	48	50.8	1.06	39	40.05	1.03	54	55.5	1.03
April	46	47.9	1.04	30	33.59	1.11	50	51.7	1.03
May	30	36	1.2	29	29.7	1.02	27	30.1	1.11
June	-	-	-	24	22.97	0.96	-	-	-
Range of (Agr.)%	-24% to 30 %			- 8% to 11%			- 16% to 30%		

(Agr.) is the Agreement factor = (**Calculated Value / Actual Value) * 100**

The Confidence Percentage of Data

Table (3),The confidence percentage of data of NEB for years 1997-2000

No. of Months	Year 97/98	No. of Months	Year 98/99	No. of Months	Year 99/2000
6	96 - 98%	5	96 - 97%	3	97 - 99%
2	94 - 95%	5	91 - 92%	5	92 - 93%
3	70 - 80%	1	89%	3	70 - 89%

Out of the three tables we may estimate the confidence percentage of the data for NEB as follow:- Confidence = 1/3 [(0.97 * 6/11 + 0.945 * 2/11 + 0.75 * 3/11) + (0.965 * 5/11 + 0.915 * 5/11 + 0.89 * 1/11) + (0.98 * 3/11 + 0.925 * 5/11 + 0.795 * 3/11)] = 0.915

Confidence percentage = 92%

Estimation of the Characteristic Equation

There are different trials have been deduced for the estimation of the suitable equation to be used as a characteristic equation. By using Microsoft Excel version 97, The regression equation has been done for the water discharge in the horizontal (X- direction), while the generated hydropower is in the vertical direction.

The first equation was in the power type, it is in the following form

$$\mathbf{P = 10.12 * Q^{0.9235}}$$

The second equation was logarithmic type, it is in the following form:

$$\mathbf{P = 1031.4 * Ln (Q) - 4099.1}$$

The third equation was polynomial type of fourth degree, it is in the form

$$\mathbf{P = 1E\text{-}06*Q^4 - 0.0009*Q^3 + 0.2251*Q^2 - 15.79*Q + 834.34}$$

The fourth equation is linear type, it is in the form

$$\mathbf{P = 6.2449*Q + 97.122}$$

The comparison between these trials has been done by using standard deviation and standard errors, where they means that: Standard Errors of Estimation a measure of the variability of the observed around the regression line.

Out of this comparison, as indicated in table (4), it was found that the linear type should be the form of the characteristic equation.

Table (4), Comparison between Different types to chosse the Best Equation as a Characteristic equation for the Hydropower stations.

P power		**P poly.**	
Regression Output:		Regression Output:	
Constant	85.9802711	Constant	760.647109
Std Err of Y Est.	2.5738157	Std Err of Y Est.	106.136879
R Squared	0.99991972	R Squared	0.18707033
P log.		**P linear**	
Regression Output:		Regression Output:	
Constant	107.754761	Constant	97.122
Std Err of Y Est.	33.9790713	Std Err of Y Est.	6.191E-13
R Squared	0.98564818	R Squared	1

Three trials or alternatives have been done to estimate the characteristic equation. The first trial, named, average net water head, is based on three values for net water head. The second trial, named, equation for every year, is based on an equation was created from daily data for every year at every station individually. The third trial, named, general equation of all data, is based on all daily data for all years at every station.

Average Net Water Head

This trial is based on three average values of net water head. These average values give three equations at every power station, they were taken to estimate the generated hydropower at each power station for every year. The comparison between their results is based on actual data (daily net water head). The calculated average net water head is based on the month, the year, or data of all years. It means that in 48 months (four years) there are 48 different values for monthly average net water head, four different values for yearly average net water head in four years, and one value for average net water head according to data of all years.

The developed equations at NEB power station are:

$$P_{mon.} = 0.4974 * Q - 1.0356 \qquad \text{where} \quad H = 4.08 \ m \qquad (3)$$

$$P_{year.} = 0.4673 * Q \qquad \text{where} \quad H = 5.02 \ m \qquad (4)$$

$$P_{all\ yea.} = 0.4749 * Q \qquad \text{where} \quad H = 5.10 \ m \qquad (5)$$

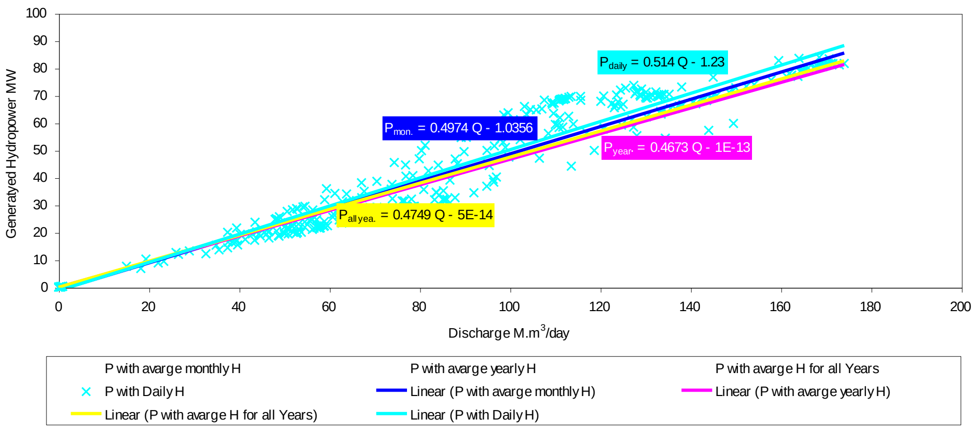

Fig.(4), First trial at NEB Power Station for Year (1999 / 2000) with different cases Net Water Head

Equation for Every Year

The main objective for this study is to develop one equation or more to represent the power station at each hydraulic structures to help the operator staff in the station at varying conditions of water irrigation to predict the generated power when the turbines discharge is known. In this alternative, there is one equation for every year created from its actual data and this equation has been applied on data of another year, i.e, equation of year 1999/2000 was applied on data of year 1998/1999, data of year 1997/1998, and data of year 1996/1997. This step is repeated on data of every year individually. If the equation for any year can represent the data for another year precisely, it will be concluded that this equation is the characteristic equation for this station. It was found that there is shift between the results of this trial and the results of the actual data. It was assumed that the results can be improved when the average of coefficients of all equations is used to create one equation at every power station for all years. The equation represents NEB power station is:

$$P_{av} = 0.474Q + 0.987 \qquad \text{where} \quad H = 5.10 \text{ m} \qquad (6)$$

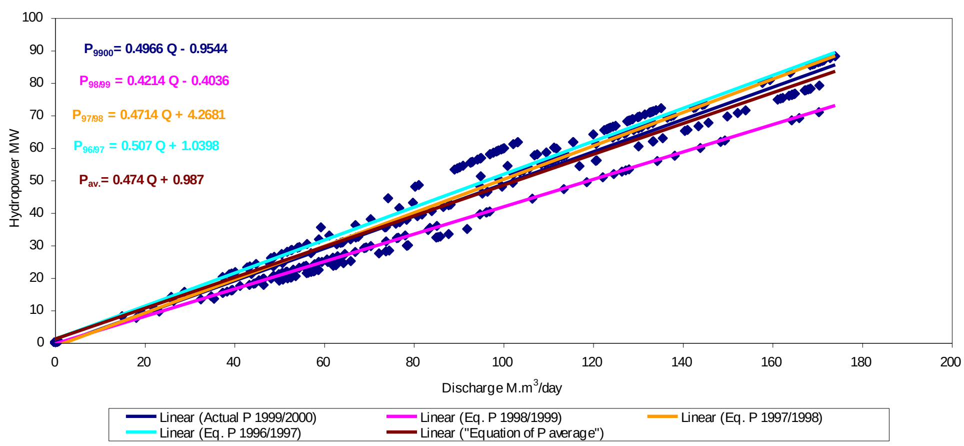

Fig.(5), Second trial (Equation for every year) at NEB Power Station for Year 1999 / 2000

General Equation of all data

In the third trial, the whole collected data for the period (1996 to 2000) were used to create one equation. This equation was applied with data of every year at the same station, i.e, the equation that was created from all data was applied on data of year 1999/2000 and equations of other years (1998/1999, 1997/1998, 1996/1997). To test the accuracy of this equation, it was applied for the data of each year individually with equations of other years.

The equation at NEB power station is:

$$P_t = 0.4748Q + 0.0254 \qquad \textit{where} \quad H = 5.10 \text{ m} \qquad (7)$$

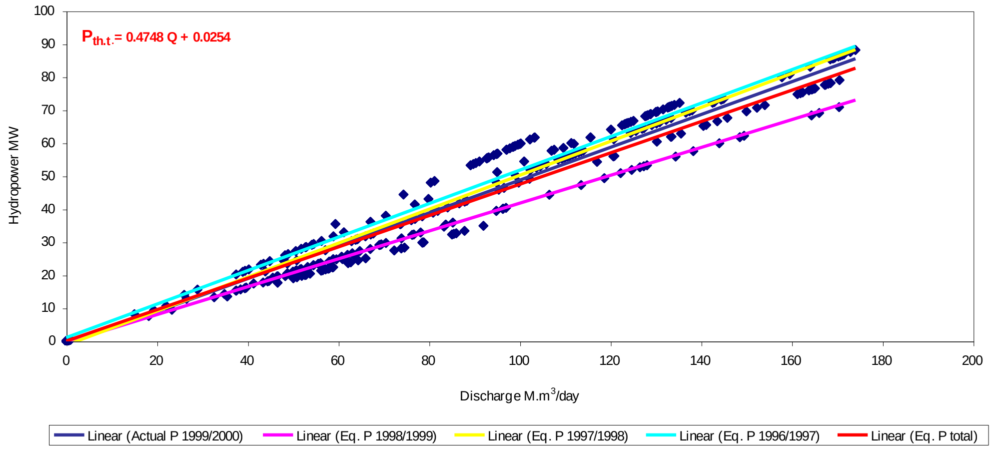

Fig.(6), Third trial (general equation for all data) at NEB Power Station for Year 1999 / 2000

Discussion of Results

First trial gives three equations, it was found that the best is P_{mon} because its results are very near to the actual data, but this is valid only for the same year. The second trial gives one equation, when applied on NEB power station it was found that there is slight difference between its curve and actual data curve. The third trial gives also one equation applied on data and the comparison of its results has been done. From the comparison between the results of all trials, which is indicated in tables (7, 8), it was found that the third trial equation are very near to the curves of actual data for all years except data of year 1998/1999. Therefore it was concluded that there are two characteristic equations at NEB power station, one represents the normal or (medium) flood years this indicated in fig. (8) and the second represents the high flood years this is indicated in fig. (9).

Table (7), Comparison between Actual and Estimated Values of generated hydropower at NEB Station

Year	Act. val.	Est. val1	Agr.Fact	Est.val2	Agr.fact	Est.val3	Agr.fact
96/97	416.4	426.67	1.02	364.65	0.87	367.18	0.88
97/98	394.3	410.96	1.04	328.19	0.83	369.79	0.94

98/99	288.9	295.14	1.02	358.02	1.24	330.74	1.14
99/00	351.6	360.32	1.02	334.43	0.95	336.73	0.96
Rang of Agr. Factor			4 to 2%		24 to -17%		14 to -12%

Table (8), Comparison between Estimated and Actual Values of Generated hydropower at NEB

Regression Output: Second Trial		Regression Output Third Trial	
Constant	0.987	Constant	0.0287
Std Err of Y Est.	2.55291E-14	Std Err of Y Est.	1.4E-14
R Squared	1	R Squared	1

The first characteristic equation for normal flood years is:

$$P_{ch} = 0.4748 * Q + 0.0254 \qquad \text{in} \quad (MW) \qquad (8)$$

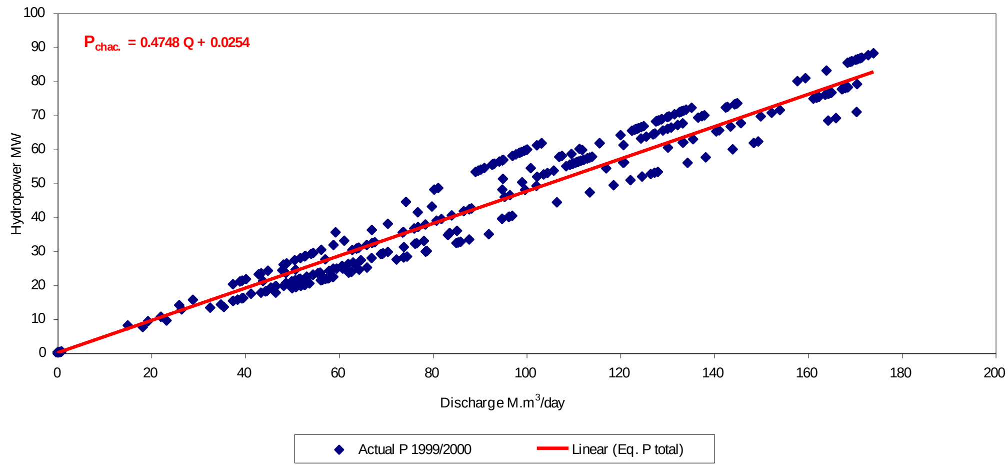

Fig.(7), Characteristic Curve represents normal years at NEB Power Station

The second characteristic equation for very high flood years is:

$$P_{98/99} = 0.4215 * Q - 0.408 \qquad \text{in} \quad (MW) \qquad (9)$$

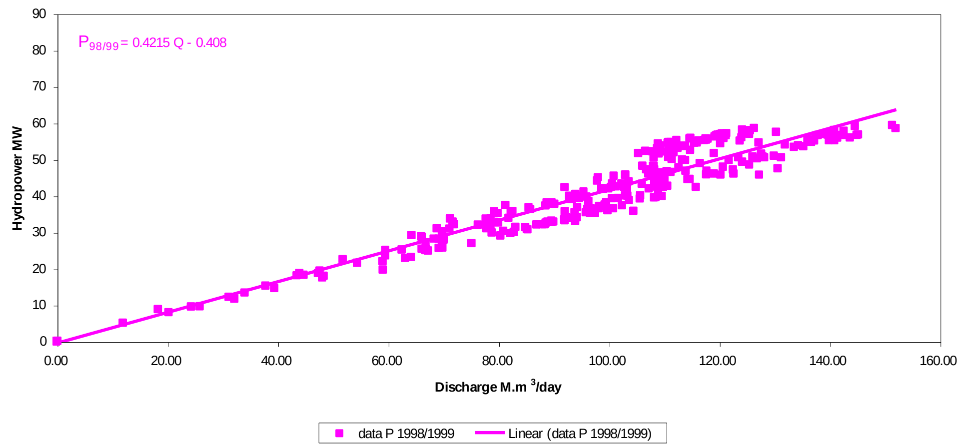

Fig.(8), Characteristic Curve represents Very high flood years at NEB Power Station

Conclusions

1. Different types of equations (Logarithmic, Polynomial, Power, and Linear) were applied on data to choose the suitable characteristic equation. The analysis and comparison indicated that the best representative form is the linear equation in the economical operational range.
2. There are two characteristic equations at NEB power station, one equation for normal or medium flood years (equation 8),and the second equation for high flood years(equation 9).
3. Based on calculated hydropower at different cases of net water head, it was found that the operation of NEB station isn't uniform.

Recommendations:

1. More studies are required to develop the operation strategy at the hydropower station of New Esna Barrage station.
2. Regulation of operation periods for generated hydropower at all hydropower stations will help the operators and decision-makers to increase the generated hydropower during high seasons of discharges and to execute the maintenance during seasons of low discharges.
3. The same procedure of estimation the characteristic equation of NEB can be applied at the other main hydraulic structures.

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