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OPTIMAL WATER MANAGEMENT MODELING FOR HYDROPOWER SYSTEM ON RIVER NIGER IN NIGERIA

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ABSTRACT: *The paper presents optimal water management modeling for a hydropower system, the optimization model considered the uncertainties in reservoir inflow subject to physical, operational and environmental constraints. The model consists of an objective function to maximize energy generation, while reservoir characteristics and flood control are incorporated in the constraints. Application of the model was made to a hydropower system on the River Niger in Nigeria and the formulated model was solved with LINGO software. The values of the energy generation and reservoir hydrology such as storage and turbine releases were determined. The results were used to formulate the operational guide for the system using various scenarios. Water management options (scenarios) were analyzed by considering percentage increase in the upper limit of active storage at the upstream reservoir and historical upper limit of turbine releases at both reservoirs on energy generation. Mean reservoir inflow was used for the scenario and the energy value obtained was compared with the historical observed mean energy obtained based on conventional operation. The analysis revealed that an optimal energy of 5995.60 GWH can be generated, which is about 41% higher than the average energy generation of 4261.12 GWH obtained from the historical records at the power plants. The study also revealed that flood wall with the crown level at 76.50m (a.m.s.l) would be sufficient to prevent flooding downstream of Jebba dam.*

KEYWORDS: *hydropower system, reservoir operation, linear programming, water management, flood control*

INTRODUCTION

Optimization techniques are used in water resources planning and management to model and study different types of problems relating to water supply, flood control, reservoir systems, hydropower operation, irrigation, etc. Model results are very helpful in providing information and relevant data, to formulate alternative plans and strategies (Johnson, 1972). When a system contains multiple hydropower units the problem is further complicated due to high dimensions introduced via the state and control variables, as well as the seasonal and cyclic variability of stochastic quantities like the reservoir inflows. These notwithstanding, investigators have employed different optimization techniques to derive regulating policies for multidimensional hydropower systems (Trott and Yeh, 1973 and Turgeon, 1980). Some of these works were mainly concerned with maximization of hydropower benefits subject to constraints on flood control, navigation and recreation. In the cases cited, the methods of analysis were based on Linear Programming (LP), Dynamic Programming (DP) or other system analysis methods and were either deterministic or stochastic. The advent of computers has greatly enhanced the development of algorithms to solve various types of optimization problems. But the key to successful implementation of any model rests on the ability to take advantage of the system features that lead to simpler mathematical models and of the proper choice of solution algorithms to overcome dimensionality and stability problems (Marino and Loaiciga, 1985).

The application of LP to water resources field is traced back to the early 1960s (Simonovic, 1992). Yeh (1985) reviews the "state of art" in LP models; his examination includes stochastic LP models, stochastic programming with recourse, chance-constrained LP, and linear decision rules. Based on the review, he concluded that LP is a useful tool for the optimization of reservoir operations. In particular he stated that through the use of linearization techniques (e.g., piecewise linearization and Taylor series expansion), LP can be used to successfully model non-linear constraints and objectives. Additional reasons for the popularity of LP cited by Yeh (1985) and Wurbs (1993) are : (i) it is a well defined and easily understood technique; (ii) the ability with which problems of relatively large dimension, as compared to other methods, can be solved; (iii) global optima are obtained; (iv) an initially feasible trial policy is not required; and, (v) commercial programs are widely available, so that the method does not need to be developed from scratch for each application.

Falguni and Kumar (2001) applied stochastic linear programming (SLP) technique for optimal operation of Hirakud reservoir in Mahanadi river basin of Orissa State, India. The investigators revealed that linear programming (LP) has the advantage over dynamic programming (DP) in that there is availability of standard well defined algorithms and also there is no dimensionality problem. However, the limitation to the use of SLP is that a separate program needs to be developed to incorporate the uncertainty of inflow and to insert the LP parameters in the LP package. With the availability of powerful packages to solve SLP problems, such as LINGO, the above difficulties are overcome and the application of SLP to practical problems became easy to handle. LINGO is capable of solving linear, nonlinear and integer programming problems. LINGO uses the branch-and-bound algorithm to deal with the integer variables. The details of LINGO are described in the LINGO 6.0 and LINGO 10.0 user's guide.

Bosona and Gebresenbet (2010) modeled and studied Melka Wakana Hydropower plant in Ethiopia using Powersim Simulation software. Mean monthly data of reservoir inflow, evaporation rate, historical energy production, turbine discharge and reservoir elevation were used as time series input data. The results of the simulation analyses indicated that the annual energy production was increased by 5.67% while evaporation loss was reduced by 38.33%.

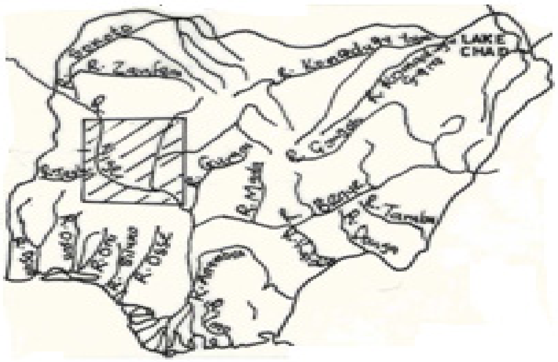

Figure 1.a. Map of Nigeria showing study area hatched

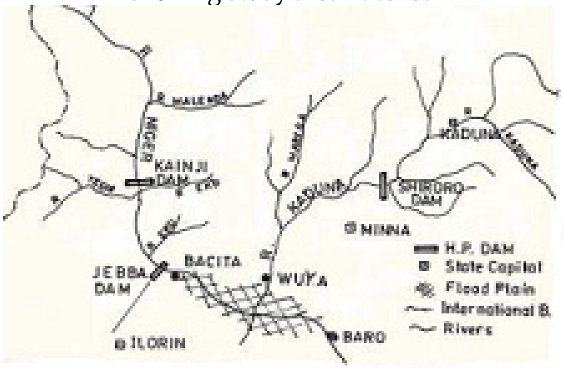

Figure 1.b. Location of hydropower dams and flood plain

DESCRIPTION OF THE STUDY AREA

The Kainji, Jebba and Shiroro hydroelectric power projects are the hydropower schemes in Nigeria. They have installed capacities of 760 MW, 560 MW and 600 MW respectively and a total output of 1900 MW. Hydropower (HP) is one of the few sources of energy that has assumed great significance since the beginning of the twentieth century. One major reason that makes HP attractive is that water, like wind and sun, is a renewable resource and is sustainable through the hydrologic cycle. Moreover HP systems are easy to run and generally have low maintenance cost compared to other sources of energy (Aribisala and Sule, 1998). The location of the hydropower reservoirs, irrigation projects and the flood prone lowland areas are presented in Figure 1.

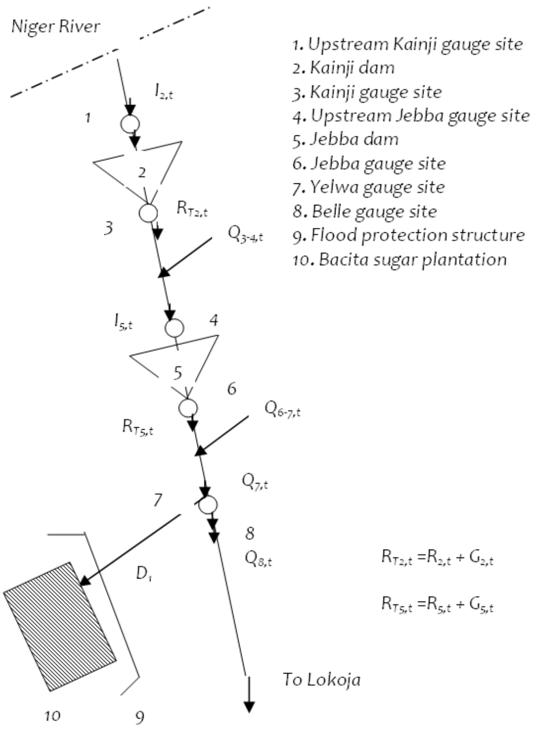

Figure 2. System diagram of the study basin

Table 1. Basic Data on the Hydropower System

	Kainji	Jebba
First year of operation	1968	1984
Installed capacity (MW)	760	560
Design power plant factor	0.86	0.70
No. of generators	8	6
Reservoir flood storage capacity (Mm^3)	15,000	4,000
Reservoir flood level (m)	143.50	103.55
Maximum operating reservoir elevation (m.a.s.l)	141.83	103.00
Minimum operating reservoir elevation (m.a.s.l)	132.00	99.00
Maximum storage (Mm^3)(active storage capacity)	12,000	3,880
Minimum storage (Mm^3)(Dead storage capacity)	3,000	2880

Source: Power Holding Company of Nigeria (PHCN) 2003

METHODOLOGY - SYSTEM ARRANGEMENT

The reservoir arrangement, irrigation projects, and the lowland areas are represented schematically as a line diagram in Figure 2. The system under consideration has six flow gauge sites (at sites 1, 3, 4, 6, 7, and 8) a flood prone area at site 9, two hydropower reservoirs (at sites 2 and 5), and an irrigation projects at site 10. Table 1 shows the basic data on the Kainji – Jebba Hydro Electric Power system.

DEVELOPMENT OF LONG RANGE OPERATIONAL GUIDE FOR KAINJI AND JEBBA H.P DAMS

Optimization methods are basic tools, which are useful in reservoir management studies. The problem of optimal reservoir operations consists of obtaining optimal releases, reservoir storage and downstream reach routed flows based on forecasted inflows. In formulating the models the time step can be yearly, monthly, weekly, daily or hourly. For hydropower operations coupled with flood control or other uses daily and hourly time steps are more appropriate. However, when available data for the analysis are not in appropriate form, as is the case with system of interest, then a larger time steps will be used.

The model with monthly time step can be said to describe a long range operation problem. In such a case the stochastic influences of the inflows have to be considered (Yeh and Becker 1982). The stochastic aspect was handled by fitting the monthly reservoir inflow with normal probability distribution. In this study the two reservoirs in the basin were considered as a single system and the optimal monthly releases from the reservoirs were determined subject to various constraints. Maximization of energy output was considered as the objective function, while reservoir characteristics, the irrigation requirements and flood control were included in the constraints.

The objective function for the long term operation of the system is to maximize the total annual energy generation over the two hydropower plants. Using the numbering system in Figure 2 and a monthly time step (Salami 2007) the objective function is:

$$Z = Max \sum_{i=\{2,5\}} \sum_{t=1}^{12} (A_{i,t}R_{i,t} + B_{i,t}S_{i,t} + C) \tag{1}$$

where: A_{it} = coefficients for turbine releases in the linear objective function, B_{it} = coefficients for reservoir storage in the linear objective function, C = constant in the linear objective function.

Equation (1) is subject to the following constraints

The mass balance equation between the inflows and the outflows is given as:

a) Kainji hydropower dam

$$S_{2,t+1} = S_{2,t} + I_{2,t} - R_{2,t} - L_{2,t} - \overline{G}_{2,t} \qquad t = 1 \quad to \quad 12 \tag{2}$$

b) Jebba hydropower dam

$$S_{5,t+1} = S_{5,t} + I_{5,t} - R_{5,t} - L_{5,t} - \overline{G}_{5,t} \qquad t = 1 \quad to \quad 12 \tag{3}$$

The limit on reservoir capacity is given as

a) Kainji hydropower dam

$$S_{2,t\,min} \le S_{2,t} \le S_{2,t\,max} \qquad t = 1 \quad to \quad 12 \tag{4}$$

b) Jebba hydropower dam

$$S_{5,t\,min} \le S_{5,t} \le S_{5,t\,max} \qquad t = 1 \quad to \quad 12 \tag{5}$$

The limit on turbine release is given as follows

a) Kainji hydropower dam

$$R_{2,t\,min} \le R_{2,t} \le R_{2,t\,max} \qquad t = 1 \quad to \quad 12 \tag{6}$$

b) Jebba hydropower dam

$$R_{5,t\,min} \le R_{5,t} \le R_{5,t\,max} \qquad t = 1 \quad to \quad 12 \tag{7}$$

Sites 7 and 8: Water available for downstream users depends on turbine release, lateral inflow and excess release (if there is any)

$$\begin{aligned} Q_{7,t} &\le R_{5,t} + Q_{6-7,t} + G_{5,t} \qquad t = 1 \quad to \quad 12 \\ Q_{8,t} &= Q_{7,t} - D_{10,t} \end{aligned} \tag{8}$$

Sites 9 and 10: Limits on flood at Bacita sugar plantation depends on available water for downstream users

$$Q_{8,t} \le q_9 \qquad t = 1 \quad to \quad 12 \tag{9}$$

where: $S_{2,t}$ = Kainji reservoir Storage (Mm^3); $S_{5,t}$ = Jebba reservoir Storage (Mm^3); $R_{2,t}$ = Releases from Kainji reservoir (Mm^3); $R_{5,t}$ = Releases from Jebba reservoir (Mm^3); $Q_{7,t}$ = Available water for downstream users including irrigation(Mm^3); $Q_{6\text{-}7,t}$ = Runoff from catchment from Jebba to site 7 (Mm^3); $Q_{8,t}$ = Available water for downstream users excluding irrigation(Mm^3); $D_{10,t}$ = Diversion water for irrigation at downstream of Jebba dam (Bacita) (Mm^3); $q_{9,t}$ = Limit on flood flow (Mm^3); $G_{2,t}$ = Spillage from Kainji reservoir (Mm^3) ; $G_{5,t}$ = Spillage from Jebba reservoir (Mm^3)

MODEL SOLUTION FOR HISTORICAL MEAN FLOW

In solving the formulated model for the hydropower reservoir system and to estimate other associated parameters, a software (LINGO 10.0 Version) was used. The optimal solution obtained gave the total annual energy of 5339.70 GWH. The values of reservoir storage and turbine releases along with other parameters are presented in Table 2.

Table 2. Model results based on historical mean reservoir inflow

Parameters	$R_{2,t}$ (Mm^3)	$S_{2,t}$ (Mm^3)	$R_{5,t}$ (Mm^3)	$S_{5,t}$ (Mm^3)	Z_t (GWH)	$Q_{8,t}$ (Mm^3)
Value	33889.03	101840.88	31681.22	43812.76	5339.73	33825.78

MODEL SOLUTION FOR RESERVOIR INFLOW OF DIFFERENT RELIABILITIES

The optimization model was also solved by considering the forecasted reservoir inflows of 75%, 70%, 60%, 50% and 40% reliabilities. The values of energy generation and reservoir hydrology based on forecasted reservoir inflow of different reliabilities are presented in Table 3.

Table 3. Energy generation and reservoir hydrology based on forecasted reservoir inflow

Reliability (prob. of excedence)	Total energy (GWH)	Total turbine release (Mm^3)		Total reservoir inflow (Mm^3)		Average reservoir storage (Mm^3)	
		Kainji	Jebba	Kainji	Jebba	Kainji	Jebba
75%	4144.16	27017.7	23555.1	22809.5	23231.7	8462.45	3572.84
70%	4431.04	28584	25407.4	22809.5	23231.7	9049.84	3570
60%	4913.01	31312.3	28634	27336.2	28608.0	8799.83	3646.67
50%	5339.72	33889	31681.4	30052.2	31833.7	8486.89	3651.06
40%	5738.92	36840.7	34044.8	32768.2	35059.5	8003.72	3608.91

WATER MANAGEMENT OPTIONS (SCENARIOS)

The scenarios for water management are the alternative ways by which the reservoir operation can achieve optimal energy generation. The scenarios considered were:

(a) The effect of percentage increase in the upper limit of active reservoir storage at Kainji (upstream reservoir) on the energy generation. The percentage increases considered were 5%, 10% and 15%.

(b) The effect of percentage increase in the upper limit on historical or conventional turbine releases at both reservoirs on the energy generation. The percentage increases considered were 10%, 20%, 30%, 40% and 50%.

(c) The effect of combinations of (a) and (b) on the energy generation. In this case, the effect of certain percentage increase in the upper limit of active reservoir storage at Kainji combined with various percentages increase in the historical or conventional turbine releases at both reservoirs on energy generation were investigated.

The values of the upper limits of reservoir storage and turbine releases based on operational and design data are presented in Table 4, while the upper limits with the percentage increase in turbine releases and reservoir storage for the scenarios are presented in Table 5.

Table 4. The upper and lower limits of reservoir storage and turbine releases based on operational and design data

Reservoir parameters		Kanji reservoir	Jebba reservoir
Turbine releases (Mm^3)	Upper limit (historical)	3900.00	3550.00
	Lower limit (historical)	500.00	800.00
Reservoir storage (Mm^3)	Upper limit (active)	12000.00	3880.00
	Lower limit (dead)	3000.00	2880.00

Table 5. The upper limits with the percentage increase in turbine releases and reservoir storage for scenarios cases

Percentage increase on historical turbine releases (%)	Upper turbine release limit with percentage increase (Mm^3)		Percentage increase on upper active reservoir storage (%)	upper active storage limit with percentage increase (Mm^3)
	Kainji reservoir	Jebba reservoir		Kainji reservoir
0%	3900.00	3550.00	0%	12000.00
10 %	4290.00	3905.00	5%	12600.00
20 %	4680.00	4260.00	10%	13200.00
30%	5070.00	4615.00	15%	13800.00
40%	5460.00	4970.00		
50%	5850.00	5325.00		

Figures 3 and 4 show the various storage zones for Kainji and Jebba reservoir respectively. The Figures show the convectional rule curves (three levels of storage) i.e firm storage, target storage and flood control storage. The increase in upper limit of Kainji storage can be achieved by claiming part of the flood storage as target storage. For the purpose of this study, the upper active storage limit for lower reservoir (Jebba reservoir) was maintained at the same value for all scenarios. This is to allow for the designed flood control capacity and to cater for any extra releases that might result from the upper reservoir (Kainji reservoir).

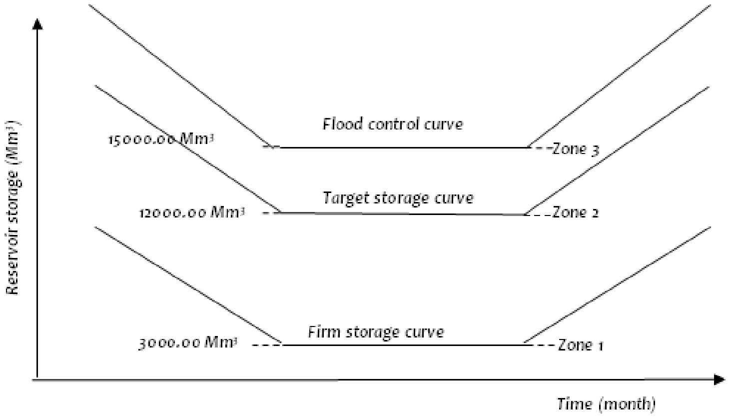

Figure 3. Rule curves for a multipurpose reservoir (Kainji dam)

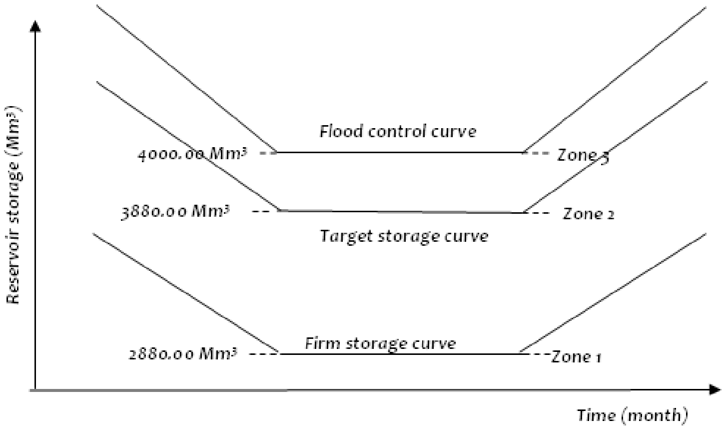

Figure 4. Rule curves for a multipurpose reservoir (Jebba dam)

□ ***Scenario one*** *(Increase in active reservoir storage zone at Kainji)*

The result of the effect of percentage increase in the upper limit of active reservoir storage at Kainji reservoir (upper reservoir) on energy generation shows that the values of energy corresponding to 0%, 5%, 10% and 15% increase are 5339.72, 5420.72, 5499.63, and 5574.16 GWH respectively. The percentage increase in energy generation is 25.31%, 27.21%, 29.07% and 30.80% respectively over the historical energy output of 4261.12 GWH. This implies that with the mean reservoir inflow without physically increasing the storage at Kainji reservoir, an additional 25% increase in energy generation compared to the average value of energy from the historical data is realizable. However, with the percentage increase in upper limit of active storage at Kainji by 5%, 10% and 15%, the corresponding increase in energy generation compared to the average value obtained from historical data (convectional operation) is about 27%, 29%, and 31% respectively.

□ ***Scenario two*** *(Increase in turbine releases at both reservoirs)*

The result for the effect of increase in upper limit of the historical or conventional turbine releases at both reservoirs on energy generation based on the mean reservoir inflow shows that the values of energy corresponding to 0%, 10%, 20%, 30%, 40% and 50% increases at both reservoirs are 5339.72, 5443.96, 5524.39, 5606.22, 5686.72 and 5752.56 GWH respectively. The average value obtained from historical energy generation is 4261.12 GWH. This shows that with 0%, 10%, 20%, 30%, 40% and 50% increases in upper limit on the historical or conventional releases at both reservoirs the corresponding increases in energy generation were 25%, 28%, 30%, 32%, 34% and 35% respectively. These can be achieved without any changes in active storage zone at both reservoirs.

□ ***Scenario three*** *(Increase in storage at Kainji and in turbine releases at both reservoirs)*

The results for scenario 3, which is the combined effect of increase in upper limit of active storage at Kainji with various percentage increases in turbine releases at both reservoirs showed that the values of energy corresponding to 5% increase in the upper limit of active reservoir storage at Kainji reservoir (12600.00 Mm^3) combined with 0%, 10%, 20%, 30%, 40% and 50% increases in upper limit on the historical or conventional turbine releases at both reservoirs were 5420.72, 5520.53, 5604.35, 5684.29, 5768.14, and 5826.95 GWH respectively. The percentage increases are 27.21%, 29.56%, 31.52%, 33.4%, 35.37% and 36.75% respectively over the historical energy output of 4261.12 GWH.

The values of energy corresponding to 10% increase in the upper limit of active reservoir storage at Kainji reservoir (13200.00 Mm^3) combined with 0%, 10%, 20%, 30%, 40% and 50% increases in upper limit on the historical or conventional turbine releases at both reservoirs were 5499.63, 5599.22, 5686.42, *5764.66, 5841.31, and 5910.21 GWH respectively. The percentage increase are 29.07%, 31.40%, 33.45%, 35.29%, 37.08%, and 38.70% respectively over the mean historical energy output of 4261.12 GWH.*

The values of energy corresponding to 15% increase (13800.00 Mm^3) in the upper limit of active reservoir storage at Kainji reservoir combined with 0%, 10%, 20%, 30%, 40% and 50% increases in upper limit on the historical or conventional turbine releases at both reservoirs. The corresponding values of energy generation are 5574.16, 5680.03, 5767.38, 5847.33, 5920.99, and 5995.60 GWH respectively. The percentage increases are 30.81%, 33.30%, 35.35%, 37.23%, 38.95%, and 40.70% respectively over the historical mean energy output of 4261.12 GWH.

The result of scenarios with increase on the upper limit of active reservoir storage at Kainji on energy generation is summarized in Table 6, while that with increases on the upper limits of active reservoir storage at upper reservoir and turbine releases at both reservoirs on energy generation is presented in Table 7. The values of annual energy generation along with the total turbine releases and the percentage increase in upper limit of reservoir storage at the upper reservoir are presented in Table 8. More importantly, the summary of the results presented in Tables 6, 7 and 8 are used in recommending various operational guides.

Table 6. Effect of increase in upper limit of active storage at Kainji for mean annual flow

% increase in active storage, S (Kainji)	% increase in total energy	Annual energy (GWH)	Turbine releases (Mm^3)	Average reservoir storage (Mm^3)
0%	25.31	5339.72	65570.37	12137.96
5%	27.21	5420.72	66170.40	12404.56
10%	29.07	5499.63	66770.40	12721.35
15%	30.81	5574.16	67370.40	12971.35

Table 7. Effect of increase in upper limit of active reservoir storage at Kainji and turbine releases at both reservoirs on energy generation for mean annual flow

	ΔS=0%	ΔS=5%	ΔS=10%	ΔS=15%
% increase on historical turbine releases	% increase in total energy	% increase in total energy	% increase in total energy	% increase in total energy
0%	25.31	27.21	29.07	30.81
10%	27.76	29.56	31.40	33.30
20%	29.65	31.52	33.45	35.35
30%	31.57	33.40	35.29	37.23
40%	33.46	35.37	37.08	38.95
50%	35.00	36.75	38.70	40.70

Table 8. Values of annual energy generations and turbine releases for mean annual flow

ΔS=0%		ΔS=5%		ΔS=10%		ΔS=15%	
Turbine releases (Mm^3)	Energy (GWH)	Turbine releases (Mm^3)	Energy (GWH)	Turbine releases (Mm^3)	Energy (GWH)	Turbine releases (Mm^3)	Energy (GWH)
65570.40	5339.72	66170.70	5420.72	66770.40	5499.63	67370.00	5574.16
66315.40	5443.96	66915.40	5520.53	67515.40	5599.22	68115.40	5680.03
67060.40	5524.39	67660.40	5604.35	68260.40	5686.42	68860.40	5767.38
67805.40	5606.22	68405.40	5684.30	69005.40	5764.66	69605.40	5847.34
68550.40	5686.72	69150.40	5768.14	69750.40	5841.31	70350.40	5920.99
69395.40	5752.56	69895.40	5826.95	70495.40	5910.21	71095.40	5995.60

N.B Average energy from historical data = 4261.12 GWH

OPERATION GUIDES

☐ *UPPER LIMIT STORAGE AND TURBINE RELEASES BASED ON DESIGN AND OPERATIONAL DATA*

At the beginning of the year, which is January, the storage at Kainji and Jebba should be at upper level (that is 12,000 Mm^3 and 3880 Mm^3 respectively). Based on the above condition the following annual energy generation and turbine releases can be achieved.

(i) Total energy of 4144.16 GWH can be generated when the turbine releases are 27017.73 Mm^3 and 23555.14 Mm^3 at Kainji and Jebba respectively.

(ii) Total energy of 4485.62 GWH can be generated when the turbine releases are increased to 28967.73 Mm^3 and 25330.14 Mm^3 at Kainji and Jebba respectively.

(iii) Total energy of 5339.72 GWH can be generated when the turbine releases are increased to 33889.00 Mm^3 and 31681.37 Mm^3 at Kainji and Jebba respectively.

(iv) Total energy of 5752.56 GWH can be attained by increasing the turbine releases to 35939.03 Mm^3 and 33456.37 Mm^3 at Kainji and Jebba respectively.

Increase in turbine release can be achieved by increasing the number of turbines in operation. The release from Jebba reservoir which depends on the release from Kainji reservoir has to be regulated to alleviate flooding of the downstream project and villages. The Jebba reservoir releases for the optimal energy generation is 33456.37 Mm^3 annually, which is an average of 2788.03 Mm^3 monthly. The average storage at Jebba is 3646.67 Mm^3 for generating such energy; this implies that a storage space of 233.33 Mm^3 will be available at Jebba since the maximum active storage is 3880.00 Mm^3.

Also for this energy generation, Kainji reservoir release is 35939.03 Mm^3 annually, which is an average of 2994.92 Mm^3 monthly. The implication is that, Jebba reservoir has to provide storage for the difference between average releases at Kainji and Jebba, which is 206.89 Mm^3. The storage space of 233.33 Mm^3 at Jebba can absorb extra release of 206.89 Mm^3. Consequently the storage at Jebba will rise to 3853.56 Mm^3 which is still less than 3880 Mm^3. Therefore, additional flood problem will not occur as a result of generating such amount of energy.

☐ UPPER LIMIT STORAGE AT KAINJI INCREASED BY 5% AND UPPER LIMIT RELEASES AT BOTH RESERVOIRS INCREASED BY 50%

At the beginning of the year, the storage at Kainji should be maintained at 12600 Mm^3 (5% higher) and the storage at Jebba should be at 3880 Mm^3. Increase in upper limit of active storage at Kainji can be achieved by claiming some space out of the flood control storage by raising the spillway gate (mechanical control). In this case an annual total energy of 5826.95 GWH can be attained with turbine release of 36439.00 Mm^3 and 33456.40 Mm^3 at Kainji and Jebba respectively.

Also in this case Jebba reservoir releases an average of 2788.03 Mm^3 monthly with average storage of 3646.67 Mm^3. This also provides an empty space of 233.33 Mm^3 since the maximum storage is 3880 Mm^3. For the generation of this energy, Kainji reservoir releases an average of 3036.59 Mm^3 monthly. Jebba reservoir has to provide storage for the difference which is (3036.59-2788.03 =) 248.56 Mm^3. This would leave an average of 15.23 Mm^3 of water to cater for, when 233.33 Mm^3 empty space in the reservoir is filled up. The excess water (15.23 Mm^3) can be stored by claiming part of the space for flood control (zone 3 of Jebba). The water can then be released gradually to generate more energy at Jebba dam.

☐ UPPER LIMIT STORAGE AT KAINJI INCREASE BY 10% AND UPPER LIMIT RELEASES AT BOTH RESERVOIRS INCREASE BY 50%

At the beginning of the year, the storage at Kainji should be maintained at 13200 Mm^3 (10% higher) and the storage at Jebba should be at 3880 Mm^3. In this case an annual total energy of 5910.21 GWH is attained with turbine release of 37039.03 Mm^3 and 33456.40 Mm^3 at Kainji and Jebba respectively.

Also in this case Jebba reservoir releases an average of 2788.03 Mm^3 with average storage of 3646.67 Mm^3. With the increase in turbine releases at Kainji, the possibility of flooding problem at Jebba is investigated. At Jebba reservoir an empty space of 233.33 Mm^3 is available to store part of excess release from Kainji. For the generation of this energy, Kainji reservoir releases an average of 3086.59 Mm^3 monthly. Thus, Jebba reservoir has to provide storage for the difference which is (3086.59-2788.03 =) 298.56 Mm^3. This would leave an average of 65.23 Mm^3 of water to cater for, when 233.33 Mm^3 empty space in the reservoir is filled up. The remaining water of 65.23 Mm^3 can also be stored in part of the space for flood control and can then be released gradually to generate more energy at later time.

☐ UPPER LIMIT STORAGE AT KAINJI INCREASED BY 15% AND UPPER LIMIT RELEASES AT BOTH RESERVOIRS INCREASED BY 50%

At the beginning of the year, the storage at Kainji should be maintained at 13800 Mm^3 (15% higher) and the storage at Jebba should be at 3880 Mm^3. In this case an annual total energy of 5995.60 GWH is attained with turbine release of 37639.03 Mm^3 and 33456.40 Mm^3 at Kainji and Jebba respectively.

The Jebba reservoir release is an average of 2788.03 Mm^3 monthly with average storage of 3646.67 Mm^3. For the generation of this energy, Kainji reservoir releases an average of 3136.59 Mm^3. Thus Jebba reservoir has to provide storage for the difference between average releases at Kainji reservoir and that of Jebba which is (3136.59-2788.03 =) 348.56 Mm^3. This would leave an average of 115.23 Mm^3 of water to cater for, when 233.33 Mm^3 empty space in the reservoir is filled up. The excess water of 115.23 Mm^3 can be used to generate more energy at Jebba dam or it can be stored in flood control space and release gradually to generate more energy at later time. However, the release of excess 115.23 Mm^3 of water will generate additional 9545.00 MWH of energy based on the rate of 83.00 MWH per Mm^3 obtained from the analysis.

Also the flood level as a result of releasing the excess water is less than the suggested 76.03m flood wall height.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn from the outcomes of this study

- *The study has established that 83.00 MWH of energy can be generated with 1 Mm^3.*
- *An optimal energy of 5995.60 GWH can be generated annually, which is about 41% higher than the average annual energy generation of 4261.12 GWH obtained from the historical operations data.*
- *The optimal energy of 5995.60 GWH required total turbine releases of 37639.03 Mm^3 and 33456.37 Mm^3 at Kainji and Jebba reservoirs respectively, while the average storage volumes at Kainji and Jebba reservoirs were 10916.00 Mm^3 and 3646.67 Mm^3 respectively. The flood level was about 76 m a.m.s.l.*
- *The peak flood of 3532 Mm^3 (76.40 m, a.m.s.l) corresponds to about 6011.44 GWH of Energy. A flood wall with a crown level at 76.50 m, (a.m.s.l) can be built along the downstream lowland area below Jebba dam in order to prevent flooding.*

The following recommendations are made based on the results from the study

- *The hydrological department at hydropower stations needs modern equipment such as automatic recorder to monitor the reservoir hydrology for better performance. It is unfortunate that adequate reservoir inflow data could not be obtained at our hydropower stations. The complete reservoir inflow at Yindere-Bode was collected at Global Runoff Discharge Center (GRDC) and used to validate and compliment data records from Kainji H.P dam.*
- *The flood control structure at the downstream of Jebba dam, which was constructed before the establishment of the two upstream dams need complete replacement. A dyke (flood wall) of 76.50 m (a.m.s.l) is recommended.*
- *It is recommended that joint release policy need to be established between Nigeria and Niger Republic / Mali in order to alleviate persistence flood problem in our country since the analysis of the reservoir inflow at Kainji revealed that it is a control releases from upstream reservoirs in another region.*
- *It is recommended that a study should be carried out to assess the state of facilities at the hydropower stations and identify the components that are malfunction.*
- *Similar model should be developed to simulate the operational performance of Shiroro hydropower station and the proposed Zungeru hydropower on Kaduna River.*

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