**Sequential Simulation of Integrated Hydropower Releases: Case Study Of Ero-Omola Falls, Kwara State, Nigeria.**

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**Abstract:** The sequent peak algorithm and sequential streamflow routing technique were used to simulate integrated development of Ero-Omola Falls, for hydropower, water supply, irrigation and flood control. The analysis indicated hydropower releases of 21m3/s, municipal water supply of 0.538m3/s, irrigation water supply of 0.24m3/s and ecological water releases of 1.6 x 10-3m3/s. The result shows that the entire reservoir was drafted effectively for hydropower generation with minimal hydraulic losses of about 1.83m3/s. The simulation result indicated about 20.6% more potential hydropower, while additional 23.4% annual energy could be generated. The computed net head routed through the usable discharge falls within the minimum range of head and discharge respectively for a cross-flow turbine recommended for the scheme. The results established that conjunctive use of hydropower releases is an effective mitigation measures against seasonal flooding downstream of power plant in addition to allowing for withdrawal for other uses such as water supply and irrigation.

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1. **Introduction**

Sequential simulation analysis of streamflow associated with hydropower is of paramount importance in the planning, design and operation of water resources development project. In order to design and construct hydroelectric systems, the analysis of the system (runoff or reservoirs and power plants) operations over a representative hydrologic period is required (Zolgay and Stedinger, 1991). This may be done by using mathematical simulation for analysis of hydropower reservoir systems. Descriptive simulation models due to their computational advantages are able to consider more details of real systems than optimization model (Kelman, 1980).

Sequential Stream flow Routing (SSR) is a common method for assessing energy potential in practical hydropower projects design and operation in most part of the world (Labaide, 2004). The quality and accuracy of hydrologic and hydraulic analysis can govern the project feasibility and engineering design to a great extent. The most common hydraulic parameters of interest to engineers are the temporal and spatial distribution of depth and velocity of various discharges. Methods for determining these parameters vary considerably depending on the complexity of the flow pattern, time and budget limitations, data availability, applications of results, available equipment, etc. The general practice has been to use one dimensional steady state algorithms for flurial streams and two dimensional unsteady state models for lakes, reservoirs and coastal projects (Koch-Guibert, 1985). The diversity of hydro project provides engineers with a range of challenging hydrodynamic problems such as flood routing in rivers, flood plain hydraulics, urban storm drainages, circulation in lakes and reservoir that must be dealt with. While all of these are basically three dimensional flow problems, some of them may be approximated adequately either by one–dimensional or two dimensional mathematical models. Numerical flows simulation plays an important role in optimization of the hydraulic turbines and other components of a hydropower plant. The roles include:

1. Prediction of power output of turbine
2. Achievement of maximum hydraulic efficiency
3. avoiding penstock cavitation
4. minimizing plant vibration

Beard and Kumar (1999) re-appraised the efficiency of Sequential Stream flow Routing (SSR) technique with optimization of reservoir inflow to meeting energy demand of Chatawa reservoir in Nepal. They reported that SSR is an acceptable method for assessing energy potential in practical hydropower projects designs and operations. In order to simulate sequential releases an iterative single period linear programming (LP) model was utilized. The linear programming model minimizes the sum of reservoir releases and maximizes the sum of reservoir storages. Reservoir optimization for hydropower, irrigation & municipal water supply was simulated by Hingis et al (2001) where maximization of energy output was considered as the objective function, while reservoir characteristics, the irrigation requirements, water supply and ecological needs were included in the constraints. Beard (1982) utilized Monte Carlo technique to extract maximum degree of pertinent information from monthly stream flow data and generated values whose statistical characteristics were consistent with the observed monthly stream flow data. Nash (1984) deployed hourly rainfall of annual storms to develop a non linear mathematical model to represent the stochastic process of the hourly rainfalls in which the random variables denote trend components of various functions.

It was found that the non-stationary Markov chain model is consistently satisfactory and most practical for the purpose. Analysis of low flow series were also reported by Jensens (1998) where the low flows in m3/s were arranged in decreasing order of magnitude and were ranked accordingly using the Weibul algorithms. It is widely believed that reservoir operations policy alone may not guarantee security against seasonal flooding. The formulation of sustainable conjunctive use of hydropower releases is the best mitigation measures against seasonal flooding of farmland downstream of the dam. Conjunctive use of hydropower releases involves provision of fish passes, water supply facility, irrigation and drainages as well as ecological water balance for downstream eco-systems (IHA, 2007).

It has also proved to be the most effective and most sustainable ways of controlling flood since almost 90% of releases would be diverted for useful purposes. The conjunctive use of hydropower releases also ensures that economic activities of benefitting communities are not disconnected by developmental projects (IHA, 2004).

**2. Study Approach And Methodology**

Accumulation of reliable hydrological data for hydropower development projects demands intelligent and painstaking endeavour and continuous effort. Inadequate water availability has contributed significantly to low capacity utilization and failure of most hydropower plants in Nigeria (Umolu, 2006). Over optimism and conclusions based on insufficient and inaccurate streamflow data are common and are sources of economic waste to government. Over or under estimation of runoff for hydropower projects are frequently reflected in the inability to operate the plants at full capacity soon after completion. The problem is compounded by the occurrence of climatic cycle which cannot as yet be predicted with precision, together with wide variation of precipitation and stream flow from season to season. This study was carried out in three stages. These are (a) development of monthly flow rating equations, (b) extension of stream flow data, and (d) sequent peak analysis and simulation.

The study area is located along Osi- Isolo-Ajuba Road off Osi-Idofin road in Oke-Ero LGA, Kwara State of Nigeria. It is about 116 km from Ilorin the state capital. The height of the fall is about 59.01m high. The catchment area of Ero-Omola-Falls is about 145km2 with contribution from two rivers namely, Ero-river from Iddo- Faboro near Ifaki in Ekiti State and Odo-Otun river from Ajuba. Ero-Omola Falls lies between Latitude North N080 09’ 34.6” and N080 09’ 30.8” and between Longitude East E 050 14’ 07.4” and E 050 14’ 06.7”. Figure 1 shows map of Nigeria and the location of the study area.

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**Figure 1: Project Location Map**

**ERO-OMOLA FALLS**

**2.1 Development of Monthly Flow Rating Equations from Streamflow Data**

A staff gauge is the simplest device for measuring river stage or water surface elevation. The staff gauge is a graduated self-illuminated strip of metal marked in metres and fractions thereof. Water levels were read daily, recorded and collated on monthly basis at the gauging station at Ero-Omola Falls from 2009 to 2011. Streamflow discharge measurement were taken several time and used along with gauge heights, to develop the rating equations. In general for a gauge height H (m); the discharge *Q* (m3/s) is related to height H (m) as (Punmia and Pande (2008) :

*Q = K (H +/-Ho) n* ***(1)***

*When Ho=0,*

The rating equation is given as(Sharma, 1979)

*Q = K H n* ***(2)***

Where

Q = Discharge (m3/s)

H = Gauge Height (m)

Ho=Gauge Height when the flow is zero (m)

n and k are constants

This is a parabolic equation which plots as a straight line on double logarithmic graph sheet. K & n are determined using the least square methods

**2.2 Extension of Streamflow Data**

One year stream flow data generated by the rating equation at Ero-Omola Falls, Kwara state, was extended in order to fulfill other hydrological analysis requirement. In order to achieve this, the model proposed by Thomas and Fierring in 1962 (McMachon and Mein, 1978) was adopted. The model utilized Markov theory to represent actual stream flow when the monthly stream flow, qi, are normally distributed and follow a first – order auto regressive model. The algorithm for the Thomas and Fierring model is giving as Karamouz (2003):

 (3)

 (4)

where  ; qj = monthly flow (5)

**2.3 Sequent Peak Algorithm**

It is imperative to make provision for a reservoir due to three months break of inflow at Ero-Omola during the dry season. This will allow the storage to provide the needed flow to the turbines uninterrupted throughout the year. The capacity required for a reservoir depends upon the inflow available and the demand. If the available inflow in the river is always greater than the demand, there is no storage required. On the other hand, if the inflow in the river is small but the demand is high, a large reservoir capacity is required. The required capacity for the reservoir at Ero-Omola was evaluated using sequent peak algorithm. Linsely et al (1992) and Louck and Sigvaldson (2004) described the use of sequent peak algorithm stating that values of cumulative sum of inflow minus withdrawal including average evaporation and seepage are calculated. The first peak local maximum of cumulative net inflow and the sequent peak ( next following peak that is greater than the first peak) are identified. The required storage for the interval is the difference between the initial peak and the lowest trough in the interval. The process is repeated for all cases in the period under study and the largest value of the required storage can be found.

**2.4 Simulation**

The sequential stream flow routing method sequentially computes the energy output at a specified interval in the period of analysis. A continuity equation is used to route the stream along the natural channels, taking into account the variations in reservoir elevation as a result of the inflow simulations. Use of the sequential routing in the continuity equations allows the simulation of the hydropower, but also includes flood control operation, irrigation and water supply operation. This system is based upon continuity equation given as:

$∆S=I-O-L $ (6)

Where AS=change in reservoir storage (m3)

I = Reservoir Inflow (m3)

O = Reservoir outflow (m3)

L = Sum of the losses due to evaporations, diversions, etc. (m3)

The sequential stream flow routing method can be applied to basically any type of flood analysis. These include run-off-the river projects; run-off-the river project with pondage; flood control project only; storage regulated for power only; and storage regulated for multi-purpose, including power, peaking hydro-projects and pumped storage hydro-projects. The basic type of data needed are the historical stream flows and other information from the flow duration analysis. The basic steps for this procedure are (US Army Corps of Engineers, 1995):

Step 1-Select plant capacity

Step 2-Compute stream flow available for power generation

Step 3-Determine average pond elevation

Step 4- Compute net head

tep 5- Estimate efficiency

Step 6-Compute generation

Step 7-Compute Average Annual Energy

To perform the routing, the continuity equation is expanded as:

∆S =I - (Qp +QL +QS) – (E +W) (7)

Where Qp =Power Discharge

QS =Overflow or spill

QL = Leakages or waste

E = Net Evaporation Losses (Evaporation –Precipitation)

W = Withdrawal for water supply, irrigation, recreation etc.

the rate of storage ∆S for a given time interval can be defined as;

$∆S= \frac{(S\_{t+∆\_{t}} –S\_{t})}{C\_{s}}$ (8)

Where St = beginning of period of storage

St+∆t = end of period of storage

∆t = is the storage or routing period (30days, 7days, 1day, 1hour)

Cs = Discharge to storage conversion factor

Substituting (8) in (7) and rearranging gives

St+∆t = St - Cs [I –Qp - QL-QS – (E +W)]

Or S2 = S1 - Cs[ (I –Qp - QL-QS –(E +W)] (9)

**3. Results And Discussion**

**3.1 Rating Equations and Streamflow Extension**

The twelve rating equation developed using the recorded data on gauge heights and the corresponding measured discharges between Januarys to December is presented below. The discharge generated from the Rating equations is presented in Table 1, while the extended monthly discharges from 2009-2038 are presented in Table 2.

Q = 9.206 H 0.491 (10)

Q = 9.253 H0.765 (11)

Q = 9.089 H0.934 (12)

Q = 10.496 H1.049 (13)

Q = 10.229 H1.455 (14)

Q = 8.539 H2.258 (15)

Q = 0.610 H7.789 (16)

Q = 12.65 H1.517 (17)

Q = 25.308 H0.400 (18)

Q = 1.166 H5.505 (19)

Q = 17.167 H2.753 (20)

Q = 1.617 H5.977  (21)

|  |
| --- |
| **Table 1: Ero-Omola Daily Discharge Data Generated From Rating Equations** |
| **DAY** | **JAN** | **FEB** | **MAR** | **APR** | **MAY** | **JUNE** | **JULY** | **AUG** | **SEPT** | **OCT** | **NOV.** | **DEC.** |
| 1 | 6.177 | 4.908 | 3.220 | 5.285 | 4.399 | 16.815 | 6.690 | 9.710 | 25.104 | 6.596 | 40.024 | 6.436 |
| 2 | 6.177 | 4.866 | 3.580 | 5.285 | 15.320 | 15.983 | 5.961 | 9.188 | 25.001 | 6.083 | 39.219 | 5.849 |
| 3 | 6.177 | 4.846 | 3.526 | 5.179 | 14.816 | 14.389 | 4.997 | 30.337 | 29.118 | 5.375 | 36.102 | 5.052 |
| 4 | 6.143 | 4.977 | 3.491 | 5.072 | 14.317 | 13.132 | 4.172 | 29.821 | 28.787 | 4.538 | 33.148 | 4.573 |
| 5 | 6.143 | 4.941 | 3.437 | 7.111 | 13.014 | 11.029 | 3.468 | 29.821 | 28.620 | 3.810 | 31.037 | 4.132 |
| 6 | 6.143 | 4.905 | 3.384 | 6.895 | 12.219 | 7.4255 | 2.692 | 28.546 | 28.280 | 9.363 | 29.013 | 3.538 |
| 7 | 6.143 | 4.887 | 3.313 | 6.572 | 9.785 | 6.563 | 2.072 | 27.040 | 27.131 | 8.352 | 26.449 | 3.017 |
| 8 | 6.143 | 4.869 | 3.259 | 6.464 | 9.639 | 5.916 | 1.474 | 26.298 | 27.131 | 7.144 | 26.139 | 1.347 |
| 9 | 6.143 | 4.832 | 3.187 | 6.464 | 9.493 | 5.305 | 3.258 | 24.113 | 28.704 | 6.083 | 24.623 | 1.117 |
| 10 | 6.143 | 4.260 | 3.134 | 6.356 | 9.932 | 4.872 | 2.692 | 22.928 | 28.451 | 5.155 | 23.452 | 0.920 |
| 11 | 6.143 | 4.225 | 3.845 | 6.141 | 9.348 | 13.878 | 1.811 | 21.995 | 28.194 | 4.161 | 15.342 | 0.656 |
| 12 | 6.143 | 4.172 | 3.736 | 6.034 | 8.917 | 13.378 | 1.375 | 21.303 | 28.021 | 3.563 | 14.058 | 0.530 |
| 13 | 6.143 | 4.119 | 3.626 | 5.927 | 8.492 | 12.408 | 0.376 | 19.275 | 27.492 | 2.900 | 12.074 | 0.395 |
| 14 | 6.143 | 4.084 | 3.535 | 5.713 | 8.352 | 11.252 | 0.318 | 16.051 | 32.646 | 2.285 | 12.074 | 0.289 |
| 15 | 6.110 | 4.013 | 3.205 | 5.392 | 7.937 | 10.589 | 0.318 | 15.431 | 32.438 | 2.071 | 11.700 | 0.246 |
| 16 | 6.110 | 4.959 | 3.187 | 5.179 | 7.527 | 6.563 | 0.097 | 12.078 | 32.087 | 0.931 | 10.974 | 0.208 |
| 17 | 6.110 | 4.814 | 3.152 | 7.653 | 9.932 | 5.916 | 0.064 | 11.331 | 30.845 | 0.879 | 30.353 | 0.147 |
| 18 | 6.110 | 4.704 | 3.718 | 7.328 | 9.639 | 7.971 | 19.479 | 0 | 30.466 | 0.781 | 27.712 | 0.102 |
| 19 | 6.110 | 4.365 | 3.827 | 6.356 | 9.348 | 7.073 | 12.262 | 0 | 30.000 | 0.576 | 25.831 | 3.926 |
| 20 | 6.110 | 4.209 | 3.736 | 6.249 | 8.917 | 6.316 | 9.891 | 9.710 | 29.604 | 0.446 | 22.880 | 3.183 |
| 21 | 6.110 | 4.030 | 3.663 | 8.305 | 8.352 | 20.068 | 6.316 | 8.846 | 29.604 | 4.161 | 15.786 | 1.433 |
| 22 | 6.110 | 4.866 | 3.590 | 8.087 | 8.213 | 18.549 | 4.997 | 8.677 | 30.234 | 3.810 | 14.478 | 1.266 |
| 23 | 6.110 | 4.783 | 3.498 | 9.836 | 7.937 | 17.670 | 3.690 | 8.677 | 29.843 | 3.329 | 13.241 | 1.117 |
| 24 | 6.110 | 4.741 | 3.442 | 9.288 | 7.799 | 16.535 | 2.364 | 8.342 | 29.684 | 2.900 | 11.700 | 0 |
| 25 | 6.110 | 4.699 | 3.294 | 8.741 | 7.527 | 15.174 | 1.580 | 24.353 | 29.282 | 2.639 | 10.278 | 0 |

**Table 2: Projected Mean Monthly Streamflow Dischages(M3/S) Data For Ero-Omola (2009-2038)**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |
| January | 6.049 | 6.074 | 6.100 | 6.125 | 6.150 | 6.176 | 6.201 | 6.226 | 6.252 | 6.278 | 6.303 | 6.329 | 6.355 | 6.381 | 6.407 | 6.433 | 6.459 | 6.485 | 6.511 | 6.537 |
| February | 4.939 | 3.610 | 3.957 | 4.338 | 4.755 | 3.475 | 3.810 | 4.177 | 4.578 | 5.018 | 5.500 | 6.028 | 6.606 | 4.827 | 3.528 | 3.868 | 4.240 | 4.648 | 5.094 | 5.583 |
| March | 3.755 | 3.423 | 3.122 | 2.847 | 2.597 | 3.001 | 3.465 | 4.001 | 4.618 | 4.209 | 3.837 | 3.498 | 3.189 | 2.909 | 2.654 | 2.421 | 2.504 | 2.589 | 2.677 | 2.767 |
| April | 12.840 | 12.223 | 11.635 | 11.076 | 10.544 | 10.038 | 10.405 | 10.786 | 11.1808 | 11.589 | 12.013 | 12.452 | 12.907 | 13.379 | 13.867 | 14.374 | 14.899 | 15.443 | 16.006 | 16.591 |
| May | 19.648 | 20.021 | 20.399 | 20.786 | 21.180 | 21.582 | 21.991 | 22.408 | 22.833 | 23.266 | 23.707 | 24.156 | 24.614 | 25.081 | 25.556 | 26.041 | 26.534 | 27.037 | 27.550 | 28.072 |
| June | 21.391 | 21.910 | 22.441 | 22.985 | 23.541 | 24.111 | 24.693 | 25.289 | 25.899 | 26.524 | 27.163 | 27.816 | 28.485 | 29.170 | 29.870 | 30.587 | 31.320 | 32.071 | 32.839 | 33.625 |
| July | 24.097 | 25.941 | 27.927 | 30.064 | 32.364 | 34.840 | 20.838 | 12.464 | 14.165 | 16.098 | 18.295 | 20.790 | 23.625 | 26.846 | 30.506 | 34.665 | 39.390 | 44.758 | 34.798 | 39.541 |
| August | 36.955 | 39.537 | 40.677 | 41.850 | 43.056 | 44.296 | 45.571 | 46.883 | 38.589 | 31.765 | 32.685 | 33.631 | 34.604 | 35.604 | 36.632 | 37.690 | 38.778 | 39.897 | 36.955 | 39.537 |
| September | 49.071 | 45.150 | 41.542 | 38.224 | 38.687 | 39.156 | 39.631 | 40.111 | 40.597 | 41.089 | 41.587 | 42.090 | 42.600 | 43.116 | 43.638 | 44.166 | 44.701 | 45.242 | 45.790 | 46.344 |
| October | 39.917 | 42.858 | 46.015 | 42.858 | 46.015 | 49.404 | 46.015 | 32.937 | 35.365 | 37.971 | 40.768 | 43.771 | 46.995 | 46.883 | 38.589 | 36.632 | 37.690 | 38.778 | 39.897 | 36.955 |
| November | 32.307 | 33.242 | 34.204 | 35.193 | 36.210 | 37.256 | 38.331 | 39.437 | 40.575 | 41.745 | 42.948 | 44.185 | 45.458 | 46.766 | 48.112 | 37.126 | 33.425 | 37.838 | 38.741 | 39.664 |
| December | 19.979 | 19.852 | 19.725 | 19.600 | 19.475 | 19.352 | 19.230 | 19.108 | 18.988 | 18.868 | 18.750 | 18.632 | 18.515 | 18.400 | 18.285 | 18.171 | 18.058 | 17.946 | 17.835 | 17.724 |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Months | 2029 | 2030 | 2031 | 2032 | 2029 | 2030 | 2033 | 2034 | 2035 | 2036 | 2037 | 2038 |
| January | 6.857 | 6.884 | 6.911 | 6.938 | 6.857 | 6.884 | 6.965 | 6.993 | 7.020 | 7.048 | 7.075 | 7.020 |
| February | 7.458 | 8.172 | 8.954 | 9.811 | 7.458 | 8.172 | 10.750 | 11.778 | 12.903 | 14.137 | 15.487 | 12.903 |
| March | 4.101 | 4.236 | 4.375 | 4.518 | 4.101 | 4.236 | 4.666 | 4.819 | 4.976 | 5.139 | 5.306 | 4.976 |
| April | 25.500 | 26.430 | 27.393 | 28.391 | 25.500 | 26.430 | 29.425 | 30.498 | 31.609 | 32.760 | 33.953 | 31.609 |
| May | 35.164 | 35.831 | 36.510 | 37.201 | 35.164 | 35.831 | 37.906 | 38.624 | 39.356 | 40.101 | 40.861 | 39.356 |
| June | 44.614 | 45.675 | 46.760 | 47.870 | 44.614 | 45.675 | 49.006 | 50.169 | 51.359 | 52.576 | 53.822 | 51.359 |
| July | 27.497 | 31.245 | 20.556 | 23.360 | 27.497 | 31.245 | 26.545 | 30.164 | 34.276 | 38.948 | 44.256 | 34.276 |
| August | 36.955 | 39.537 | 40.677 | 41.850 | 36.955 | 39.537 | 30.835 | 31.419 | 32.014 | 32.621 | 33.239 | 32.014 |
| September | 53.537 | 54.184 | 54.839 | 55.501 | 53.537 | 54.184 | 56.172 | 56.851 | 57.538 | 58.233 | 58.936 | 57.538 |
| October | 36.533 | 37.405 | 38.298 | 39.211 | 36.533 | 37.405 | 40.145 | 41.101 | 42.080 | 43.081 | 44.106 | 42.080 |
| November | 52.576 | 53.822 | 36.738 | 37.615 | 52.576 | 53.822 | 38.512 | 39.430 | 40.370 | 41.331 | 42.315 | 40.370 |
| December | 16.468 | 16.369 | 16.270 | 16.172 | 16.468 | 16.369 | 16.075 | 15.979 | 15.884 | 15.789 | 15.695 | 15.884 |

**3.2 Reservoir Elevation - Storage Computation**

The reservoir elevation - storage computation is presented in Table 3 and the elevation – capacity and elevation – area curves are given in Figure 2.

**Table 3: Reservoir Elevation Storage Computation**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Contour** | **Area Enclosed** | **Average Area** | **Height Between Contour** | **Volume Between Contour** | **Volume Up To Contour** |
| **m** | **m2 (103)** | **m2 (103)** | **m.** | **m3** | **m3 (106)** |
| 450 | 0 |  |  |  | 0 |
| 451 | 2.4 | 1.2 | 1 | 1.2 | 1.2 |
| 452 | 7.9 | 3.95 | 1 | 3.95 | 5.15 |
| 453 | 35 | 17.5 | 1 | 17.5 | 22.65 |
| 454 | 57 | 28.5 | 1 | 28.5 | 51.15 |
| 456 | 89 | 44.5 | 1 | 44.5 | 95.65 |
| 457 | 159 | 79.5 | 1 | 79.5 | 175.15 |
| 458 | 243 | 121.5 | 1 | 121.5 | 296.65 |
| 459 | 361.2 | 180.6 | 1 | 180.6 | 477.25 |
| 460 | 434 | 217 | 1 | 217 | 694.25 |
| 461 | 490.5 | 245.25 | 1 | 245.25 | 939.5 |
| 462 | 510.7 | 255.35 | 1 | 255.35 | 1194.85 |
| 463 | 645 | 322.5 | 1 | 322.5 | 1517.35 |
| 464 | 761 | 380.5 | 1 | 380.5 | **1897.85** |

**Figure 2: Elevation - Capacity and Elevation- Area Curve**

**3.3 Flow Duration Curve**

Twenty years of streamflow records (2009-2028) were utilized. The streamflow data was arranged in ascending order. The percentage of exceedence and annual projected hydropower generation potential were computed as shown in Table 4. The Flow Duration Curve as well as the Power Duration Curve are plotted as shown in Figures 3 and 4.

**Table 4: Computation of Flow Duration Curve Using 20 years of Data**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | No. | Year | Flow(m3/s) | Flow in Ascending Order | Power=9.81QHe (kw) | % of time of availability |
|  |  |  |  |  |  |  | $$\frac{N+1-n }{ N}(\%)$$ |
|  | 1 | 2009 | 22.57 | 21.97 |  | 12789.18 | 100 |
|  | 2 | 2010 | 22.82 | 21.98 |  | 12795 | 95 |
|  | 3 | 2011 | 23.14 | 22.03 |  | 12824.1 | 90 |
|  | 4 | 2012 | 22.99 | 22.57 |  | 13138.45 | 85 |
|  | 5 | 2013 | 23.71 | 22.79 |  | 13266.51 | 80 |
|  | 6 | 2014 | 24.39 | 22.82 |  | 13283.98 | 75 |
|  | 7 | 2015 | 23.34 | 22.99 |  | 13382.94 | 70 |
|  | 8 | 2016 | 21.98 | 23.14 |  | 13470.26 | 65 |
|  | 9 | 2017 | 21.97 | 23.34 |  | 13586.68 | 60 |
|  | 10 | 2018 | 22.03 | 23.61 |  | 13743.85 | 55 |
|  | 11 | 2019 | 22.79 | 23.71 |  | 13802.07 | 50 |
|  | 12 | 2020 | 23.61 | 24.34 |  | 14168.8 | 45 |
|  | 13 | 2021 | 24.49 | 24.39 |  | 14197.91 | 40 |
|  | 14 | 2022 | 24.94 | 24.49 |  | 14256.12 | 35 |
|  | 15 | 2023 | 24.8 | 24.8 |  | 14436.58 | 30 |
|  | 16 | 2024 | 24.34 | 24.83 |  | 14454.04 | 25 |
|  | 17 | 2025 | 24.83 | 24.94 |  | 14518.07 | 20 |
|  | 18 | 2026 | 26.06 | 25.39 |  | 14780.03 | 15 |
|  | 19 | 2027 | 25.39 | 26.06 |  | 15170.05 | 10 |
|  | 20 | 2028 | 26.07 | 26.07 |  | 15175.87 | 5 |

**Figure 3: Ero-Omola Flow Duration Curve**

**Figure 4.: Ero-Omola Power Duration Curve**

**3.4 Sequent Peak Algorithm Computation**

Input to sequent peak algorithm computation consists of hydropower water demand, municipal water supply, irrigation water requirement, ecological water requirement, point rainfall, evaporation and runoff. The various requirements are:

**a) Hydropower Water**

From the flow duration curve Figure 3, 100% dependable hydropower demand flow was estimated at 21.80m3/s. The hydropower releases for all year round generation is approximately 21.00m3/s. The yearly demand is computed thus:

Yearly demand = 24 x 3600 x 365 x 21.00 = 662.256 x 106m3

**b) Municipal Water Supply Requirement**

Estimated total water requirement for the benefiting communities within the three LGAs with a population of 172,207 (NPC, 2007) =46,495.89m3/day

A daily dependable release is estimated as;

$$46,495.89m^{3}/day =\frac{46,495.89}{24 ×60 ×60} = 0.538m^{3}/s$$

Total Annual Supply: 0.538m3/s x 24 x 60 x 60 x 365 =16.966 x 106m3

**c) Irrigation Water Requirement**

Gross Area =480 ha

The water requirement is:43.07m3/ha/day=20673.6m3/day = $\frac{ 20673.6}{24 x 60 x 60 }= 0.2392 or 0.24m^{3}/s$

0.24m3/s x 24 x 60 x 60 x 365 = 7.568 x 106m3 annually.

**d) Ecological Water Requirement**

The ecological water releases = 1.6 x 10-3m3/s x 60 x 60 24 x 30 = 4.1472 x 10-3Mm3/Month or 50.366 Mm3/annumbased on the average wash bores and tube wells recharge rate of 1.6 l/s, in Fadama areas downstream of tailrace channels (FMWR, 2007).

The sequent peak algorithm is based on the above and data on rainfall, evaporation for the area and was used to determine reservoir storage to meet the demand of the system for hydropower, water supply, irrigation, ecological releases and losses. The detail computation is indicated in Table 5 and Figure 5.

**Figure 5: Sequent Peak Algorithm**

**Figure 6: Tailrace Rating Curve**

**Figure 7: Head Discharge Curve**

**Table 5: Reservoir Capacity Simulated with Sequent Peak Algorithm**

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**3.4 Simulation Results**

The objective of simulation is to optimize potential firm energy. The simulation procedure and the results are shown in Table 6.

**(1) Critical Period** (Column 1 and 2)**:**  The critical drawdown period has been defined as the seasonal cycle between the period when the reservoir is empty and when it is refilled to full capacity. Or the period during which all usable storage would have been fully drafted for optimum generation. The length of the critical drawdown period would be 29 months, (September 2009-January 2012)

**(2)** **Average Streamflow** (Column 3)**:** From the flow records, the average discharge into Ero-Omola reservoir during the critical drawdown period was found to be 21.39m3/s.

**(3) Net Reservoir Evaporations Loss:** Evaporation = {19.44 x 106 m2 x 150mm/1000 x 0.75} = 2.187 (Mm3) or 2.187Mm3/24x60x60x30=0.844m3/s (column 4)

**(4) Consumptive Withdrawals and Demands:** (Column 5).Irrigation and Water Supply 0.24m3/s + 0.538m3/s = 0.778m3/s {section 3.4(a) and (b)}.

**(5)**  **Net Reservoir Inflow.** Given the reservoir inflow in (Column 3), evaporation rate, and reservoir withdrawal in (Column 5), then the net reservoir inflow for the same period is

Net inflow = I - E – W = 49.071+ 0.8437m3/s) – 0.778m3/s =49.137m3/s.( Column 6).

**(6) Annual Energy** (Column 7), is computed as

= P = 9.81 x 21 x 57.63 x 0.85 x 24 x 365 =8839272.486KWh/12 =736385.037 KWh.

This value is distributed on monthly bases in accordance to demand allocation. (Column 7)

**(7) Average Pool Elevation:** (Column 8). The reservoir elevation over the critical drawdown period is approximated as 50% of the usable storage. The storage at the top of Forebay is 1420m2 and the storage at the bottom of Reservoir is 25m2

The total reservoir storage at 50% usable storage is estimated as:

$\frac{1420+25}{2} =722.5m^{2}$ The pool elevation at 50% usable storage is found to be El. 455.21m

**(8) Hydraulic Net Head:** (Column 9). The net head corresponding to successive average pool elevation in column 8 is estimated from tailwater rating curve in Figure 6 and head discharge curve in Figure 7.

**(9) Determine Required Power Discharge.** (Column10). The firm energy requirement for September, 2009 was found to be 736385.037 kWh. The required power discharge would be computed as follows;

$$Q\_{P}= \frac{(736385.037 kWh/month)}{(9.81 x 49.83 x 0.85 x 30 x 24)} = 24.146 m3/s.$$

This value is inserted in Column 10.

**(10) Minimum Discharge for Downstream Requirement:** (Column 11). Ecological water requirement is presented in column 11 as 4.2 x 10-3m3/s. per month.

**(11) Total Discharge.** (Column12).The total required discharge is the sum of the power discharge needed to meet firm energy (Q, Column 10) plus estimated leakage losses (QL = 2.5m3/s) . If this value exceeds the required power discharge plus losses, it would serve as the total discharge requirement. For the month of September, the minimum discharge requirement is 26.646m3/s, so the power discharge requirement establishes the total discharge requirement (Column 12). Qp + 2.5.

**(12) Compute Change in Storage.**(column 13)**.** The change in reservoir storage is a function of net inflow (Column 6), total discharge requirements (Column 12), at the start-of-month, reservoir elevation (Column 16 for the previous month). The difference between the net reservoir inflow and the total discharge requirement would establish whether the reservoir would draft, fill, or maintain the same elevation. This computation represents the solution of the continuity equation, which, when rearranged, would be as follows;

$∆S=\left(I-E-W\right)- (Q\_{P}+ Q\_{L})$ (22)

For the month of September $∆S $ = 22.491m3/s

$$∆S=\left(49.137m3/s\right)- \left( 26.646m3/s\right)=\left(22.491m3/s\right).$$

The$ ∆S $value would be converted to 106m3 using the discharge-to-storage conversation factor ($C\_{S})$ for 30-day month,

$∆S=\left(22.491 x 24 x 60 x 60 x 30.\right)= 58.296$ x 106m3

These values are inserted in Columns 13 and 14. For those months where net inflow exceeds total discharge requirements, the reservoir would store the difference unless it is already at the top of forebay pool. If the reservoir is full, the full net inflow (minus losses) would be discharged through the powerhouse, if possible over and above the firm energy requirement (Column 7)

**(13) Compute End-of-Month Reservoir Status** (Column 15)**.** The change in storage, $∆S$, can also be expressed as follows: $∆S=S\_{2}- S\_{1}$

where: S1=start-of-period storage volume

S2=end-of-period storage volume

The change in reservoir storage would be applied to the start-of-month storage volume (Column 15) of preceding month to determine the end-of-month storage volume. The end-of-month reservoir elevation was obtained from the storage-elevation curve (Table 3 and Figure 2). For September, 2012;$S\_{2}=S\_{1}+ ∆S=1800Mm3+\left(58.296Mm3\right)=1858.296Mm3$

From Figure 2, the end-of-month reservoir elevation is found to be El. 454.50m.

**(14) Reservoir Elevation at the End of Critical Drawdown: (column 16):** This is obtained from the storage-elevation curve or from column 15.

**(15**) **Compute Total Generation (Column 18):** During the critical period, generation will be limited to meeting firm energy requirements. The generation is computed by applying the net head (Column 9) to the greater of the required power discharge or the water quality requirement (Column 11) minus 2.5 m3/s losses. For September 2009, the generation would be:

$\left(\frac{24.1469m3}{s}\right)(49.83m) (24 x 30hours) =$736385.036$ kWh,$

Which is, of course, equal to the firm energy requirement for the month of September as calculated in step 6.



**(16). Summary**

Thesimulation was carried out on ‘excel’ with the above items as input. The reservoir simulation was based on the initial estimate of reservoir capacity of 1812 x 106m3 at 2.7 x 103m3/s maximum inflow and dead storage of 1.8075 x 106m3. The initial analytical estimates of potential hydropower was estimated at 8.01101MW, while annual generation potentials was estimated at 14035.272 MWh at hydraulic capacity of 21m3/s.

The simulation result given in Table 6 however show that the potential power could be higher

i.e P= 9.81 x 21 x 57.63 x 0.85 =10.091 MW while the annual energy of =18,401.56501 MWh was reached.

Hence the result indicated about 20.6% more potential hydropower, while annual energy was increased by additional 23.4%.

**Conclusion**

The major conclusions derived from the study are:

1. The theoretical potential hydropower generating capacity of Ero-Omola fall at 100% dependable flow of 80 years return period is estimated at 8.011MW. The annual average energy is estimated at 14035.272MWh.
2. The simulated potential hydropower generating capacity of Ero-Omola fall at 100% dependable flow of 80 years return period is estimated at 10,091.502MW. The annual average energy is estimated at 18,401.56501MWh
3. The simulation result indicated about 20.6% for more potential hydropower, while annual energy was optimized by 23.4%.
4. Water treatment plant capacity is estimated at 22,500 litres or 22.5m3/s.
5. Irrigation water requirement is estimated at 2.2 x 106m3 with peak irrigation water demand of 43.07m3/ha/day.
6. The minimum ecological water requirement downstream is estimated at 1.6 x 10-3m3/s, which would minimize or eliminate seasonal flooding downstream.

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