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Reservoir capacity yield reliability analysis

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STORAGE YIELD RELIABILITY analysis is used to determine the volume of water that should be stored in order to provide a specified water demand with a stated reliability. Storage depends on the volume of demand D, reliability R and the hydrology of the catchment supplying the reservoir. The effect of hydrology of the catchment on the required storage volume depends upon the temporal uniformity, or lack of it, of the streamflow and the causal rainfall[4]. For a given D and R, a reservoir on a catchment having substantially variable wet and dry season rainfall, needs to be larger than if the rainfall is more or less uniformly distributed throughout the year. The reliability gives a measure of certainty that a given yield can be met without failure. Failure in this context was considered as the interval during which the reservoir is empty. The reliability is an index between 0 and 1 and can be expressed in one of three ways (annual, time based and volumetric). In this study the time-based reliability was used.

Objectives

The objectives of the study were to, apply methods of reservoir, yield reliability analysis to two selected catchments and in order to study their response within year storage and relate it to the reliability of yield and to compare these results with application of the mass curve analytical technique.

Two rivers were chosen namely:

- R. Nyagak in northwestern Uganda. It flows from Western Congo, through Nebbi district and pours into the Albert Nile. This catchment receives a unimodal type of rainfall.
- R. Chambura in Western Uganda. It originates in the Kasyoha-Kitoma forest reserve and pours into the Kazinga Channel. It receives a bimodal type of rainfall.

Methodology

The Behaviour Analysis method was applied This was because a previous study in this field by J. Carty and C. Cunnane(1990) revealed that the Behaviour Analysis method and Modified Gould method resulted in the lowest bias and standard error of results and therefore are more accurate. The data requirements for this method are river flows, evaporation, other losses and the demand. The outputs are the capacity and reliability. The advantages are that it can be used for final designs and simulate the behaviour of the reservoir during operation. The disadvantage is that it requires a computer program for usage. The main assumption is that historic flows will repeat themselves in the future. A computer program was developed which analysed the data using the following procedure[1].

- Three levels of reliability (90%, 95% and 99%) were selected
- The draft was selected in the range 0-100% of the mean annual flow (MAF).
- An arbitrary value of the reservoir capacity C was then selected and assuming the reservoir to be initially full routing was carried out month by month for the whole period using the behaviour equation below.

$$Z_{t+1} = Z_t + Q_t - D_t - \Delta E_t - L_t$$
$$0 \le Z_{t+1} \le C$$

where C is the capacity of reservoir, Z_t is the storage, Q_t is the inflow, D_t is the demand, ΔE_t are the draft evaporation losses, L_t are other losses; at time *t*

- Periods when the reservoir was empty were noted and the time based reliability obtained using:-

$$R_e = \left[1 - \frac{\Sigma E}{N} \right] 100\%$$

where-ΣE is the sum of months when the reservoir is empty and N is the total number of months.

- If the reliability value does not differ significantly from the set value then the selected capacity is adequate for the demand.
- If the reliability differs significantly from the set value, another capacity is selected and the procedure repeated until there is convergence.
- The reservoir capacity yield reliability curves for the different draft levels for the respective rivers are shown in Figure 1. Behaviour diagrams for the rivers are shown in Figure 2.

Deductions

For zero storage, there is a small yield possible. This is the yield of the river without the reservoir. If the demand is low, this yield may sometimes be sufficient to meet it. For run of river schemes the chosen demand is in this region. From Figure 1 it can be noted that the drafts for which the capacity departs from zero decreases with increasing reliability. The values for R. Chambura are higher than those for R. Nyagak. This means that R. Chambura would have a higher yield than R. Nyagak in case a run of river scheme was considered.

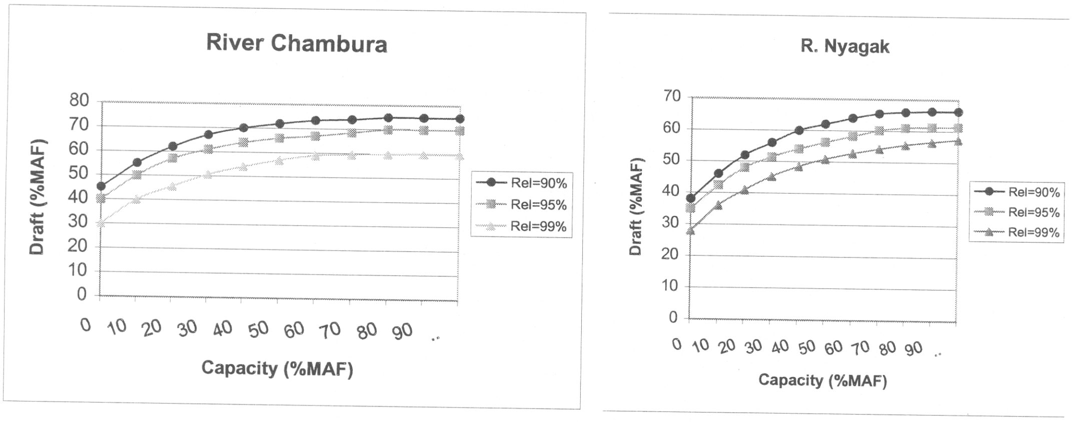

Figure 1. Reservoir Capacity Yeild Reliability Curves

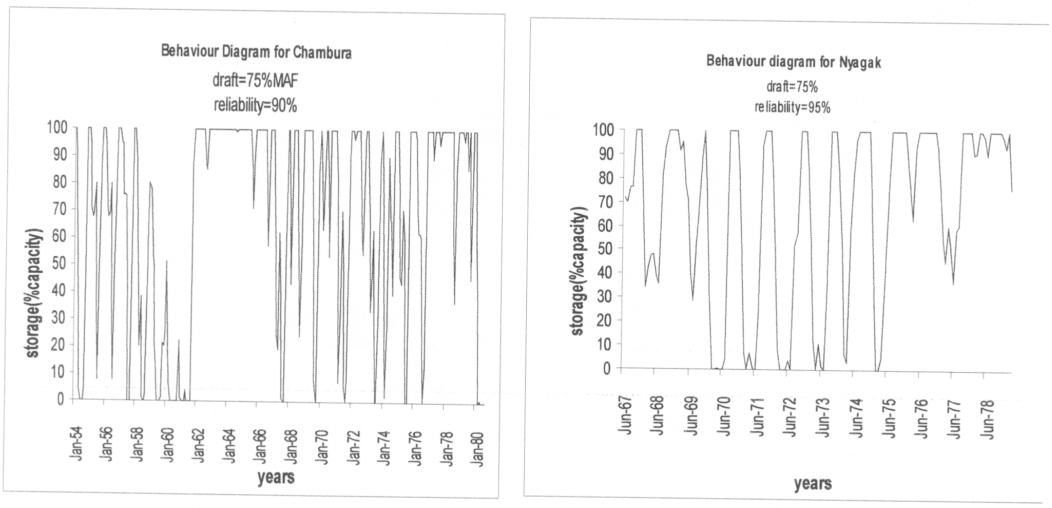

Figure 2. Behaviour Diagrams

- For any storage, a higher yield will result in a lower reliability
- As yield increases, the storage requirements also increase before flattening out as the yield approaches the mean flow. In the flat region, a large storage increase is required to meet a modest increase in yield.
- The shape of the storage-yield curves gives an indication of the relative costs of reservoir development on the respective rivers. For example the steeper the storage-yield relationship, the lower the reservoir storage required to meet a given level of demand and hence the lower the reservoir construction costs (assuming that material and labour costs are comparable at the two sites).
- The less the reservoir storage capacity, the lower will be the exposed surface area and any evaporation fluxes through this surface. Evaporation losses can be so significant in a hot climate like Uganda that it can form a major factor influencing the choice for the site for development.

Mass Curve Analytical Technique:

In the process of determining the initial capacity of the storage required, using the mass curve technique, an analytical approach for determining the spill and capacity of a reservoir was developed. This method gives the same result as the mass curve graphical technique. The data requirements for this method are the river flows, evapora-

Table 1. Comparison of results

		Draft/Demand %MAF	Capacity %MAF	Reliabilty %
River Nyagak	Mass Curve	75	173	99.4 (13 years)
Behaviour Analysis		65	100	90
River Chambura	Mass Curve	75	211	99.7 (27 years)
Behaviour Analysis		75	100	90

tion, other losses and the demand. The output is the capacity, with no definate measure of reliability. If reliability is determined in using time based reliability, it is high and is dependant on the number of years of record. With more years of record, the reliability increases. This fact alone means that reliability is not well defined by this procedure. Furthermore, because capacities are determined using a critical year, they tend to have very large capacities which may often take years to fill, if at all. See Table 1. The advantage is that it is simple and can be used in preliminary design. Further more, a computer program to analyze the whole sequence of flows can be developed instead of just analyzing a critical period. The main assumption is that historic flows will repeat themselves. This technique is presented as below:

Procedure

- Construct a table of flow Q and Draft D
- Obtain the difference (Q - D) for the whole period
- Obtain the cumulative of (Q - D)
- Obtain the maxima and minima for **each cycle.**

Note

- The maxima represent a full reservoir
- The minima represent the minimum reservoir level (maximum depletion).
- A cycle is the period from when the reservoir is at maximum level to the next time it returns to maximum or from when it is at the minimum level to the next time it is minimum again.
- To obtain the amount of water that should be stored in any cycle get the difference between the maxima and the subsequently minima. **i.e.**

  Storage = Max(å(Q-D)) - Min (å(Q - D)),

  in a cycle
- The maximum value of the storage gives the necessary capacity of the reservoir.
- To obtain the amount of spill in any **cycle,** add the storage of the cycle to the minimum (to fill the reservoir) and subtract the subsequent maxima. i.e.,

  Spill = Min (å(Q - D)) + Storage - Max(å(Q - D))

Conclusions

The mass curve analytical approach can be used to obtain an initial estimate for the capacity of a reservoir to meet a specific demand and can be used for preliminary designs. It can easily be used when considering different rivers or sites from which one may be selected. A computer programme can also be developed for use. Behavior analysis gives a more specific estimate with a known reliability which can be used in final designs.

By examining the curves it is possible to select a river that has the maximum capacity and reliability of flows in comparison to the costs.

Generally, it can be noted that River Chambura gives a higher yield than River Nyagak for any reliability level. Therefore it can be said that the yield of River Chambura is more reliable than River Nyagak. This is partly due to the bimodal type of rainfall.

By plotting such curves for rivers under consideration, an empirical relationship between the capacity of a reservoir for any reliability and mean annual flow can be obtained.

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