Journal of Hydroscience and Hudraulic Engineering
Vol. 4, No. 2, November, 1986, pp.71-77.

A CASE STUDY OF RESERVOIR OPERATION USING STRETCHED THREAD RULE

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SYNOPSIS

A so-called stretched thread rule developed by Varlet and Klemes was applied successfully for almost 200 cases of reservoir operation studies in Thailand, one of which is presented here as an illustration. Firstly a gist of the rule is explained that an outflow mass curve can be represented by a thread stretched between a pair of congruent inflow mass curves placed parallelly keeping a mutual distance equal to a reservoir capacity. Then, by applying the rule for the illustrated project, a unique outflow mass curve is constructed. The obtained outflow mass curve is found out to be correct in a sense that it strictly conforms to the commonly accepted reservoir operating policy of flow equalization. Optimal values of various indispensable parameters of the project are readily computed based on this outflow mass curve. Thus the stretched thread rule is verified to be very useful and powerful.

INTRODUCTION

A concept of the mass curve was established long ago and the curve has been used since then as a powerful tool to estimate available discharges from a reservoir. A residual mass curve is a slightly modified version of the mass curve in that the horizontal axis of the residual mass curve represents the mean river flows in a entire period as against that of the original one is merely a zero axis.

It is customary that the term residual mass curve is abbreviated simply as mass curve especially by practioners in Japan. The abbreviation will be followed in this paper too where no ambiguities will arise.

A definition of the mass curve with mathematical terms and its characteristics appear in many textbooks or handbooks of applied hydrology (5) so in the following discussions the fundamental knowledge of the mass curve theory is assumed to the reader.

A deeper analysis of the characteristics of the mass curve was developed by V. Klemes (2) who also introduced an interesting and useful idea which he said was first published by Varlet (4) in 1923. This idea will be adopted in the present discussion so it will be explained briefly in the following section.

RELATION BETWEEN INFLOW MASS CURVE AND OUTFLOW MASS CURVE

A gist of the idea is illustrated on Fig. 1: The upper figure (a) shows two molds, a male mold and a female mold, being placed wide apart one another so that a string is spanned horizontally without touching either of them. Both shapes of a bottom edge of the upper mold and a top edge of he lower mold are congruent to the inflow mass curve.

Then these molds are brought close keeping the directions of the horizontal axes unchanged until the distance between them equals the value V, an effective reservoir capacity. The string is pushed up and down by the molds and finally the shape as shown on figure (b) will be resulted. This shape of the string makes the

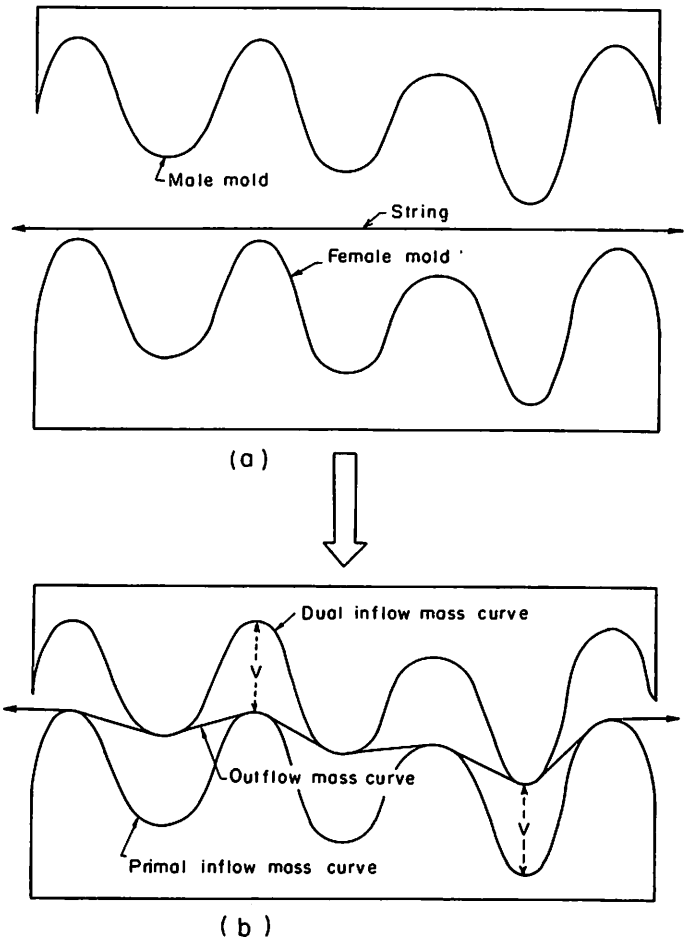

Fig. 1. Outflow mass curve construction by primal and dual inflow mass curves

outflow mass curve conceptually. The fact that this is the best or the most desirable outflow mass curve for a flow equalization was proved by Klemes.

Thus, given the inflow mass curve and the effective reservoir capacity, the unique outflow mass curve can be obtained by the shape of the imaginary string at the final position.

This method is called "the stretched-thread rule" after Varlet (4) and Klemes (2).

For the convenience of later reference, the male mold and the female mold are called a dual inflow mass curve and a primal inflow mass curve (3) respectively as shown on Fig. 1.

RESERVOIR SIMULATION USING MASS CURVE

A principal function of a reservoir is to regulate the natural riverflow, namely store surplus riverflows in a rainy season and release these stored water in a future dry season or seasons when the riverflow is reduced and supplement for this reduction is needed. In short, the purpose of the reservoir is to equalize the natural riverflow.

Klemes (2) pointed out that "The common view that flow equalization is the best operating policy is held so widely probably because ...." and he shew that the outflow mass curve constructed using the stretched-thread rule conformed exactly to this policy.

Note that the flow equalization principle is applicable not only for a reservoir for water supply purposes (irrigation , municipal watersupply, etc) but also for a reservoir for purely power generation purpose because a major benefit of a hydro power project accrues from a firm power and energy which are available at any time throughout an entire period (secondary energy is available only in a rainy season) and these firm values can be maximized only by observing the flow equalization principle.

Then, let us apply this rule for our own actual example and see whether it works well or not.

APPLIED EXAMPLE

An applied example concerns with a hydropower project, Nam Mae Ngao No. 2, located in a north-western part of Thailand. The main project features are included in Table 1 together with the main results of the reservoir simulation study which will be explained below.

The primal and dual mass curves and the outflow mass curve plotted in parallel with the computation by a plotter are shown on Fig. 2, where the outflow mass curve was computed using the stretched-thread rule. Basic data and conditions given were as following:

(i) The purpose of the project was for power generation only.

(ii) Effective monthly inflows to the reservoir estimated for 300 months from Jan. 1960 to Dec. 1984 using partially observed and partially estimated river runoff data with evapolation losses being subtracted.

(iii) A normal high water level (NHWL) and a low water level (LWL) of the reservoir were set at 260 m and 235 m respectively.

(iv) A reservoir water level vs. reservoir capacity curve was given. (actual computation utilized a spline function subroutine (1) to interpolate the reservoir capacity or conversely reservoir water level at every month required in the course of computation).

(v) A daily plant factor of the power plant was stipulated to be at least 15%, where the daily plant factor is defined as daily operation hours of the power plant devided by 24 hours. (in case of a reservoir type hydro power plant, the operation hours are usually restricted within peak demand hours only).

Table 1 Reservoir Simulation

Project	Nam Mae Ngao No.2	Simulation Case No.	N02A260-25C

Catchment area at dam	835 sq·km
Annual inflow to dam	1,292 MCM
Project type	storage
NHWL 260m / LWL 235m / Draw down 25m	
Mean WL 248.4m / TWL 163m	
Max. head 97m / Normal head 82.5m	
Total storage	661MCM
Effective storage	355MCM
Effective storage/annual inflow	0.27
Installed capacity	116.8MW
Firm capacity	97.9MW
Annual energy (97% base)	246 GWH
Annual firm energy	129 GWH
Annual 2nd energy (97%)	117 GWH
Daily plant factor	0.15
Annual capacity factor *)	0.24
Machine efficiency	0.87

Annual min. discharges obtained by reservoir simulation in cms

Year	Min. dis.	Year	Min. dis.
2	32.935	14	34.872
3	32.935	15	33.690
4	32.692	16	32.359
5	32.126	17	32.045
6	30.996	18	28.539
7	26.976	19	24.894
8	26.976	20	24.894
9	31.120	21	28.109
10	31.120	22	32.101
11	33.913	23	25.111
12	30.651	24	25.111
13	30.651		—

Least min. discharge	24.894cms
Firm discharge (95%)	24.931 cms
Max. discharge	166.205cms
Head loss	2.9m
Flow utilizability = (inflow spill)/inflow	99.5%

*) annual capacity factor = $\frac{\text{annual energy production (97\% base)}}{\text{installed capacity} \times 8760 \text{ hrs}}$

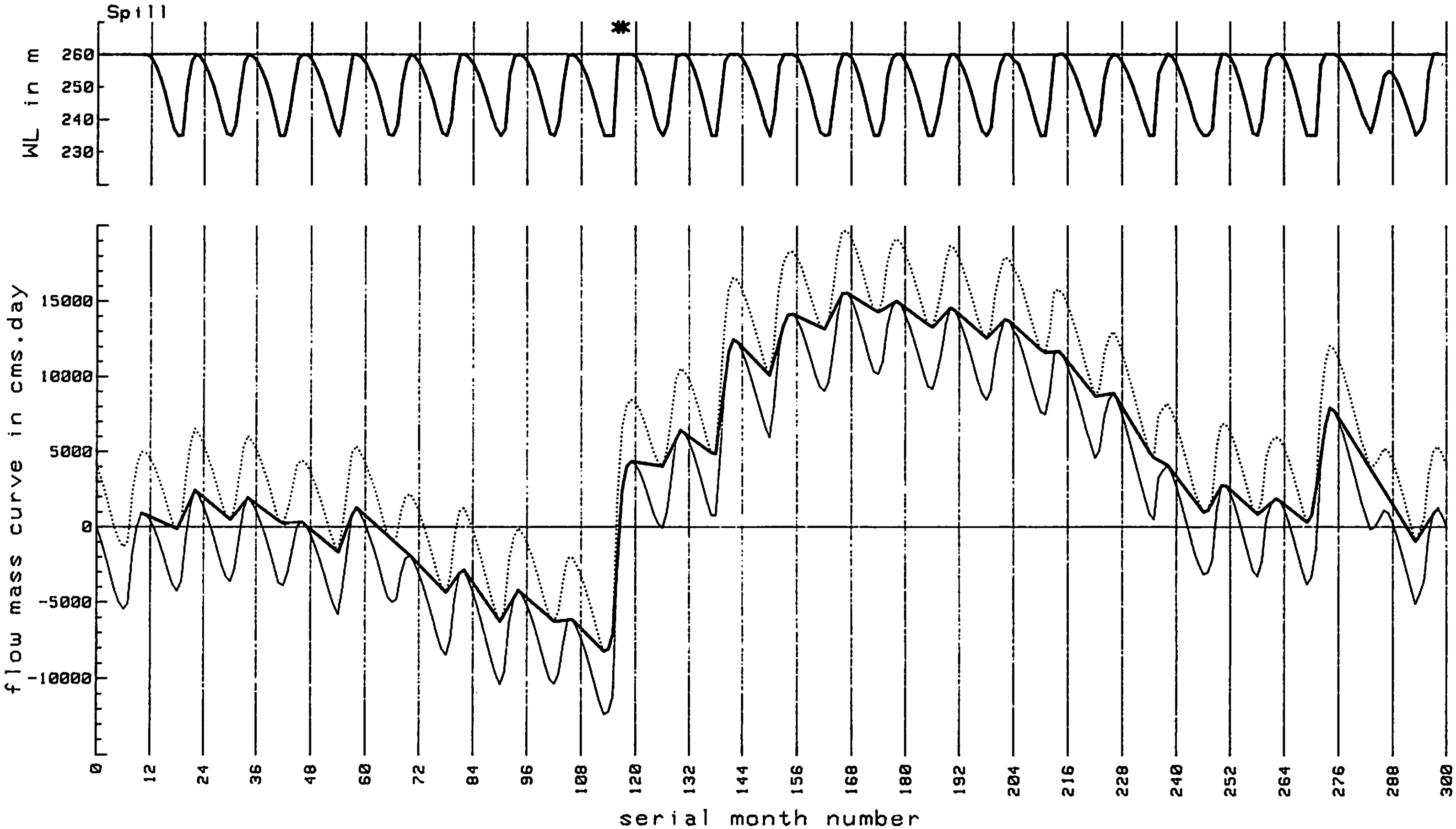

Fig. 2 NAM MAE NGAO No. 2 (case NO2A260.25c)

(vi) Other values, such as tail water level (TWL), head loss ratio, machine efficiency, etc. which were necessary for estimations of power and energy outputs were also given. These values, however, are not directly related to the present study hence their explanations are omitted.

A key portion of the simulation program was the outflow mass curve construction. Although the program used was developed independently (reservoir operation rule too), it agrees in essence with the one outlined by Klemes (2) hence the explanation of the program is also omitted here.

All the monthly values were calculated, such as inflow mass curve, discharge, effective storage, outflow, outflow mass curve, water level, spillage, power, energy, daily peak output and daily peak duration hours. An installed capacity and an annual mean energy generation of the project were estimated to be 117 MW and 246 GWH respectively.

It will easily be seen by an experienced engineer that the obtained outflow mass curve is correct. That all these results are exact shows that the stretched-thread rule has worked perfectly.

Moreover, the actual computation was so simple that it could be done by a small and slow personal computer (Hewlett Packard 9835B) within about 30 minutes including plotting operation, free from any extra budgetary trouble. Thus the usefullness and the superiority of the stretched-thread rule has been verified by the actual project being planned.

In passing it may be helpful for the recognition of the usefullness of the rule to comment that the same method as above has so far been applied for almost 200 cases in Thailand successfully.

SUPERIORITY OF THE STRETCHED-THREAD RULE

Whether or not one has a knowledge of the stretched-thread rule, fundamental rules that should be observed for the construction of the outflow mass curve are as following:

(i) The outflow mass curve should be constructed such that the greatest possible equalization of the reservoir outflow can be achieved.

(ii) The outflow mass curve should not cross the inflow mass curve.

(iii) A height difference between outflow mass curve and inflow mass curve should at no point exceed an effective reservoir capacity.

Now if an experienced engineer without the knowledge of the stretched-thread rule constructs the outflow mass curve observing the above three rules strictly, then the result will, of course, be correct and an optimal solution that conforms to the common view of the greatest possible flow equalization will be obtained.

However, many novices without the knowledge of the stretched-thread rule, have often been plagued by the rule (i) which is rather an abstract rule than the rule (ii) and (iii). They might tried to replace or supplement the rule (i) by some other concrete rules to avoid many trial and error calculations. The candidates that came across their minds might be as following:

(iv) Whenever there are chances to recover the high water level in the ensueing season or seasons, then the amount of discharge at present should be as large as possible.

(v) Whenever there are possibilities that the amount of spillage over the dam can be restricted to a certain minimum quantity, then the present water level should be kept as high as possible.

(vi) The length of the straight line portion of the outflow mass curve should be as long as possible in order to obtain a constant discharge in as long a period as possible.

(vii) If there are two alternatives conceivable, the one with a steeper slope of outflow mass curve segment and the other with a flatter slope, any other conditions being equal, then the flatter one should be selected because the flatter slope more conforms to the principle of flow equalization. (flatter means nearer to horizontal.)

That all of these additional rules are not always true and can be applied only locally will easily be seen. For example, rule (iv) contradicts rule (v): The upper case (a) in Fig. 3 shows that at present, Ia, the reservoir is full while the lower case (b) represents the reservoir is empty. In both cases, the rule (iv) maintains that the outflow mass curve should be the line ab because it gives the larger discharge than ac, whereas the rule (v) insists that the line ac should be adopted because during the period ac the water level goes up and will be full at point c. Thus two rules contradict each other.

It seems that the rule (vi) mediates the dispute so in case of (a) the line ac, whilst in case of (b) the line ab shall be adopted.

Then, how the rule (vi) works in case of (c)? The line ab shall be adopted because it is longer than ac, but, as the result, the available discharge in the period bd will be smaller than in cd because the line bd is steeper than cd. This contradicts with the fundamental rule (i).

Lastly, how about rule (vii)? This can solve the problem of case (c) and adopts the line ac as the correct one as it should be, but if it is applied to the case (a) back, the line ab shall be wrongly selected because ab is flatter than ac.

In short, all these additional rules puzzle the novices and lead them to the wrong results.

In general, shapes of inflow mass curves are notoriously different from river to river and from year to year as many practioners have encountered. Therefore even a skilled engineer would have to try many alternative outflow mass

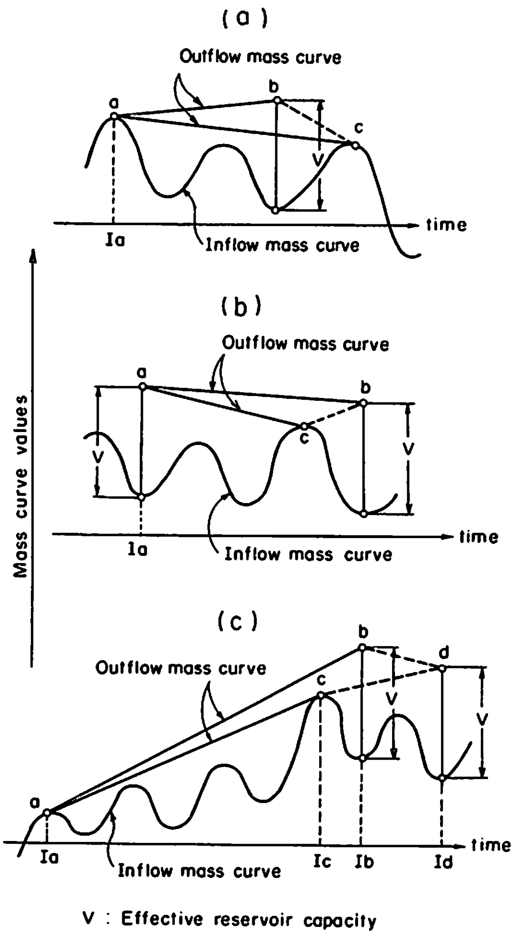

Fig. 3. Various relative positions of inflow and outflow mass curves

curve before he got the correct result if he observed the three fundamental rules only. The stretched-thread rule gives the correct answer at once and the result strictly conforms to the three fundamental rules.

CONCLUSION

The optimal schedule for the reservoir operation can be set up simply by observing the so-called stretched-thread rule. The principle of the rule is extremely simple so that no mathematical background is required at all. However, the rule developed by Varlet and Klemes is based upon the rigorous mathematical manipulation, hence the obtained result is unique and numerically precise as against some false beliefs that the mass curve method gives only an approximate solution. Yet the rule preserves the excellent property of the mass curve that the whole aspect of the variation of inflow, outflow and active storage of the reservoir can be commanded a sweeping view. Thus the rule will be very useful in many practical application both in planning stage and in actual operation.

Finally, the author would like to express his sincere gratitude to the officials of Electricity Generating Authority of Thailand for their vast cooperation.

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