RESERVOIR OPERATION UNDER CRITICAL CONDITIONS

Dayantha Wijeyesekera

1.0—Introduction

The primary function of a reservoir is to provide storage and control of water and distribute it with respect to time. The input and output of the system, the storage capacity and the losses of the system, should be suitably combined to produce an optimum performance.

Impounding reservoirs are normally required for two functions:—

(i) to impound water for beneficial uses,

(ii) to retard and control flood flows.

These two functions may be suitably combined to some extent by careful operation.

The purpose of this paper is to convey a method of operation concerning the former function, during critical conditions. Impounding reservoirs of the former function are usually used for the purpose of irrigation, hydro-power generation and water supply. The method of operation under critical conditions would differ for each of the above uses.

Water requirements for municipal, recreational and industrial or power uses should be determined by population projections with per capita requirements and are largely independent of hydrologic considerations. On the other hand the requirements for irrigation should usually be determined by combining estimates of potentially irrigable land area with estimates of probable consumptive use per unit area. The outflow from a reservoir is perhaps the only variable which could be easily controlled in considering the other variables such as inflow, losses and reduction in storage due to silting etc.

When the estimates of available water and the various items of water use and water loss are assembled, the reservoir capacity is usually determined by an operation study. This is a simulation of the reservoir operation which would take place during a critical period if specified rules are followed.

2.0—Factors Causing Critical Conditions

2.1—Drought Conditions

A chief factor concerning critical conditions would be the occurrence and the duration of droughts. Droughts may be local, confined to a single basin or area or they may be widespread covering many provinces or even parts of the world. Low precipitation and high variability usually occur together because in areas where the total annual rainfall is small, it is usually due to a relatively small number of storms or rainy periods. Furthermore since the number of occurrences is small it is natural that the variability will be high. In Sri Lanka the two monsoon periods have failed to be consistent throughout, in intensity and duration. The severity of droughts may be measured by various parameters: such as deficiencies in rainfall, decline in soil moisture, reduction in groundwater levels etc.

2.2—Forest and Range Cover Effects

There are certain variables such as rainfall, climate, geology and soil that cannot be controlled directly by man's activities. There are however other influences such as vegetation and forests which can be manipulated to supply a degree of control of rates and amount of run-off, erosion and sedimentation etc.

Various available information on the hydrologic behaviour of forest lands and the relationship of land use to water yield has indicated the impact of:

(a) rainfall,

(b) direct interception of a part of the precipitation by the aerial portions of the plants,

(c) dissipation of soil moisture by transpiration,

(d) reduction in the loss of soil moisture by evaporation,

(e) binding the soil against erosion and

(f) holding back of some of the moisture by the 'blotter' effect of the litter.

The use or the misuse of forests and vegetation on the land may have a very great effect on water production in both quantity and quality. Therefore consideration has to be given when excessive logging, cultivation, burning and grazing of forest lands are made.

2.3 Sedimentation

Erosion, transportation and deposition of sediment are natural processes which have occurred throughout geologic times. These amounts vary greatly depending upon geologic, climatic, physical, vegetative and other conditions. Sedimentation of a reservoir created by a dam constructed on a natural water course is inevitable.

The problem of sedimentation in reservoirs in Sri Lanka has not been significant, however this could be confirmed only by field investigations.

The distribution and deposition of sediment in a reservoir is dependent upon several interrelated factors such as nature of sediment, inflow-outflow relation, shape of reservoir and the reservoir operation in general.

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2.4 Evaporation

Evaporation losses can be substantial in shallow reservoirs or in reservoirs storing a long-term supply. Evporation losses are normally calculated for the surface area exposed to evaporation during draw down, and this is normally taken as two-thirds of the maximum area of the reservoir.

Although it would be useful to correlate evaporation data with climatic conditions, this is not possible due to insufficient information and therefore it is necessary to use average values for computing losses during droughts. By combining appropriate rainfall data with maximal evaporative losses, net evaporative losses for drought periods of various frequencies and durations could be estimated.

2.5 Seepage and Other Losses

Losses due to seepage, and leaks in the transmission and distribution systems contribute largely towards the depletion of the supply. For various reasons such as poor construction control, differential settlement cracks etc. leakages first commence as a small seep.

As water seeps through compacted soil of an embankment or the natural soil of a foundation, the pressure head is dissipated in overcoming the viscous drag forces which resist the flow through the small soil pores. The seeping water then generates erosive forces which tend to pull the soil particles with it in its path of travel through and under the dam.

Usually seepage losses are small and perhaps only 10% of the outflow. Some of the methods adopted to reduce seepage is to have cut-off walls, Bentonite blankets, grouting etc.

A further loss would be due to leakages which occur in the transmission and distribution systems. The existence of a leak may be known or suspected, but its exact location may be difficult to discover. However there are various methods of investigations which can be employed.

2.6 Outflow Demand

The rate of draw-off from a reservoir is usually determined by the mass flow curve analysis, depending on the expected inflow and reservoir capacity. Once the designed rate of draw-off is established it will have to be frequently confirmed depending on the variation of reservoir capacity and rainfall pattern.

Furthermore outflow demand increases with other factors such as population changes, industrialisation, losses in the distribution systems etc. Although an optimum value of the safe continuous maximum draw-off could be determined to a single reservoir, during times when the storage is less than expected (for the particular time of the year), measures will have to be taken to prevent a crisis.

3.0 Reservoir Analysis

A generalised reservoir system consists of a stochastic input y(t) and a reservoir with a maximum capacity Q, in which the quantity of water stored is q(t). A release x(t) is allowed to meet downstream water requirements. The fundamental problem of operation is to determine x(t) as a function of both q(t) and y(t).

The critical operation of a reservoir is necessary due to the high variability of inflow into the reservoir. It is therefore necessary to establish a critical storage relationship c(t) which would be dependent on the following in the case of impounding reservoirs used purely for the purpose of water supply.

(i) draw-off levels,
(ii) frequency of droughts,
(iii) reliability of other sources,
(iv) unexpected output demands etc.

The performance of a reservoir has to be optimised both individually and also as an integral component of a system of reservoirs and other sources.

During normal operation of such a system, if output levels have been properly designed, there will be the high inflow months in which water must be spilled for lack of available storage space.

The critical storage curve would differ for each reservoir depending on its use. This curve should be reviewed periodically as more hydrological data become available. This is necessary due to the presence of the factors mentioned in section 2.

Once the critical storage curve is available the reservoir operation should be based so that within the period of study the storage does not fall below the critical value. In a very small reservoir the analysis may have to be based on daily data as a drought of a few weeks duration could overtax the reservoir. On the other extreme are reservoirs with a capacity of several times the annual inflow, storing water for several years and a critical drought period measured in years.

With the availability of high speed computers it is possible to construct a precise numerical definition of the critical operation as a function of

(i) the target output x(t),
(ii) the maximum active storage Q, and
(iii) the historical sequence y(t) of input.

For best results the target output of firm releases should be distributed from month to month so as to at least approximate the normal seasonal demand characteristics.

The first step in determining the functional critical period is to normalise all quantities in terms of the mean annual discharge $\bar{y}$. Thus, x(t), Q etc. are expressed in units of $\bar{y}$.

The analysis could be modified depending on the use of the reservoir and the cruciality of the output level.

4.0 Application of the Critical Operation
Case Study — Kalatuwawa 1976

Since hydrological data is available for Kalatuwawa reservoir for the current year the suggested methodology is applied to elucidate the application of the method and highlight the desirability of the net result.

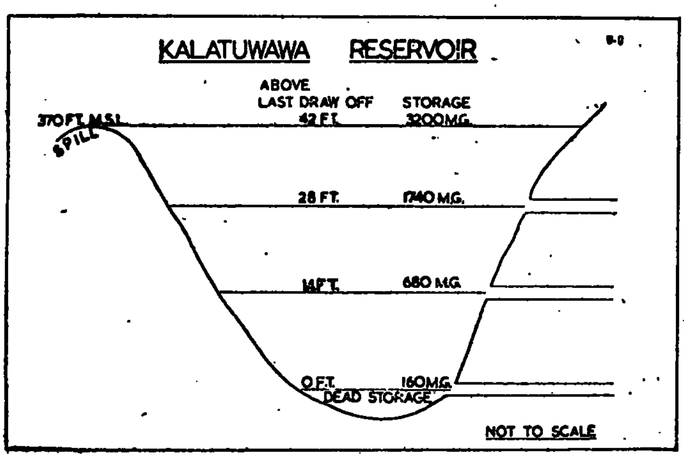
The supply of water to Colombo and its suburbs should be studied by considering all three sources namely Kalatuwawa, Labugama and the Kelani. (Fig. 1 indicates how this has taken place during the past 2½ years).

The aim of this section is to apply the critical operation method to the Kalatuwawa reservoir only to obtain an optimum performance of the reservoir by ensuring that the storage level does not fall below the critical storage curve unless two consecutive monsoon periods have completely failed.

A study of the Kalatuwawa reservoir and its catchment with the available limited data has been carried out. When the Kalatuwawa scheme was originally designed the expected safe uniform draw-off had been fixed at 20 M.G.P.D. Studies indicate that the procedure of maintaining a constant uniform outflow throughout is not a satisfactory method of operation and that the original designed uniform outflow at 20 M.G.P.D. seems to be much in excess of what the reservoir could safely deliver continuously.

A major limitation in this study has been the non-availability of inflow data to the reservoir. However this has been computed by considering the storage changes and by assuming the outflow as recorded by the meters to be correct. Another major assumption made in the study is the adoption of the original bed contour survey, thus neglecting the possibilities of reduction in storage due to sedimentation. The study revealed a total capacity of 3200 MG as against a capacity of about 3900 MG, indicated by the original designers and 3580 MG as mentioned in the UNDP (WHO) report of 1972. Another limitation in this study has been the inability to ascertain the accuracy of the outflow recorders.

With the hydrological analysis for the years 1968-1973 (inclusive) being available, a method of regulating the reservoir was presented at the SLAAS session 1974 under the title "The study of the Kalatuwawa reservoir and its catchment".



4.1 Kalatuwawa Operation 1976

This section attempts to make a comparison between the situation which existed in 1976 and what would have been if the method of critical operation was adopted during the year.

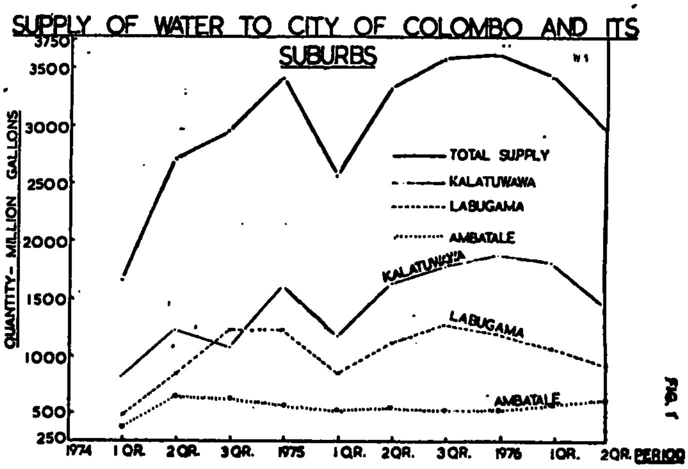


Fig. 1

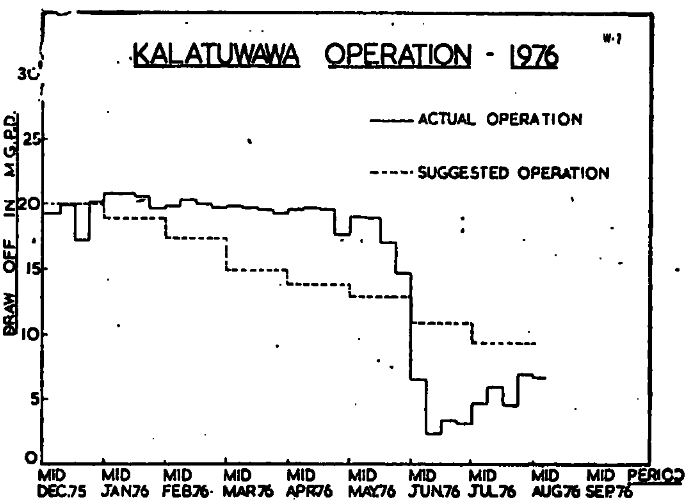


Fig. 2

The hard line in figure 3 indicates the water level and storage changes from spill level which was reached in mid-December 1975. The outflow pattern during these months are indicated by the hard line in figure 2. This outflow has been at an average of about 19.5 M.G.P.D. from mid December 1976 till about early June 1976 and a sudden reduction to about 2.5 M.G.P.D. which occurred in mid-June when the water level was at the alarming low level of about 4-5 feet above the last draw-off point.

A major factor adopted in the suggested operation is that the water level is maintained above the 1st draw-off at all times except when the first monsoon has completely failed. At such an event the rate of outflow is further regulated so that there would be a limited supply, till the next monsoon. This period between the two monsoons should be such that the critical storage would reach the 1st draw-off only after the second monsoon has failed. With the above criteria the reservoir outflow could have been regulated as indicated by the broken line in figure 3 from mid January itself. This would have resulted with water level at the 2nd draw-off during mid-July which would have been 13 ft. above the last draw-off point. In

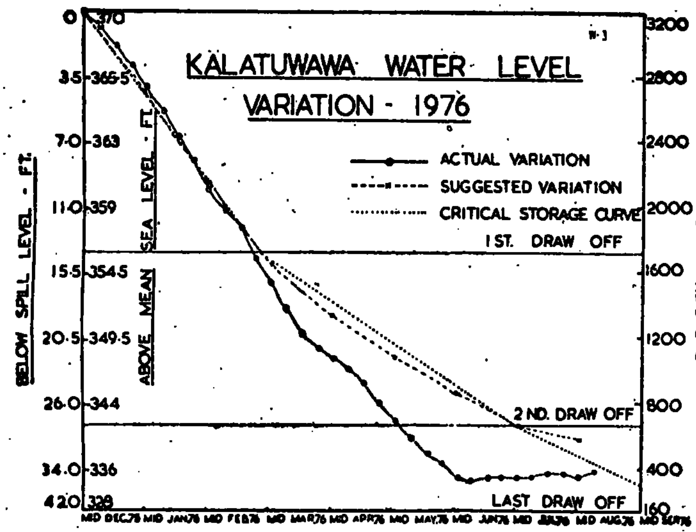


Fig. 5

doing so (as seen in figure 2) the lowest rate of outflow by this method would have been 9.5 M.G.P.D. during mid-July which is nearly 2-3 times the supply which was made available in mid-July 1976.

What really happened was that the water level was as low as 7 feet above the last draw-off point and contained only 345 MG. of storage; furthermore the supply depleted to a very low value of 3 M.G.P.D.

Table (1) indicates reservoir operation for the months mid-December to mid-August 1976. Sequence of computation is as shown in chart (1).

5.0 Conclusions

Planning for the operation of reservoirs is an essential feature of project design. It is necessary that a schedule or a guide for reservoir operation is developed in a preliminary form at the operation planning stage, so that the information would enable to determine in advance at optimum performance.

If the only purpose of the reservoir is the release of conservation storage, and if it is essential that the regulated output is never less than a specified minimum amount, the operation plan is simple, but should be carefully followed to avoid a crisis. Such a plan should be based on the critical storage curve for the particular reservoir which has to be predetermined and refined as often as possible on gaining actual operating experience.

The critical operation method should be considered for intervals as short as possible. The success and the effectiveness of this method of operation would be evident when the plan is applied well in advance and preferably right through the year, once it is established that a particular reservoir is prone to critical conditions.

The role of hydrology in reservoir studies should not be only at the early stages of the analysis but should be continued to estimate precipitation changes, sedimentation studies, evaporation studies etc.

(1)	S(1)	T(1)	NS(1)	A(1)	F(1)	Q(1)	MS(1)
Month	Storage	Out flow	New storage	Actual storage	Net in flow	Max safe D.O.	Modified storage
Dec' 75				3200			
		580			120	20.0	
Mid Jan' 76	3200		2620	2740			2720
		620			0	19.0	
Mid Feb' 76	2740		2120	2120			2150
		597			17	17·5	
Mid March' 76	2120		1523	1540			1642
		591			151	15·0	
Mid. April' 76	1540		949	1100			1343
		594			194	14·0	
Mid May' 76	1100		506	700			1117
		527			167	13·0	
Mid June' 76	700		173	340			896
		120			130	11·0	
Mid July' 76	340		220	350			694
		176		171		9·5	
Mid Aug' 75	350		174	345			580

Notation

S (1) Storage (MG) at the beginning of the month
T (1) Total outflow (MG) during the month
NS (1) New storage (MG) at the end of month if there was no inflow
A (1) Actual storage (MG) as observed at the end of the month
F (1) Net inflow (MG). i.e. difference between NS (1) and A(1)
D (1) Designed draw off (MGPD)
Q (1) Safe. max draw off (MGPD) if different from designed draw off D(1)
MS(1) Modified storage (MG) at the rate of Q (1) during the month
C (1) Critical storage (MG) as estimated for each month.

Table (1)

The output demand at the initial operation of a reservoir would be very different after several years and steps would be necessary in certain cases to augment the available supply by combining with other sources.

Wherever possible measures should be taken to avoid the use of traditional forms of energy for pumping in the light of the present energy crisis. Gravity flow methods should be considered even at the expense of high initial costs as running costs would be negligible.

The annual critical operation plan for a particular reservoir should be reviewed each year with the increase of hydrological data and techniques.

Acknowledgements

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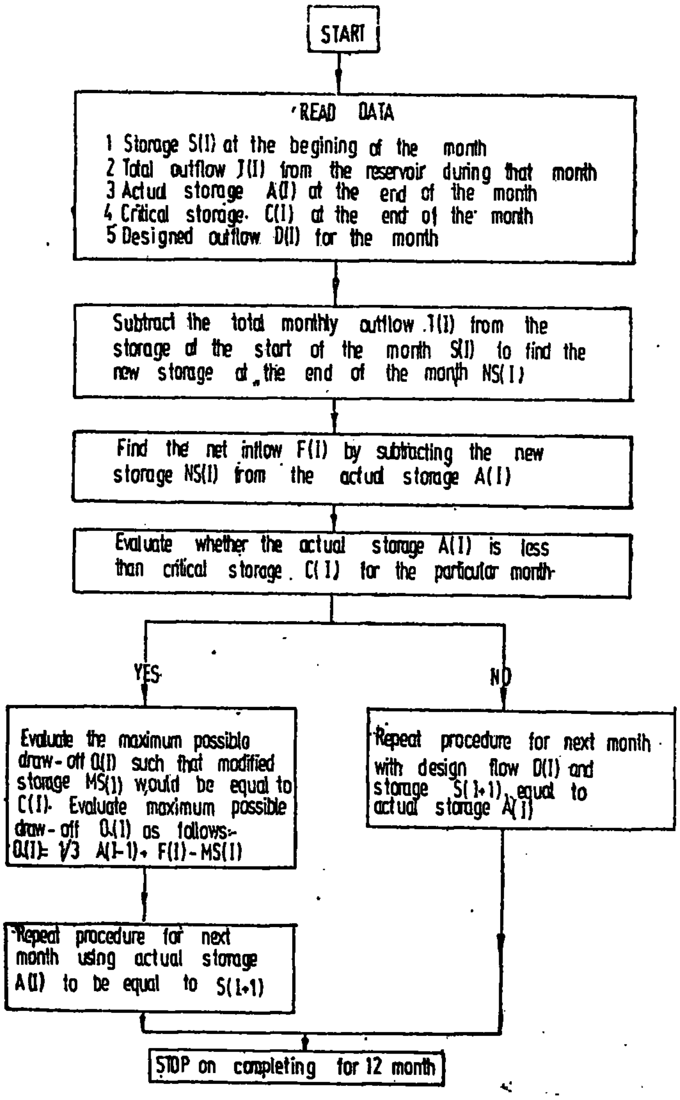

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Chart (1)

අවධි අවස්ථාවලදී ජලාශ පාලනය

ජලාශ පාලනය කිරීමේදී, අවධි අවස්ථාවන්හිදී අනුගමනය කල හැකි ක්‍රියා මාර්ගයක් මෙම ලිපියෙන් විස්තර කෙරේ. අවධි අවස්ථාවන් ඇති කෙරෙන සාධක සහ ජලාශයේ පාලනය නිතර නිතර පරීක්ෂා කලයුතු පිළිවෙල මෙහි සඳහන් වේ:

නිදසුනක් වශයෙන් 1976 වර්ෂයේදී කලටුවාව ජලාශය කල පිළිවෙල සලකා බලා ඇත. යෝජිත ක්‍රියා මාර්ගය අනුගමනය කලා නම් වතුර හිඟය මෙතරම් උග්‍ර ලෙස බල නොපාන බව මෙයින් පෙන්වනු ඇත.

பார ரமான நிலைகளுக்கிடையில் வாவியின் நீர் விநியோகம்

பார ரமான நிலைகட்கிடையில் வாவியின் நீர் விநியோகத்தைச் செயற்படுத்தும் முறையொன்றை இக் கட்டுரை விரிவாகத் தருகின்றது. பார ரமான நிலைகளை உண்டாக்கும் காரணங்களை இது விளக்குகின்றது. உதாரணத்திற்காக இங்கு குறிப்பிட்ட முறை 1976 ம் ஆண்டின் களத்து வாவியின் நீர் விநியோகத்தில் கையாளப்பட்டிருக்கின்றது. நீர் விநியோக நெருக்கடியினால் ஏற்பட்ட கஷ்டம், இம் முறையைப் பாவித்திருப்பின், அவ்வளவு கடுமையாகத் தாக்கியிருக்காதென்று மேற்படி உதாரணம் எடுத்துக் காட்டுகின்றது.