The effect of serial correlation on reservoir capacity using the modified Gould's probability matrix method (MGPM)

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Abstract

The effect of serial correlation of inflows on estimating the reservoir capacity using the modified Gould's probability matrix method was investigated using the historical monthly streamflow sequences of 6 potential reservoir sites in Kenya. The ratios of the capacities determined using the starting months of analysis, giving the maximum to those determined using the starting month of analysis and giving the minimum lag1 annual serial correlation coefficient for each flow sequence, were used as the indicators of this effect. This approach was adapted after it was observed that the correlation coefficients varied highly with the starting month of analysis. Average ratios of 1.02, 0.91, 0.85 and 0.76 were obtained at the 30, 50, 70 and 90% draft levels respectively. Serial correlation therefore had an effect for drafts greater than 30% of the mean flow and this effect increased with the draft. It has therefore been recommended that the starting month of analysis giving the minimum annual serial correlation coefficient should be applied when using the modified Gould's probability matrix (MGPM) method if the demand is greater than 30% of the mean flow. It is likely that the same recommendation could be as valid for other capacity determination methods that assume independence of annual flows. The minimum serial correlation coefficients for 5 of the 6 sites were however still considerable with 4 of them being greater than 0.1 and the maximum being 0.349. Using the starting month of analysis giving the minimum annual serial correlation coefficient may therefore not adequately prevent the risk of an underdesign of reservoir capacity. It has been proposed that a method similar to the MGPM method but which routes the reservoir contents for periods longer than the one year used in the MGPM method has the potential to adequately check the serial correlation problem. The requirement is that the period should be long enough to give an insignificant correlation coefficient with one of the starting months of analysis that could be applied with that period. A 2-year period has been found to give practically insignificant correlation coefficients with 5 of the 6 streamflow sequences.

Introduction

The reservoir capacity determination problem involves the computation of the capacity of a reservoir required to meet specific water demands. The main components of a typical problem are illustrated in Fig. 1. As shown in the figure, the sources of water into the reservoir are the streamflow sequence Q_t, and the rainfall R_t on the reservoir. The main losses are the evaporation E_t and infiltration I_t through the reservoir bottom and the dam. It is usually assumed that the historical streamflow, rainfall and evaporation series at the site are satisfactory representatives of the respective series during the life of the reservoir. The historical records or sequences generated from them are therefore used in the analysis. The capacity C of the reservoir which is required to meet the demand D_t and also satisfy the downstream water rights DOR_t needs to be determined. Some reservoir capacity determination methods associate the capacity with a reliability R_e which is usually quantified by the probability of failure P_f using the relationship $R_e = 1\text{-}P_f$. A common definition of probability of failure is the probability of emptiness of the reservoir. With some methods, it is also possible to associate the capacity with the volumetric reliability defined as the proportion of water actually supplied to that which was demanded in the simulation period. Beshay and Howell (1986) have proposed other measures of the hydrologic performance of reservoir in addition to volumetric reliability.

In comprehensive reviews of river and reservoir yield, (McMahon and Mein,1978; 1986), reservoir capacity determination methods have been broadly classified into critical period, Moran theory-based techniques and methods based on stochastically generated data. The third class involves the use of stochastically generated data with methods of the first two classes. The basis of critical period techniques, is the simulation of the reservoir through the low-flow periods, usually termed the critical periods. Some critical period procedures such as Mass curve and the Sequent peak algorithm run through the streamflow data and select the single most serious critical period. The design capacity is then computed as the size just adequate to ensure that the demand will be met up to the end of this critical period. Consequently, these methods do not associate the capacity with a reliability level. Another set of critical periods that include Alexander's method, Dincer's method and the frequency mass curve analysis (partial duration series analysis) uses the historical

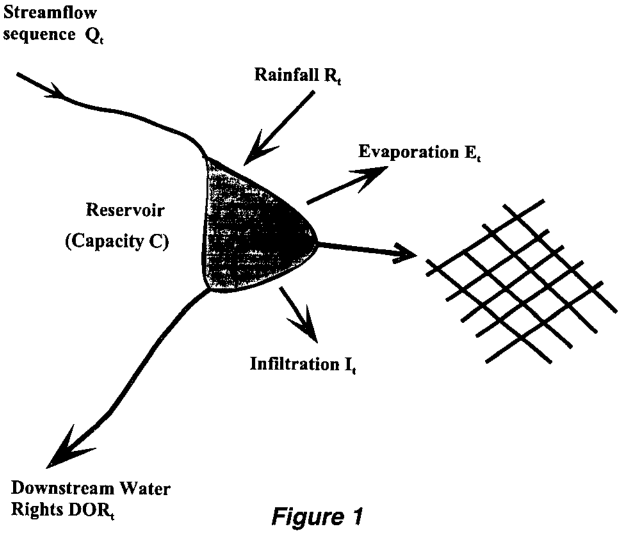

Figure 1
· The reservoir capacity determination problem

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streamflow sequence to derive drought curves(synthetic critical periods) of specific probabilities of occurrence. These curves are then used to determine the capacity that is then associated with the probability of occurrence of the drought curve. The above two subgroups have problems dealing with time - varying fluxes (Dt, R_t, DOR_t and E_t) and reservoir operation rules such as restrictions to supply once the reservoir storage falls below certain levels. [The sequent peak algorithm can handle time-varying fluxes not associated with storage level]. The behaviour analysis (BA) method has the ability to include these components realistically and has therefore been ranked higher than the other critical period techniques (McMahon and Mein, 1978; 1986). In applying the BA method, the quantity of water in the reservoir is calculated period by period using the mass balance equation as follows:

$$Z_{t+1} = Z_t + Q_t + R_t - D_t - DOR_t - E_t - I_t \qquad (1)$$

$$\text{subject to } 0 \le zt+1 \le C \qquad (2)$$

where:

Z_{t+1} = quantity of water in the reservoir at the beginning of period t+1
Q_t = inflow during period t
R_t = rainfall gain onto the reservoir in period t
D_t = release during period t
DOR_t = downstream water rights release in period t
E_t = evaporation loss in period t
I_t = infiltration loss from the reservoir in period t
C = capacity of the reservoir.

The reservoir is assumed to be at a specific storage level in the initial period (t = 1). The probability of failure is determined as the proportion of time that the reservoir empties to the total period of simulation. The capacity C is varied interactively until the desired probability of failure or reliability is obtained. Alternatively, a probability of failure-capacity relationship could be established and the capacity for the design probability of failure be obtained therefrom. The BA method can deal easily with time variability of demand, rainfall, evaporation and downstream water rights. Restrictions to the demand when the storage falls below specified levels can also be incorporated easily. The main shortcomings of this procedure are the requirements of an initial storage state and a continuous sequence of data.

Methods based on Moran theory simulate the reservoir water balance within specified durations and assume that the variation of the storage state is a Markov chain of that duration. The flows of those durations are assumed to be independent although streamflows exhibit persistence. [The tendency that a low flow will be followed by another low flow rather than a high one and a high flow will be followed by a high one rather than a low one]. Out of these methods, the modified Gould's Probability Matrix (MGPM) method has probably found the most practical application. The MGPM method is a modification of Gould's method (Gould, 1961) with a change in the definition of the probability of failure (McMahon and Mein, 1978; 1986).

The MGPM method consists of the following steps:

- The trial reservoir capacity C is divided into k zones (i = 1, 2, ..., k). A value of k = 20 is commonly used (McMahon, 1976; Srikanthan and McMahon, 1985a & b). McMahon and Mein (1986) also recommend a k value of 20 but suggest lower values if the annual coefficient of variation (ACV) < 0.5 and higher values if the draft is high or when ACV > 1.5. The "empty reservoir" zone and the "full reservoir" zone are assigned zero volumes and the zones in between are assigned equal volumes of C/(k-2).
- Taking one year at a time, a reservoir simulation is performed as in the BA method (Eq. (1) and (2)) for all the k zones. During the routing, a count of the following is made:
  - The number of months of failure nf_i for each starting zone i. The values $mf_i = nf_i/(12 \times N)$ are the monthly failure probabilities of the matrix of failure probabilities $[MF]=\{mf_i;\ i = 1, 2, ..., k\}$.
  - The storage zone at the end of the year j for each starting zone i $ns_{i,j}$. The values $tm_{i,j} = ns_{i,j}/N$ are the transition probabilities of the transition probability matrix $[TM]=\{tm_{i,j};\ i, j = 1, 2, ..., k\}$.
- The steady state probabilities of the reservoir being in any storage zone sst_i are then determined to give the steady state matrix $[SST]=\{sst_i;\ i = 1, 2, ..., k\}$. Two methods that could be used are:
  - Powering up the transition matrix [TM]: $[TM]^{2m}$ with m being an integer large enough to give steady state conditions. An m value of 4 or 5 is usually adequate (Srikanthan and McMahon, 1985b).
  - Solving for sst_i (i = 1, 2, ...k) using the k linear equations obtained from Eq. (3) with a replacement of one of the linear equations with Eq. (4).

$$[TM][SST]=[SST] \qquad (3)$$

$$\sum_{i=1}^{k} sst_i = 1 \qquad (4)$$

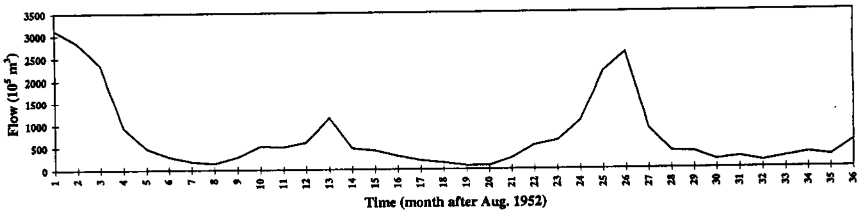
- The probability of failure P_f is computed as follows:

$$P_f = \sum_{i=1}^{k} sst_i \times mf_i \qquad (5)$$

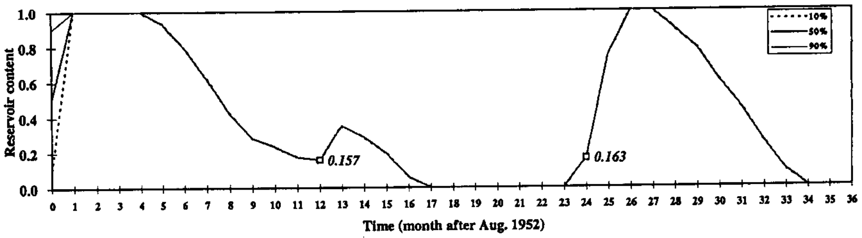
- The trial reservoir capacity C is adjusted interactively until the required failure probability is obtained. As with the BA the capacity could also be obtained from a curve of C versus P_f.

The MGPM method performs a monthly water balance of the reservoir like the BA but handles one year at a time. The advantages of the BA method stated earlier in this introduction therefore also apply to the MGPM. This procedure has the advantages of not being dependent on an initially assumed initial storage state unlike the BA. As the historical sequencing of flows is not important in applying the MGPM, discontinuous flows can be handled quite easily. Another notable advantage of the MGPM method is its ability to compute the probability of failure as a time-dependent function of a specified starting condition (McMahon and Mein, 1978, 1986). The main shortcoming of this procedure arises from the fact that the analysis takes one year of data at a time, thereby assuming that annual flows are independent. Intuitively, this assumption would be expected to result in an inadequate capacity in situations where over-year storage of water is required if the annual serial correlation is significant. During the life of a reservoir the need for over-year storage is more serious during the low-flow (critical) periods. Methods that use one year of streamflow data at a time like the MGPM are likely to separate some of the years within these low-flow periods. The effect of having low flows in one year is then not carried over to the next as new initial starting level/s of the reservoir are assumed. Consequently, some reservoir failures that would have occurred are missed out and higher levels of reliability are obtained. This effect is illustrated quantitatively with the behaviour analysis of a reservoir using a 3-year streamflow series that includes a critical period. The series (Fig. 2a) was obtained from one of the 6 sites used in this study (Site 1 of Table 1).

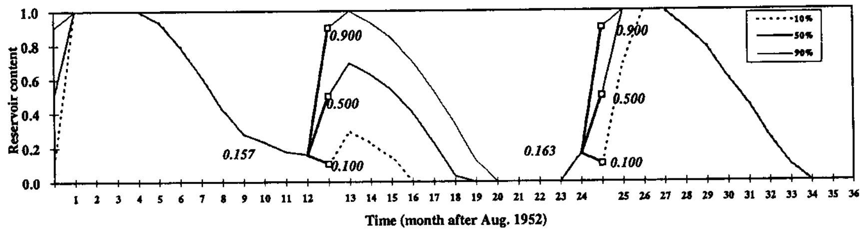
Equations 1 and 2 are used with streamflow and demand as the only fluxes. The analysis uses a reservoir size of 30% of the annual flow (2 584 $\times10^5$ m^3) and a demand level of 90% of the mean flow (646$\times10^5$ m^3). Three initial storage states of 10, 50 and 90% of reservoir capacity are assumed. In one case (Fig. 2b), the analysis is continuous and in the other (Fig. 2c), the initial storage states are set at the beginning of each year. As shown in Fig. 1c, the reservoir states of 0.157 at the end of the first year revert to 0.1, 0.5 and 0.9 at the beginning of the second year. The simulations in the second year therefore give lower failure levels than in the case of continuous simulation. The continuous simulation case (Fig. 2b) gives a failure probability of 27.8% whilst the independent-year case (Fig. 2c) gives a considerably lower failure probability of 22.8%. The significance of the effect using the years separately would be expected to depend on the level of dependence of the yearly flows with no effect where yearly flows are independent. Situations that do not call for over-year storage (low demand situations) are also likely to be unaffected by the separate use of yearly flows even when annual serial correlation (ASC) is significant. This is because the reservoir would be filling up at least once during most if not all the years. The separate analysis of yearly data is therefore expected to have serious impacts in cases where the two situations of a significant ASC and the requirement of over-year storage exist together.



A. Streamflow sequence including a critical dry period



B. Continuous simulation



C. Separate year long simulations

Figure 2
An illustration of the effect of separating yearly flows in capacity determination

A number of studies aimed at quantifying the effects of the assumption that annual flows are independent and devising corrective measures have been conducted in Australia. Applying the historical records of 156 Australian streams, McMahon (1976) developed a graph relating the correction factor (the factor with which to multiply the capacity determined assuming no ASC) to the annual serial correlation coefficient (ASCC). A 95% reliability level and drafts of 50 and 90% of the mean flow were applied. These correction factors were the ratios of the capacities determined by the BA method to those obtained by the MGPM method. [The average of the capacities determined assuming and initially full and an initially empty reservoir]. McMahon's graph is presented as Fig. A1 in **Appendix A**. Srikanthan and McMahon (1985a) undertook another study in which the correction factors were also computed as the ratio of the BA4 to the MGPM estimates and 1 000-year long monthly sequences were generated from the historical streamflows of 9 Australian rivers. Draft levels of 30, 50, 70 and 90% were used with probabilities of failure of 5,2 and 1%. Figure A2 in Appendix A presents the curves relating the correction factor to ASCC and reservoir size. In a related study (Srikanthan and McMahon, 1985b), that used the same data set, draft levels and probabilities of failure, the MGPM method was used with the 12 possible starting months of analysis (SMAs) and the values compared with BA estimates. [The BA estimates were obtained from the second simulation using an initial reservoir state equal to the final state of the first simulation. The first simulation could use any initial storage state]. The capacities determined by the MGPM were found to be closest to those determined by the BA for the SMAs coinciding with the minimum average monthly flow. Srikanthan and McMahon (1985b) therefore recommended that the MGPM should be applied using the SMA giving the minimum average monthly flow which means the water years should begin and end during a time of low flow. In another study (Srikanthan, 1985), capacities were determined by simulation (a reservoir behaviour analysis) using 1 000-year monthly flows generated synthetically to give ASCC values of -0.2, 0, 0.2, 0.4,

TABLE 1
STREAMFLOW SEQUENCES USED IN THE STUDY

Reservoir site	C. Area[I]	RGS[II]	Data length (years)	MAR[III]
1. Lugari	8237	1DA2	35 (1947-1981)	168
2. Grandfalls	16927	4F1/F13	25 (1948-1972)	344
3. Malewa	1430	2GB1	34 (1936-1969)	128
4. Magwagwa	3160	1JG1	37 (1947-1983)	448
5. Namba Kodero	2769	1KC3	33 (1951-1983)	180
6. Gongo	2323	1FG1	35 (1947-1981)	361

[I] Catchment area (km^2)
[II] Mean annual runoff (mm)
[III] River gauging station number

and 0.6. The effect of ASC was computed as the ratio of the capacities determined with flows having ASCCs of -0.2, 0.2, 0.4 and 0.6 to those determined with flows having an ASCC of 0. The effects were found to increase with draft, the ASCC and the ACV. In most cases, the correction factors were found to increase towards an asymptote at (1+ASCC)/(1-ASCC). This is in agreement with the results of Phatarfod (1986). Srikanthan (1985) considered the effect when ASCC > 0.2 to be too high (requiring correction factors of 1.5 or more) and recommended that methods that assume no ASC should not be applied in such cases.

In the current study, the effect of ASCC using the MGPM method was investigated by comparing the capacities determined using the SMAs giving the minimum with those giving the maximum ASCCs. This approach was taken after it was found out that ASCC varied highly with the SMA. Unlike the previous studies, the comparison of the MGPM with other methods is not done. Uncertainties resulting from conceptual differences among methods other than those concerning ASC have therefore been avoided. An observation of Fig. A2 (**Appendix A**) which is based on a comparison of the BA and the MGPM method reveals that correction factors are still required even when the ASCC is zero. This means that there are other conceptual differences between the BA and the MGPM that could also be significant. The previous studies were all based on Australian data and it was therefore worthwhile to try out the MGPM method with data from other regions. This study used the historical sequences of 6 potential reservoir sites in Kenya. Table 1 gives some details of the flow sequences and Fig. 3 presents the distributions of the average monthly flows (AMF).

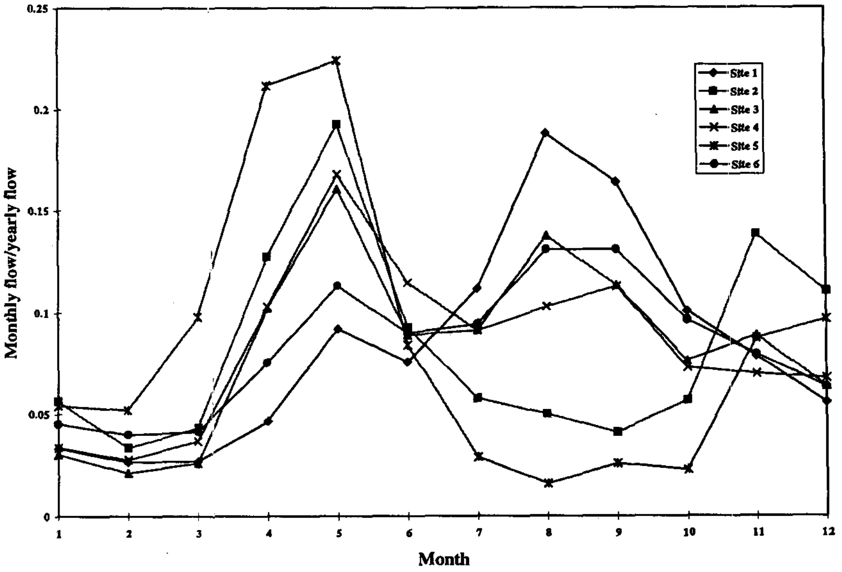


Figure 3
Average monthly flow (AMF) distributions for the streamflow sequences used in the study

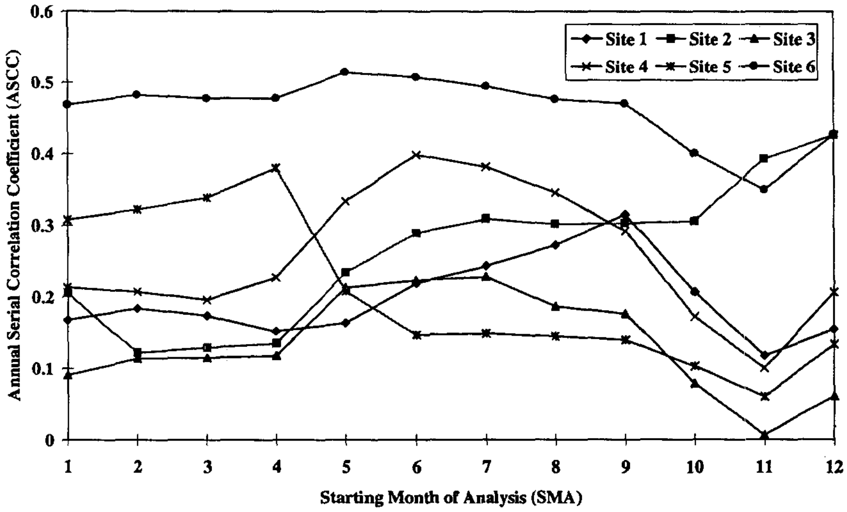


Figure 4
The variation of annual serial correlation coefficient (ASCC) with the starting month of analysis(SMA)

Description of the method

As stated in the introduction, the study approach was inspired by the large variation of ASCC with the SMA observed with all the 6 streamflows. This variation is presented in Fig. 4. However, reservoir capacity is also highly dependent on the variability of the inflows with the required capacity increasing as the variability increases. This would be intuitively expected and the studies by Srikanthan and McMahon (1985a) and Srikanthan (1985) confirm this. Furthermore, Dincer's and Gould's gamma method (see McMahon and Mein, 1978; 1986) gives capacities that are directly proportional to the square of the coefficient of variation of annual flows. It was therefore appropriate to investigate the change of the variability of monthly flows with the SMA. The monthly variability of annual flows was selected because the MGPM method carries out 1-year simulations using a monthly time step. The average monthly coefficient of variation (MCV) computed using Eq. (6) was used as a measure of the average monthly variability of annual flows. Figure 5 presents the variation of the MCV with SMA.

$$MCV = \left(\frac{\sum_{i=1}^{N} \left[\sqrt{\sum_{j=1}^{12} (x_{i,j} - \overline{XM}_i)^2 / 11} \right] / XM_i}{N} \right) \qquad (6)$$

where:

$x_{i,j}$ = flow during month j of year i
XM_i = mean monthly flow for year i
N = number of years of record

The variation of MCV with SMA was found to be much lower than that of the ASCC. A further analysis revealed that a reasonable linear relationship between ASCC and MCV existed as illustrated in Fig. 6 and Table 2. A higher flow variability has the effect of increasing the capacity whilst a higher serial correlation leads to a lower capacity. Since MCV increased with ASCC for

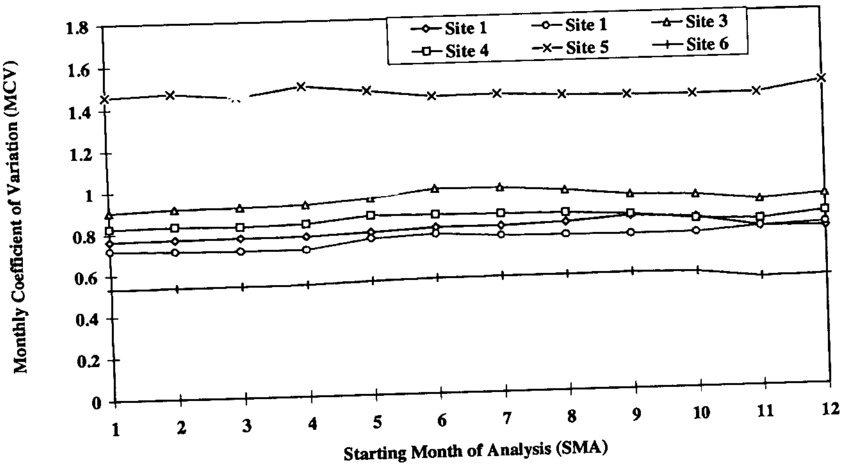


Figure 5

The variation of the average monthly coefficients of variation (MCV)) with the starting month of analysis(SMA)

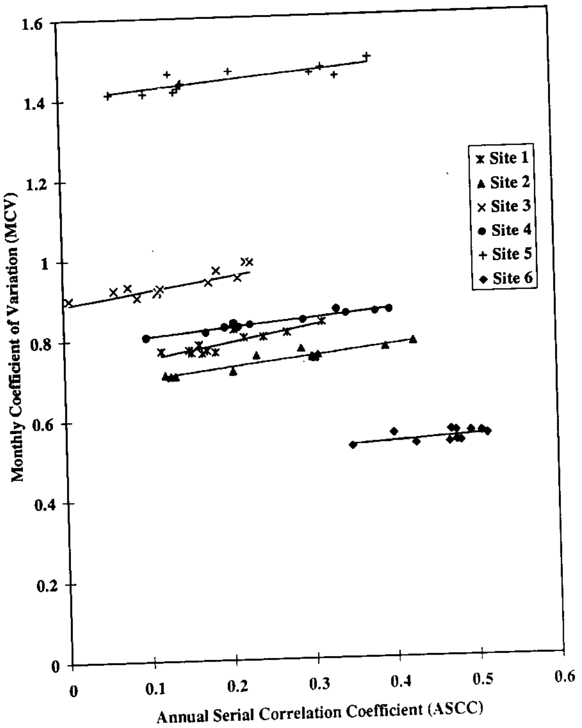


Figure 6

The relationship between average monthly coefficients of variation (MCV) and annual serial correlation coefficient (ASCC)

all the sequences, any significant monthly variability would have an effect opposite to that of ASC. It was therefore considered reasonable that the comparison of the capacities obtained using the SMAs giving the minimum with those giving the maximum ASCCs would give a satisfactory indication of the effect of the assumption that annual flows are independent.

The study aimed to include the wide range of demand levels that could be encountered in practice. Draft levels of 30, 50,70 and 90% of the mean flow were therefore used. A review of the capacity determination of four urban water supply reservoirs in Kenya (Ndiritu, 1992) indicated that probabilities of failure varying from 2 to 10% had been applied. It was thus decided that the use of probabilities of failure of 2, 4, 6, 8, 10, 12, 14 and 16% would be adequate. A computer program developed in GWBASIC by the authors was used. This program is freely available from the authors and is briefly described in **Appendix B**. For the purposes of this study, trial runs were first made to ensure that the range of failure probabilities of 2 to 16% was covered. Runs were then made with a series of reservoir capacities from which the corresponding failure probabilities were obtained. Curves of probability of failure vs. reservoir capacity were plotted and the capacities corresponding to probabilities of failure of 2, 4, 6, 8, 10, 12, 14 and 16% then read off for analysis.

Results and discussion

The ratios of the capacities determined using the SMAs giving the maximum ASCC, (R_H) and those giving the minimum ASCC, (R_L) were computed for the 8 probabilities of failure. Plots of the R_H/R_L vs. probability of failure did not reveal a relationship between the two. The R_H/R_L values were therefore averaged for each draft level. Figure 7 presents the variation of the average R_H/R_L with draft. A plot of the overall averages is also included. These are 1.02, 0.91, 0.85 and 0.76 at the 30, 50, 70 and 90% draft respectively.

The observations indicate that ASC was significant at draft levels greater than 30% with the effect increasing with draft as expected. This trend was expected and it implicitly agrees with the results of McMahon (1976) and Srikanthan and McMahon (1985a) presented in **Appendix A**. The recommendation of Srikanthan and McMahon (1985b) that the MGPM should use the SMA coinciding with the minimum monthly flow is neither supported nor contradicted by the results of the current study. However, as can be observed from Figs. 3 and 4, the relationship between the average monthly flow and ASCC is not strong. From Table 3, which gives corresponding average monthly flows and ASCCs, it is seen that the average minimum monthly flow and the minimum ASCC coincide for only Site 2. In addition, the months having the minimum monthly flows for the other five sites give

TABLE 2
A LINEAR REGRESSION ANALYSIS OF THE RELATIONSHIP BETWEEN AVERAGE MONTHLY CORRELATION COEFFICIENT (MCV) AND ANNUAL SERIAL CORRELATION COEFFICIENT (ASCC); MCV=MG×ASCC+CI

Site	mg	ci	R^2	S. E.
1	0.377	0.714	0.736	0.013
2	0.250	0.678	0.863	0.010
3	0.373	0.887	0.766	0.015
4	0.202	0.786	0.915	0.006
5	0.198	1.403	0.651	0.016
6	0.183	0.488	0.121	0.013

R^2: Coefficient of determination
S.E: Standard error

ASCCs considerably higher than the minimum values. The comparison of capacities determined using the SMAs giving the minimum ASCCs and those giving the minimum monthly flows would assess the recommendations of Srikanthan and McMahon (1985b) more effectively.

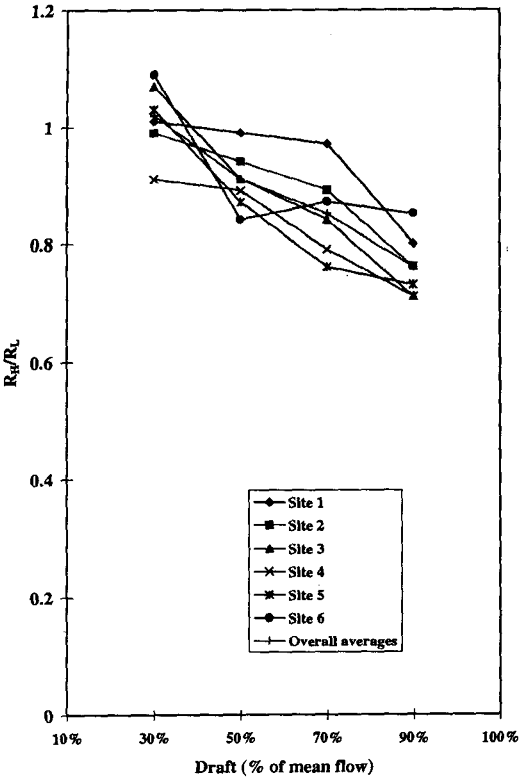


Figure 7
Reservoir size ratios at varying demand levels

The average of the minimum ASCCs for the six sequences was 0.126 with the maximum among them being 0.349. Figures A1 and A2 indicate that considerable correction factors may need to be applied at these ASC levels. The minimum value of 0.349 for Site 6 is by far much higher than the maximum ASCC of 0.2 recommended by Srikanthan, 1985 (and adopted by McMahon and Mein, 1986) beyond which methods that assume no ASC should not be used. Thus while applying the SMA giving the minimum ASCC reduces the effect of ASC, it is not likely to eliminate the problems for many streamflows.

Following is a modification to the MGPM method that could have the potential to check the serial correlation problem adequately enabling the use of the MGPM to streamflows of high ASC and also doing away with the need for correction factors. The modification involves:

- an increase in the length of the routing period from 1 year to an extent that will result in an insignificant serial correlation coefficient with one of the SMAs that could be used with that period; and
- the use of the SMA or any of the SMAs that give insignificant serial correlation coefficients in the determination of reservoir capacity.

The following advantages support the use of longer periods:

- The longer the period, the lower the serial correlation. For instance, the dependence of an annual flow on the previous annual flow would on the average be expected to be greater than that of a 2-year flow on the previous 2-year flow.
- The number of SMAs from which to obtain the minimum serial correlation coefficient increases as the period length increases (with 2-year flows, the selection would be from 24 values as compared with 12 for annual flows).
- With a longer period, separations during low flow (critical) periods are likely to occur to a lesser extent. For instance, the critical period of Fig. 2a can be contained within a 2-year period but not a 1-year period.

The lag 1 serial correlation coefficients of 2-year flows (BSCC) were computed for the 24 possible SMAs for the six streamflow

TABLE 3
AVERAGE MONTHLY FLOWS (AMF) AND ANNUAL SERIAL CORRELATION COEFFICIENTS (ASCC) FOR THE 12 STARTING MONTHS OF ANALYSIS (SMA)

SMA		1	2	3	4	5	6	7	8	9	10	11	12
Site 1	AMF	0.033	0.026	0.027	0.047	0.092	0.076	0.112	0.188	0.164	0.101	0.079	0.056
	ASCC	0.168	0.184	0.174	0.152	0.164	0.219	0.243	0.272	0.315	0.207	0.118	0.155
Site 2	AMF	0.056	0.034	0.043	0.128	0.193	0.093	0.058	0.050	0.041	0.057	0.138	0.110
	ASCC	0.205	0.122	0.129	0.135	0.234	0.289	0.309	0.302	0.303	0.306	0.392	0.426
Site 3	AMF	0.030	0.021	0.026	0.102	0.161	0.089	0.091	0.138	0.113	0.076	0.089	0.064
	ASCC	0.090	0.114	0.115	0.118	0.213	0.223	0.228	0.187	0.177	0.079	0.007	0.062
Site 4	AMF	0.034	0.028	0.037	0.103	0.168	0.115	0.091	0.103	0.113	0.073	0.070	0.068
	ASCC	0.213	0.207	0.196	0.227	0.333	0.398	0.381	0.345	0.292	0.173	0.100	0.207
Site 5	AMF	0.054	0.052	0.098	0.212	0.224	0.084	0.029	0.016	0.026	0.023	0.087	0.097
	ASCC	0.307	0.321	0.338	0.379	0.208	0.147	0.149	0.145	0.140	0.103	0.061	0.134
Site 6	AMF	0.045	0.040	0.041	0.075	0.113	0.090	0.094	0.131	0.131	0.096	0.080	0.063
	ASCC	0.468	0.482	0.477	0.477	0.514	0.507	0.494	0.476	0.470	0.400	0.349	0.427

sequences of Table 1. These values are presented graphically in Fig. 8. Table 4 gives a comparison of the average and minimum absolute ASCCs and BSCCs. These comparisons are also made in Fig. 9 and Fig. 10 respectively. As expected, the average BSCCs are much lower than the corresponding ASCCs. With five of the six sequences, both positive and negative and some very low (practically insignificant) values of BSCC have been obtained. From a practical viewpoint, it is therefore possible to obtain capacities that are independent of serial correlation for the five sites using a 2-year routing period. The minimum BSCC for Site 6, 0.063 could still be significant. A longer routing period may need to be used in such cases. The effectiveness of the proposed modifications can be tested by comparing the modified MGPM with the MGPM method.

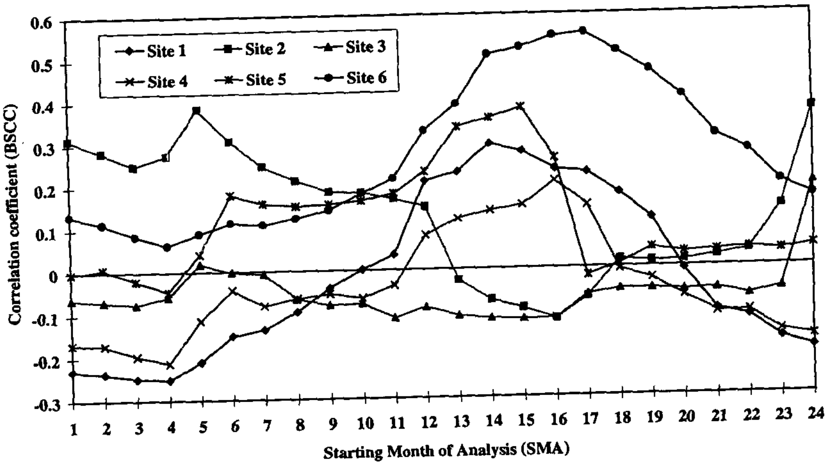


Figure 8

The variation of the serial correlation coefficients of 2-year flows with the starting month of analysis(SMA)

Conclusions

- To minimise the effect of the assumption that annual flows are independent in using the modified Gould's probability matrix method, the starting month of analysis giving the minimum lag 1 annual serial correlation coefficient should be applied in cases where the demand is greater than 30% of the mean flow. The same could apply to other procedures that assume independence of annual flows.
- The serial correlation problem in the application of the of modified Gould's probability matrix method has the potential of being eliminated by the use of longer routing periods than the 1-year period used in the modified Gould's probability matrix method. The selected period would need to be long enough to give an insignificant serial correlation coefficient with one of the possible starting months of analysis that could be applied with that period. The starting month (or any of the

TABLE 4
A COMPARISON OF THE AVERAGE AND THE ABSOLUTE MINIMUM ANNUAL (ASCC) AND 2-YEAR (BSCC) SERIAL CORRELATION COEFFICIENTS

Site	Mean ASCC	Mean BSCC	Min. Abs. ASCC	Min. Abs. BSCC
1	0.198	-0.021	0.118	0.001
2	0.263	0.137	0.122	0.012
3	0.134	-.0073	0.007	-0.002
4	0.256	-0.044	0.1	-0.006
5	0.203	0.127	0.061	0.003
6	0.462	0.246	0.349	0.063

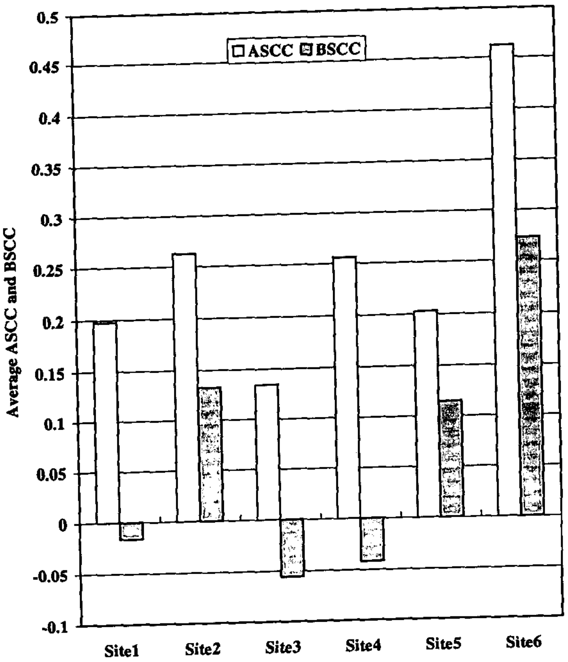


Figure 9

Comparison of the average serial correlation coefficients of annual and 2-year flows

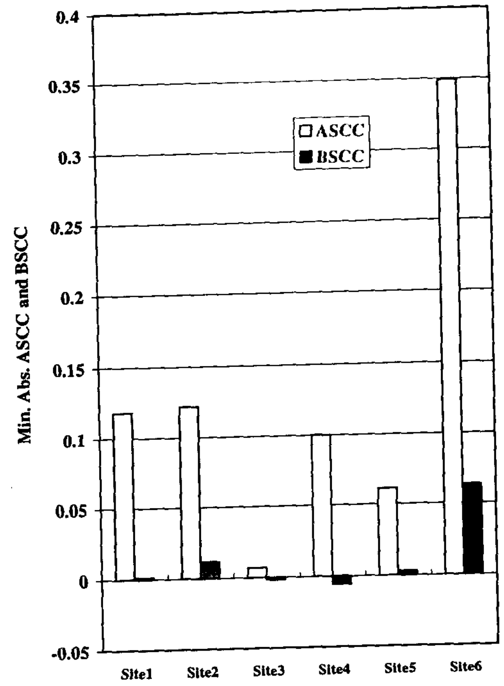


Figure 10

Comparison of the absolute minimum serial correlation coefficients of annual and 2-year flows starting months) of analysis giving insignificant serial correlation coefficients should then be used in determining the reservoir capacity. An investigation of the six streamflow sequences used in this study indicates that a 2-year routing period would be adequate for five of them.

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Appendix A
Correction factors for the effects of the assumption that annual flows are independent

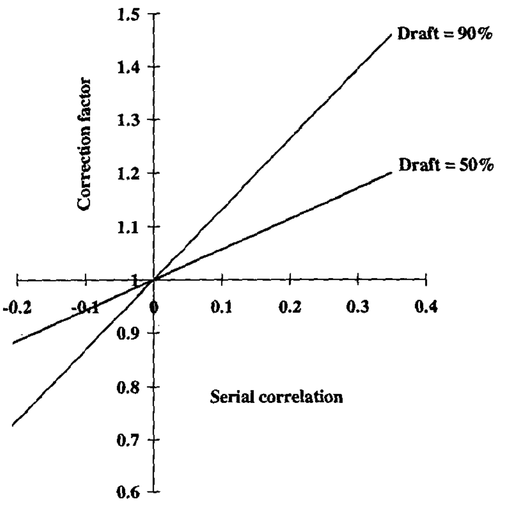

Figure A1
Reservoir capacity correction factors for annual serial correlation (after McMahon, 1976)

Appendix B
Computer program for the MGPM method

The computer program is menu-driven and user-friendly. A constant demand or demands varying on a monthly basis could be used. A constant monthly downstream water rights can also be handled. Multi-level reservoir restrictions that are constant or dependent on the month of the year could be included. A linearlised reservoir area-volume relationship is used in the estimation of rainfall gains and evaporation losses and the reservoir dead storage could also be incorporated in the analysis. Discontinuous streamflows can also be handled Probabilities of failure of up to 20 capacities can be computed in a single run but with the same SMA.

The other modules of the program are:
- a data entry component to enter the monthly runoff series, average monthly rainfall and evaporation rates and the reservoir site area-volume relationship; and
- a component to compute ASCC, ACV and mean flows of the streamflow series for the 12 possible SMAs.

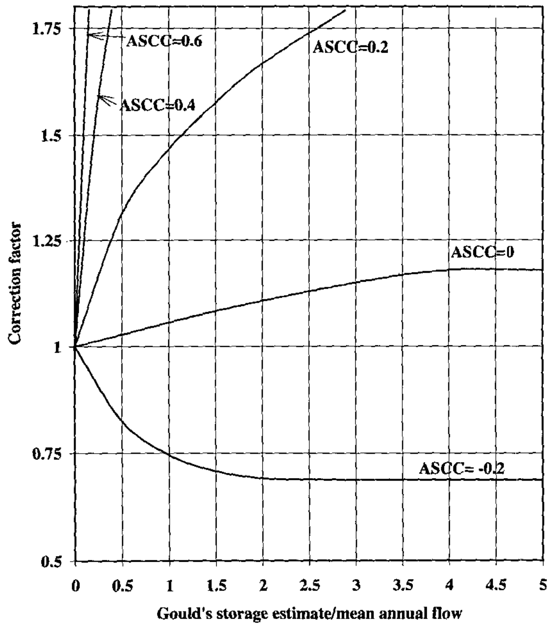

Figure A2
Factor to adjust storage size calculated by Gould's probability matrix method for annual serial correlation effect (after Srikanthan and McMahon, 1985a)