

**STOCHASTIC AND MODIFIED SEQUENT PEAK  
ALGORITHM FOR RESERVOIR PLANNING  
ANALYSIS CONSIDERING PERFORMANCE INDICES**

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ALGORITHM FOR RESERVOIR PLANNING ANALYSIS  
CONSIDERING PERFORMANCE INDICES**

by

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**Dedicated to My Dear Parents**

**Esmaeil Saket Oskoui and Nahid Azari**

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## LIST OF ABBREVIATIONS

AR	Auto Regressive
ARMA	Auto Regressive Moving Average
BL	Broken Line
CDF	Cumulative Distribution Function
CP	Critical Period
DF	Degrees of Freedom
DID	Department of Irrigation and Drainage
DP	Dynamic Programming
DRI	Drought Risk Index
$F$	Failure
FGN	Fractional Gaussian Noise
FM	Figure of Merit
ISM	Indexed Sequential Method
LP	Linear Programming
MA	Moving Average
MAF	Mean Annual Flow
MLE	Maximum Likelihood Estimates
NLP	Non-Linear Programming
PDF	Probability Density Function
PPCC	Probability Plot Correlation Coefficient
RMSE	Root Mean Square Error
RNG	Random Number Generator
$S$	Success

SC	Storage Capacity
SD	Standard Deviation
SE	Standard Error
SPA	Sequent Peak Algorithm
SPSS	Statistical Package for Social Sciences
SROC	Spearman Rank Order Correlation
WMO	World Meteorological Organization

## LIST OF SYMBOLS

$A$	Coefficient matrix of ( $MN \times N$ ) in the V-S model
$AR(1)$	auto regressive model of 1 order
$AR(p)$	autoregressive model of p order
$ARMA(p, q)$	autoregressive moving average models
$A_c$	regression coefficient for modeling the critical period
$A_s$	regression coefficient for modeling the storage capacity
$A_k$	Kirby parameter for modifying Pearson type III reduced variate
$A_t$	reservoir water surface area at the beginning period t
$A_{t+1}$	reservoir water surface area at the end of period t
$a$	parameter, linearized slope of the area-storage curve for the reservoir
$B$	Coefficient matrix of ( $MN \times MN$ ) in the V-S model
$B_c$	regression coefficient for modeling the critical period
$B_s$	regression coefficient for modeling the storage capacity
$B_k$	Kirby parameter for modifying Pearson type III reduced variate
$B_0, B_1, B_2$	specific coefficients for autoregressive model
$b$	parameter, reservoir water surface area at the dead storage level
$Cov$	Covariance
$CP_E$	critical period for English systems
$CP_I$	critical period for Iranian systems
$CP_{(Johor)}$	critical period for Johor system
$CP_{(Melaka)}$	critical period for Melaka system
$CP_{(Muar)}$	critical period for Muar system
$CP_{(3 \text{ Systems})}$	critical period for the three study systems together

$C_v$	coefficient of variation
$c$	minimum fraction of target demand to be guaranteed in a failure period
$D$	demand expressed as a ratio of mean annual flow
Demand	annual demand from the reservoir as a ratio of mean annual flow
$D_w$	a window width of a given duration in moving window method
$E[ \ ]$	Expectation function
$EP_t$	depth of evaporation from reservoir surface in period $t$
$EV_t$	volumetric storage-dependent fluxes during period $t$
$EV_t^{sys}$	net evaporation losses of the system during period $t$
$e^{( )}$	exponential function employed for modeling the storage capacity
$e_i$	independent zero mean and unit variance normal random variable
$\bar{e}$	the average of independent zero mean and unit variance normal random variables
$en_t$	net evaporation (i.e. evaporation minus rainfall) in period $t$
$F$ -stat	$F$ -statistic
$f_s$	the number of continuous sequences of failure periods
$f$	total number of failure periods
$f$	annual risk i.e. $1-f$ is the annual time-based reliability
$G_k$	Kirby parameter for modifying Pearson type III reduced variate
$g$	skewness of Pearson type III variable corrected for serial correlation
$g_0$	original sample skewness
$H_k$	Kirby parameter for modifying Pearson type III reduced variate
$H_0$	the null hypothesis
$h$	Hurst coefficient
$I_t$	volumetric inflow into reservoir during period $t$

ICRIT	the time period corresponding to the end of the critical period
ICY	current critical period
IOVF	the time period corresponding to the beginning of the critical period
i	time / rank of observation values
K	reduced variate or frequency factor
$K_a^*$	minimum active storage capacity obtained by the modified SPA
$K_{t-1}$	volumetric sequential storage deficits at the beginning of period t
$K_t$	volumetric sequential storage deficits at the end of period t
$K_a, K'_a$	capacity estimates during any consecutive iterations for modified SPA
$K_e$	reduced variate of Gumbel distribution
$K_g$	reduced variate of Pearson type III distribution
$K_g^m$	modified Pearson type III reduced variate developed by Kirby (1972)
$K_i$	$i^{\text{th}}$ order reduced variate or frequency factor
$K_n$	reduced variate of the standard normal distribution
$K_O$	over-year storage capacity expressed as a ratio of Mean Annual Flow
$K_T$	total (i.e. over-year plus within-year) storage capacity
k	continuous failure period
$L_e$	the length of streamflow data
LN2	the two-parameter log-normal distribution
LN3	the three-parameter log-normal distribution
LP3	the log-Pearson type III distribution
$L_t$	other losses during period t in the SPA
M	the total number of seasons per year in the V-S model
MA(1)	moving average model of order 1

$m$	standard demand parameter / standardized demand parameter
$\max(\text{sh}_k)$	maximum shortfall during the $k^{\text{th}}$ continuous failure period
$N$	the length of the observed data record
$N$	the total number of sites in the V-S model
$N_s$	the number of independent samples or replicates
$n$	the number of the data
$n_u$	the total number of data / the number of years of data
$n_1$	the number of successes in the randomness test
$n_2$	the number of failures in the randomness test
$P$	cumulative probability
$P_i$	the cumulative probability of $i^{\text{th}}$ ordered data observations
$P_t$	depth of rainfall on reservoir surface in period $t$
$P_3$	Pearson type III distribution
$\rho$	annual reliability
$\bar{q}$	historical mean annual flow
$R$	the total number of the runs in randomness test
$R$	the range of cumulative departures of annual flows from the mean
$R_e$	the time-based reliability
$R_t$	release of the reservoir system during period $t$
$R_t^{\text{sys}}$	release of the system during period $t$
$R_t^*$	target demand of the reservoir system during period $t$
$R_t^{*\text{sys}}$	target demand of the system during period $t$
$R^2$	Coefficient of determination for the regression analysis
$r()$	lag-zero cross-correlation function for the V-S model

$\text{round} \{ \}$	is a function that rounds to the closest integer number
$ru_i$	the rank of time series value during $i$ period
$S$	standard deviation of annual flows
Skew	Skewness
SN	normalized storage capacity
Storage	active storage capacity
S-Y-P	storage-yield-performance
S-Y-R	storage yield relationships
$SN_{(\text{Johor})}$	normalized storage capacity for Johor system
$SN_{(\text{Melaka})}$	normalized storage capacity for Melaka system
$SN_{(\text{Muar})}$	normalized storage capacity for Melaka system
$SN_{(3 \text{ Systems})}$	normalized storage capacity for the three systems together
$S_t$	active storage for the reservoir at the beginning of period $t$
$S_{t+1}$	active storage for the reservoir at the end of period $t$
$S_K$	the coefficient of skewness for annual flows
$S_x$	standard deviation of the observed data
$S_{xx}$	The matrix of $(MN \times MN)$ in the V-S model
$S_{xz}$	The matrix of $(MN \times N)$ in the V-S model
$S_{zz}$	the covariance matrix of $(N \times N)$ in the V-S model
$S_0$	the covariance matrix of $(N \times N)$ in the V-S model
$sh_k$	shortfall during the $k$ -th continuous failure period
$T$	total number of time periods in the record or inflow sequence
$T$	one divided by cumulative probability
T-F	Thomas-Fiering

$t$	time period
$tr$	the coefficient of the trend for trend test
$t_u$	the value of the test statistic for the trend test
$tu_i$	time of occurrence of time series data
$t\alpha_{t/2}$	value of trend test limit at $\alpha_t$ significance level
$u$	observed data record
$u^*$	a bootstrap sample
$u_i$	time series data during $i$ period
$Var$	variance
$V-S$	Valencia-Schaake
$V_i$	the vector of $(MN \times 1)$ independent standard normal random variables
$V_u$	Vulnerability
$\bar{X}$	mean of the observed data
$X_i$	the vector of $(MN \times 1)$ transformed normally distributed seasonal flows at $i$ year
$X_i, X_{i+1}$	annual flows for the $i^{th}$ and $(i+1)^{th}$ years, respectively
$X_{mi}^n$	streamflow for season $m$ , year $i$ and site $n$ in the V-S model
$X_j^n$	flows of season $j$ at the site $n$ in the V-S model
$X_l^k$	flows of season $l$ at the site $k$ in the V-S model
$x_i$	$i$ -th ordered data observations
$x_{max}$	the largest observation
$x_{med}$	sample medium
$x_{min}$	the smallest observation
$x$	streamflow data