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

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# STOCHASTIC AND MODIFIED SEQUENT PEAK 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×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×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 |
| $CP_{(3\ Systems)}$ | 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) |
| $K_i$ | $i^{th}$ 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 |
| $\max(sh_k)$ | maximum shortfall during the $k^{th}$ 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 $i^{th}$ ordered data observations |
| $P_t$ | depth of rainfall on reservoir surface in period t |
| P3 | Pearson type III distribution |
| $p$ | 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 |
| $R_t^{sys}$ | release of the system during period t |
| $R^*_t$ | target demand of the reservoir system during period t |
| $R_t^{*sys}$ | 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 |

| | |
|---|---|
| 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 |
| $SN_{(Johor)}$ | normalized storage capacity for Johor system |
| $SN_{(Melaka)}$ | normalized storage capacity for Melaka system |
| $SN_{(Muar)}$ | normalized storage capacity for Melaka system |
| $SN_{(3\ Systems)}$ | 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×MN) in the V-S model |
| $S_{xz}$ | The matrix of (MN×N) in the V-S model |
| $S_{zz}$ | the covariance matrix of (N×N) in the V-S model |
| $S_0$ | the covariance matrix of (N×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×1) independent standard normal random variables |
| $V_u$ | Vulnerability |
| $\overline{X}$ | mean of the observed data |
| $X_i$ | the vector of (MN×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 |