تقييم ألاعتمادية لخزانات ألعراق

رسالة
مقدمة إلى جامعة بابل - كلية الهندسة
كجزء من متطلبات نيل شهادة ماجستير
علوم في الهندسة المدنية

من قبل

وائل عبدالباري حسين

بإشراف

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٢٠٠٦

Reliability of Iraqi Reservoirs

A Thesis

Submitted to the College of Engineering of the University of Babylon in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By

Wa'el Abdul-Bari Hussien

٢٠٠٦

بسم الله الرحمن الرحيم

﴿ وَهوَ الذي مَرَجَ البَحْرَيْنِ هذا عَذْبٌ فُرَاتٌ وَهذا مِلْحٌ أُجاج وَجَعَلَ بَيْنَهُما بَرْزَخاً وَحِجْراً مَحْجُوراً ﴾

صدق الله العظيم

سورة الفرقان – الآية ٥٣

الخلاصة

طبقت في هذا ألبحث ثلاثة طرق من طرق ألسعة-ألاطلاق Capacity-yield procedures لتخمين إعتمادية خزان بخمة. هذه ألطرق هي طريقة حساب ألذروات ألمتسلسلة Sequent peak algorithm method، طريقة جولد Probability matrix (Gould) procedure، وطريقة تحليل ألسلوك Behaviour analysis. المرونة والضعف حسبا بالطريقة الأخيرة. تم إعداد برنامجي حاسوب بلغة فورتران لإيجاد هذه المقاييس.

مقاييس الخطورة أعلاه قدرت اعتمادا على كلا" من سلاسل ألبيانات التاريخية Historical data والمولدة Generated data للتصاريف ألشهرية. أستخدمت ستّة نماذج لتوليد الجريانات الشهرية لخزان بخمة والتي هي، طريقة ماركوف من الدرجة ألاولى، نموذج ثوماس-فايرينك مع استخدام ألتحويل اللوغاريتمي، نموذج ثوماس-فايرينك مع استخدام تحويل Box-Cox ، نموذج مزدوج المحور، نموذج مزدوج المحور المعدّل ونموذج ألشظى المعدّل. هذه النماذج تم اختبارها ومقارنتها مع البيانات التأريخية. وقد استنتج أنّ كلا" من نموذج ثوماس-فايرينك مع استخدام التحويل اللوغاريتمي ونموذج ثوماس-فايرينك مع استخدام تحويل Box-Cox هما الأفضل لتمثيل جريان خزان بخمة، بالإضافة إلى ذلك وجد أن تحويل Lognormal type three هو أفضل من ألتحويلين Lognormal type two و Like-gamma في تمثيل ألتسجيلات ألتاريخية.

ثلاثة عوامل تم فحصها لايجاد تأثيرها على تخمين الخزن المطلوب. هذه ألعوامل هي طول سلسلة التصاريف المولدة، حالة ألخزين ألأولي للخزان، وألبدء بشهر ما. أظهرت النتائج المقدمة في هذا البحث بأنّه يحتاج إلى سلسلة جريان بحدود ١٠,٠٠٠ سنة أو أكثر لتقليل تأثير هذه العوامل.

وجد ّأن اعتمادية خزان بخمة الذي مخزونه $١٠^{٩}$ * ١٢.٦ متر مكعب هو تقريبا ٩٥ % عندما يكون إطلاق الخزان ٩٥ % من المعدل الشهري.

تم بهذا البحث أيضاً تطوير علاقات تقريبية لكن عامّة بين الخزن-الإطلاق-الاعتمادية لخزانات العراق. إنّ طريقة مصفوفة احتمال جولد طبقت على كُل من خزانِ حديثة والعظيم بالإضافة إلى خزان بخمة لِحساب الخزن الذي يُقابل اطلاقات واعتماديات مختلفة لكُل خزان. إن النَتائِج المكتسبة جمعت سوية لاشتقاق عِلاقات تجريبية عامة التي قَدْ تُستَعمل لحساب التخمينات التمهيدية مِن الخزن لأي إطلاق واعتمادية بشرط أن تتوفر البيانات التاريخية للجريان.

Abstract

In the present research, three procedures of capacity-yield methods are applied to estimate the reliability of Bekhme reservoir. These procedures are the sequent peak algorithm method, the probability matrix (Gould) procedure, and the behaviour analysis. Vulnerability and resilience are also calculated in the last procedure. Two Fortran computer programs are developed for evaluating these measurements of risk.

The above risk measures are obtained based on sequences of both historical and synthetic monthly stream flow data. Six flow generation models are used to generate monthly flow for Bekhme reservoir, namely, first order Markov model, Thomas-Fiering model with log transformation, Thomas-Fiering model with Box-Cox transformation, two-tier model, modified two-tier model, and modified fragment model. These models are tested and compared with the historical data. It is concluded that among these six procedures the Thomas-Fiering model with log transformation and the Thomas-Fiering model with Box-Cox transformation are the most appropriate for representing the Bekhme reservoir inflow. In addition, it is found that the lognormal Type ٣ distribution is better than the lognormal Type ٢ and the Like-gamma distributions in describing the historical record.

Three factors are examined to determine their influence on the minimum storage estimate. These are the length of stochastically generated sequence, the initial state of storage, and the starting month.

The results reported here show that sequences as long as ١٠,٠٠٠ years or more may be needed to minimize the effects of these factors.

It is found that the design capacity of ١٢.٦ * $١٠^{٩}$ $m^{٣}$ is so large that even when the release is ٩٥٪ of the mean monthly flow, the reliability is ٩٥٪.

This research also concerns the development of approximate but general Storage-Yield-Reliability relationships for Iraqi reservoirs. The Gould probability matrix method is applied to each of Haditha, Al-Adhaim as well as Bekhme reservoirs to calculate the storages corresponding to different yields and reliabilities for each reservoir. The results so obtained are then combined together to derive general empirical relationships which may be used to calculate preliminary estimates of storage for any release and reliability provided that historical record of inflow is available.

Acknowledgement

Praise and thankful is to “ALLAH” for enabling me to complete this work.

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I am grateful to my family especially my parents, who taught hard work, integrity and honesty by example.

I would also record my thanks to all who participate in providing help and assistance to complete this work especially Mr. Bashar Mustafa, Mr. Ziyad Ahmed, Miss. Nadia Dohuky and all my friends.

Wael Abdul-Bari

EXAMINATION COMMITTEE CERTIFICATE

We certify that we have read this thesis, titled ***"Reliability of Iraqi Reservoirs"***, and as an examining committee examined the student ***"Wa'el Abdul-Bari Hussien"*** in its contents and in what is connected with it, and that in our opinion it meets the standard of a thesis for the degree of Master of Science in Civil Engineering.

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CERTIFICATION

We certify that this thesis, titled ***"Reliability of Iraqi Reservoirs"***, was prepared by ***"Wa'el Abdul-Bari Hussien"*** under our supervision at Babylon University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

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List of Contents

List of Symbols

Symbol	Definition
A_j	The lower bound value
B_j	Regression coefficient between flows in (j)th and (j+١)th months
C	Active storage capacity
Df_t	Deficit in the reservoir at time t
D_t	Release during the tth period
K_t	Correlation component
L_t	Other losses
N	The total number of time units in the stream flow sequence
N_e	The number of time units during which the reservoir is empty
P_e	Probability of failure of reservoir
P_i	Steady state probability that the reservoir contents at state i
$q_{i,j}$	Standardized monthly flows
Q_t	Inflow during the tth time period
r_j	Lag one serial correlation of historical data during jth month
Re	Reliability of reservoir
R_j	Log-normal moment estimates of the standard deviation during jth month

Symbol	Definition
s	Sample standard deviation
S٠	Initial reservoir condition
S_j	Log-normal moment estimates of the lag one serial correlation during j^{th} month
S_t	Storage at the beginning of the t^{th} period
$S_{t+١}$	Storage at the beginning of the $t+١^{th}$ period
t	Normal random variate with zero mean and unit variance
T_t	Trend component
V	Normal random variate with any mean and any standard deviation
υ	Vulnerability of reservoir
W	Volume of each zone
x_i	Magnitude of i^{th} flow event
X_i	Generated flow in logarithmic units during i^{th} period
Y_i	Conditional probability of failure of the reservoir
Y_t	Deficit indicator
Z	Uniform random number
ρ	Resilience of the reservoir
$\triangle E_t$	Net evaporation loss from reservoir during the t^{th} period
[T]	Transition matrix
–	Sample mean of flow events
–	Log-normal moment estimates of the mean during j^{th} month
X_j ψ_t	Random component

APPENDIX A

Computer Program

```
C      THIS PROGRAM FOR ESTIMATING THE RELIABILITY, VULNERABILITY AND
RESILIENCE

DIMENSION MO(١٢), REV(١٢), Q(١٠٠٠٠, ١٣), Q١(١٢٠٠٠٠), Q٤(١٢٠٠٠٠),
*      Q١١(١٢٠٠٠٠), R(١٢), CV(١٢), CS(١٢), ST(١٢), B(١٢), Q٢(١٣),
*      Z(١٠٠٠٠, ١٣), Z١(١٢٠٠٠٠), QZ١(١٢٠٠٠٠), QZ٢(١٠٠٠٠, ١٣), STZ(١٣),
*      RZ(١٢), CVZ(١٢), CSZ(١٢), BZ(١٢), QL١(١٢٠٠٠٠), QL٢(١٠٠٠٠,١٣),
*      STL(١٣), QLV(١٣), QBX٢(١٠٠٠٠,١٣), BCX(١٠٠٠٠), QBX١(١٢٠٠٠٠),
*      QBXV(١٣), STBX(١٣), CSLG(١٢), Y(١٠٠٠٠), YR(١٠٠٠٠), YRD(١٢٠٠٠٠),
*      DD(١٢٠٠٠٠), DV(١٠٠٠٠), V(١٠٠٠٠), SL(٩٠٠), S(١٠٠٠), A(٩٠٠, ٩٠٠),
*      G(٩٠٠,٩٠٠), P(٩٠٠,٩٠٠), X١(١٠٠٠٠), QF(١٠٠٠٠,١٢), NUM(١٠٠٠٠),
*      FRG(١٠٠٠٠), CC(١٢٠٠٠), QG٤(١٢٠٠٠٠), QZV(١٣)

       DOUBLE PRECISION MO, REV, Q, Q١, Q٤, Q١١, Z١, Z, R, CV, CS, ST, B ,
*      Q٢, CSLG, Y, YR, YRD, DD, DV, V, SL, S, A, G, P, X١, QF, NUM, FRG

       READ *, K, C, DT, N, X, BG, REF, N١

       NM١ = N١
       NM = N

       OPEN (UNIT=١, FILE='D\:WAEL PROGRAM\HISTORICAL-DATA.IN)'
       OPEN (UNIT=٢, FILE='D\:WAEL PROGRAM\EVAPORATION-DATA.IN)'
       OPEN (UNIT=٣, FILE='D\:WAEL PROGRAM\MONTHS.IN)'
       OPEN (UNIT=٤, FILE='D\:WAEL PROGRAM\A.OUT)'
       OPEN (UNIT=٥, FILE='D\:WAEL PROGRAM\B.OUT)'
       OPEN (UNIT=٦, FILE='D\:WAEL PROGRAM\C.OUT)'

       DO ٢٠ I = ١, N
```

```
      DO ١٠ J = ١, ١٢
      READ (١, *) Q(I, J)
١٠    CONTINUE
٢٠    CONTINUE
      DO ٣٠ J = ١, ١٢
      READ (٢, *) REV(J)
٣٠    CONTINUE
      DO ٤٠ J = ١, ١٢
      READ (٣, *) MO(J)
٤٠    CONTINUE
      DO ٦٠ I = ١, N
      DO ٥٠ J = ١, ١٢
      V = V + ١
      Q١(V) = Q(I, J)
٥٠    CONTINUE
٦٠    CONTINUE
      DO ٨٠ J = ١, ١٢
      SUM = ٠
      DO ٧٠ I = ١, N
      SUM = SUM + Q(I, J)
٧٠    CONTINUE
      Q٢(J) = SUM / N
٨٠    CONTINUE
      DO ١٠٠ J = ١, ١٢
      SUM = ٠
      DO ٩٠ I = ١, N
      SUM = SUM + (Q(I, J) - Q٢(J)) ** ٢
٩٠    CONTINUE
      ST(J) = SQRT(SUM / (N - ١))
١٠٠   CONTINUE
      DO ١١٠ J = ١, ١٢
      CV(J) = ST(J) / Q٢(J)
١١٠   CONTINUE
```

```
      DO ١٣٠ J = ١, ١٢
      SM = ٠
      SM١ = ٠
      SM٢ = ٠
      DO ١٢٠ I = ١, (N-١)
      Q(I, ١٣) = Q(I + ١, ١)
      Q٢(١٣) = Q٢(١)
      SM = SM + (Q(I, J) - Q٢(J)) * (Q(I, J + ١) - Q٢(J + ١))
      SM١ = SM١ + (Q(I, J) - Q٢(J)) ** ٢
      SM٢ = SM٢ + (Q(I, J + ١) - Q٢(J + ١)) ** ٢
١٢٠   CONTINUE
      R(J) = SM / SQRT(SM١ * SM٢)
١٣٠   CONTINUE
      DO ١٤٠ J = ١, ١١
      B(J) = (R(J) * ST(J + ١) / ST(J))
١٤٠   CONTINUE
      B(١٢) = R(١٢) * ST(١) / ST(١٢)
      DO ١٦٠ J = ١, ١٢
      SUM = ٠.٠
      DO ١٥٠ I = ١, N
      SUM = SUM + (Q(I, J) - Q٢(J)) ** ٣
١٥٠   CONTINUE
      CS(J) = N * SUM / (((ST(J)) ** ٣) * ((N - ٢) * (N - ١)))
١٦٠   CONTINUE
      DO ١٧٠ J = ١, ١٢
      WRITE (٦, *)'MONTHLY PARAMETER',Q٢(J), ST(J), CV(J), CS(J )
     *R(J), B(J)
١٧٠   CONTINUE
      DO ١٩٠ I = ١, N
      DO ١٨٠ J = ١, ١٢
      YR(I) = YR(I) + Q(I, J)
١٨٠   CONTINUE
١٩٠   CONTINUE
```

```
      SUM = ٠
      DO ٢٠٠ J = ١, N
      SUM = SUM + YR(J)
٢٠٠   CONTINUE
      QT٢ = SUM / N
      SUM = ٠
      DO ٢١٠ I = ١, N
      SUM = SUM + (YR(I) - QT٢) ** ٢
٢١٠   CONTINUE
      STT = SQRT(SUM / (N - ١))
      CVV = STT / QT٢
      SM = ٠
      SM١ = ٠
      SM٢ = ٠
      DO ٢٢٠ I = ١, (N-١)
      SM = SM + (YR(I) - QT٢) * (YR(I + ١) - QT٢)
      SM١ = SM١ + (YR(I) - QT٢) ** ٢
      SM٢ = SM٢ + (YR(I + ١) - QT٢) ** ٢
٢٢٠   CONTINUE
      RP = SM / SQRT(SM١ * SM٢)
      SUM = ٠
      DO ٢٣٠ I = ١, N
      SUM = SUM + (YR(I) - QT٢) ** ٣
٢٣٠   CONTINUE
      AS = N * SUM / ((N - ٢) * (N - ١))
      CSS = AS / (STT ** ٣)
      WRITE (٦, *)'ANNUAL PARAMETER', QT٢, STT, CVV, CSS, RP
      WRITE (٦,*)
      IF (REF.EQ.١) THEN
      GOTO ٤٠٠٠
      ELSE
      IF (REF.EQ.٢) THEN
      GOTO ٥٠٠٠
```

```
      ELSE
      IF (REF.EQ.٣) THEN
      GOTO ٦٠٠٠
      ELSE
      IF (REF.EQ.٤) THEN
      GOTO ٧٠٠٠
      ELSE
      IF (REF.EQ.٥) THEN
      GOTO ٨٠٠٠
      ELSE
      GOTO ٢٨٠
      ENDIF
      ENDIF
      ENDIF
      ENDIF
      ENDIF
٢٤٠   FDF = FDF + ١
      DO ٢٥٠ I = ١, ١٢*NM
      RED = NM١ / NM
      N١ = N
      Q١(I) = Q١((FDF - ١) * ١٢ * NM + I)
٢٥٠   CONTINUE
      DO ٢٧٠ I = ١, NM
      DO ٢٦٠ J = ١, ١٢
      Q(I, J) = Q(NM * (FDF - ١) + I, J)
٢٦٠   CONTINUE
٢٧٠   CONTINUE
٢٨٠   IF (BG.EQ.١) GOTO ٦٠٠
      IF (BG.EQ.٢) GOTO ١٠٠٠


C     ***** THIS PROGRAM FOR EVALUATION P.O.F BY BEHAVIOR METHOD  *****
```

```
٦٠٠    IS = ٠.٠
       K١ = ١٢.٠ * NM
       Z١(١) = C
       M = K١ - ١
       DO ٦٣٠ I = ١, M
       WW = I
       M = WW / ١٢
       GD = WW - M * ١٢
       IF (GD.EQ.٠) GD = ١٢
       ET = REV(GD) * (٠.٢٥٤٩٨٨ - ٤.٠٧٧٥٨٦ * Z١(I) / ١٠٠٠ + ٣٨.٨٤٣٣٢٧٧*
*          (Z١(I) / ١٠٠٠) ** ٠.٧١٣٦١٢) * ٠.٠٠١
       Z١(WW + ١) = Z١(I) + Q١(I) * MO(GD) * ٠.٣٦٠٠ * ٠.٢٤ - DT *
*                  MO(GD) * ٠.٣٦٠٠ * ٠.٢٤ - ET
       IF (Z١(WW+١).LE.C.AND.Z١(WW+١).GT.٠) THEN
       GOTO ٦٣٠
       ELSE
       IF (Z١(WW + ١).GT.C) THEN
       GOTO ٦٢٠
       ELSE
       IS = IS + ١
       DD(IS) = -١ * Z١(WW + ١)
       Z١(WW + ١) = ٠
       GOTO ٦٣٠
       ENDIF
       ENDIF
٦٢٠    Z١(WW + ١) = C
٦٣٠    CONTINUE
       DO ٦٥٠ I = ١, IS
       DO ٦٤٠ J = I, IS
       IF (DD(I).GE.DD(J)) THEN
       GOTO ٦٤٠
       ELSE
       GOTO ٦٥٠
```

```
      END IF
٦٤٠   CONTINUE
      XX = DD(I)
      GOTO ٦٦٠
٦٥٠   CONTINUE
٦٦٠   VUR = XX
      PP = ١
      DO ٦٩٠ I = ١, K١
      IF (Z١(I).EQ.٠) THEN
      GOTO ٦٧٠
      ELSE
      GOTO ٦٨٠
      END IF
٦٧٠   CC(PP) = CC(PP) + ١
      GOTO ٦٩٠
٦٨٠   PP = PP + ١
٦٩٠   CONTINUE
      DO ٧١٠ I = ١, PP
      DO ٧٠٠ J = I, PP
      IF (CC(I).GE.CC(J)) THEN
      GOTO ٧٠٠
      ELSE
      GOTO ٧١٠
      END IF
٧٠٠   CONTINUE
      XXR = CC(I)
      GOTO ٧٢٠
٧١٠   CONTINUE
٧٢٠   RESIL = XXR
      WRITE (*, *) 'THE STORAGE AT THE END OF T-TH PERIOD IS':
      DO ٧٣٠ I = ١, K١
      WRITE (*, *) I, Z١(I)
٧٣٠   CONTINUE
```

```
      VV = IS
      YY = K١
      POF = VV / YY
      SMM = POF + SMM
      RTR = RTR + VUR
      TRT = TRT + RESIL
      IF (FDF.LT.RED) GOTO ٢٤٠
      POF = SMM / RED
      VUR = RTR / RED
      RESIL = IFIX(TRT / RED)
      RE = ١ - POF
      WRITE (*, *) 'PROBABILITY OF FAILURE =', POF
      WRITE (*, *) 'RELIABILITY OF RESERVIOR =', RE
      WRITE (*, *) 'VULNERABILITY OF RESERVIOR =', VUR
      WRITE (*, *) 'RESILIENCE OF RESERVIOR =', RESIL
      WRITE (٣, *) 'P.O.F. IS:', POF
      WRITE (٣, *) 'RELIABILITY IS:', RE
      GOTO ٨٥٠٠


C       ***** THIS PROGRAM FOR EVALUATION P.O.F BY GOULD METHOD *****

١٠٠٠  PO = ٠
      SJ = ٠
      DO ١٠٢٠ M = ١, K
      DO ١٠١٠ I = ١, K
      DV(I) = ٠
      V(I) = ٠
      Y(I) = ٠
      A(I, M) = ٠
      S(M) = ٠
١٠١٠  CONTINUE
١٠٢٠  CONTINUE
```

```
      W = C / (K - ٢)
      DO ١١٣٠ M = ١, K
      DO ١١٢٠ I = ١, NM
      IF (M.EQ.K) GOTO ١٠٣٠
      IF (M.EQ.١) GOTO ١٠٤٠
      CCS = (٢ * M - ٣) * (W / ٢)
      GOTO ١٠٥٠
١٠٣٠  CCS = (K - ٢) * W
      GOTO ١٠٥٠
١٠٤٠  CCS = ٠
١٠٥٠  Z(I, ١) = CCS
      DO ١٠٨٠ J = ١, ١٢
      ET = REV(J) * (٠.٢٥٤٩٨٨ - ٤.٠٧٧٥٨٦ * Z(I, J) / ١٠٠٠ + ٣٨.٨٤٣٣٢٧٧ *
*          (Z(I, J) / ١٠٠٠) ** ٠.٧١٣٦١٢) * ٠.٠٠١
      Z(I, J + ١) = Z(I, J) + Q(I, J) * MO(J) * ٠.٣٦٠٠ * ٠.٢٤ - DT *
*                    MO(J)* ٠.٣٦٠٠ * .٢٤ - ET
      IF (Z(I, J + ١).LE.٠) GOTO ١٠٦٠
      IF (Z(I, J + ١).GE.C) GOTO ١٠٧٠
      GOTO ١٠٨٠
١٠٦٠  Z(I, J + ١) = ٠
      S(M) = S(M) + ١
      GOTO ١٠٨٠
١٠٧٠  Z(I, J + ١) = C
١٠٨٠  CONTINUE
      IF (Z(I, ١٣).LE.٠) GOTO ١٠٩٠
      IF (Z(I, ١٣).GE.C) GOTO ١١٠٠
      F = AINT(Z(I, ١٣) / W) + ٢
      GOTO ١١١٠
١٠٩٠  F = ١
      GOTO ١١١٠
١١٠٠  F = K
١١١٠  A(F, M) = A(F, M) + ١
١١٢٠  CONTINUE
```

```
١١٣٠  CONTINUE
      WRITE (٢, *) 'TRANSITION MATRIX IS':
      DO ١١٥٠ F=١,K
      DO ١١٤٠ M=١,K
      P(F, M) = A(F, M) / NM
      P(F, M) = AINT(١٠٠٠٠ * P(F, M)) / ١٠٠٠٠
      WRITE (٢, *) P(F, M)
١١٤٠  CONTINUE
      WRITE (٢,*)
١١٥٠  CONTINUE
      WRITE (٢, *) 'THE CONDITIONAL PROBABILITY OF FAILURE IS':
      DO ١١٦٠ M = ١, K
      SL(M) = S(M) / (١٢ * NM)
      WRITE (٢, *) M, SL(M)
      WRITE (٢,*)
١١٦٠  CONTINUE
      WRITE (٢,*) 'NUMBER OF FAILURES MATRIX IS':
      DO ١١٨٠ F = ١, K
      DO ١١٧٠ M = ١, K
      SJ = SJ + A(F, M)
      WRITE (٢, *) A(F, M)
١١٧٠  CONTINUE
      WRITE (٢,*)
١١٨٠  CONTINUE
      WRITE (٢, *) 'THE SUMATION OF FAILURES IS:', SJ
      DO ١١٩٠ F = ١, K
      G(F, X) = ١
١١٩٠  CONTINUE
      DO ١٢١٠ F = ١, K
      DO ١٢٠٠ M = ١, K
      G(F, M) = P(F, M)
١٢٠٠  CONTINUE
١٢١٠  CONTINUE
```

```
      DO ١٢٢٠ F = ١, K
      G(F, F) = P(F, F) - ١
١٢٢٠  CONTINUE
      DO ١٢٣٠ M = ١, K
      G(X, M) = ١
١٢٣٠  CONTINUE
      DO ١٢٤٠ I = ١, K
      Y(I) = ٠
١٢٤٠  CONTINUE
      Y(X) = ١
      DO ١٢٦٠ I = ١, K
      DO ١٢٥٠ J = ١, K
      WRITE (٣, *) G(I, J)
١٢٥٠  CONTINUE
      WRITE (٣,*)
١٢٦٠  CONTINUE
C     SOLVER SUBROUTINE BY GAUSS EIEMINATION AND DETERMIND THE DETERMINENT
C     DETERMINED THE UPPER TRIANGULAR
      DO ١٢٩٠ I = ٢, K
      DO ١٢٨٠ J = I, K
      RRP = G(J, I - ١) / G(I - ١, I - ١)
      Y(J) = Y(J) - RRP * Y(I - ١)
      DO ١٢٧٠ M = I, K
      G(J, M) = G(J, M) - RRP * G(I - ١, M)
١٢٧٠  CONTINUE
١٢٨٠  CONTINUE
١٢٩٠  CONTINUE
C     DETERMINED THE GLOBAL RELATIVE DISPLACEMENT
      DV(K) = Y(K) / G(K, K)
      DO ١٣١٠ I = K-١, ١, -١
      DV(I) = Y(I)
      DO ١٣٠٠ J = I+١, K
      DV(I) = DV(I) - G(I, J) * DV(J)
```

```
١٣٠٠  CONTINUE
      DV(I) = DV(I) / G(I, I)
١٣١٠  CONTINUE
      DO ١٣٢٠ I = ١, K
      V(I) = DV(I) + V(I)
١٣٢٠  CONTINUE
      WRITE (٣, *) 'STEADY STATE PROBABILITY OF B. IN Z. IS':
      DO ١٣٣٠ I = ١, K
      WRITE (٣, *) V(I)
١٣٣٠  CONTINUE
      DO ١٣٤٠ I = ١, K
      X١(I) = V(I) * SL(I)
١٣٤٠  CONTINUE
      WRITE (٣,*)
      WRITE (٣,*)
      WRITE (٣, *) 'OVER ALL P.O.F. IS':
      DO ١٣٥٠ I = ١, K
      WRITE (٣, *) X١(I)
١٣٥٠  CONTINUE
      DO ١٣٦٠ I = ١, K
      PO = PO + X١(I)
١٣٦٠  CONTINUE
      SMM = PO + SMM
      IF (FDF.LT.RED) GOTO ٢٤٠
      POF = SMM / RED
      RE = ١ - POF
      WRITE (*, *) 'PROBABILITY OF FAILURE=', POF
      WRITE (*, *) 'RELIABILITY OF RESERVIOR=', RE
      WRITE (٣, *) 'P.O.F. IS:', POF
      WRITE (٣, *) 'RELIABILITY IS:', RE
      GOTO ٨٥٠٠
```

```
C      ** THIS PROG FOR GENER DATA BY THOMAS-FIERING MODEL WITH LOG TRAN.**

٤٠٠٠   DO ٤٠٢٠ I = ١, N
       DO ٤٠١٠ J = ١, ١٢
       QL٢(I, J) = LOG(Q(I, J)+.٠١)
٤٠١٠   CONTINUE
٤٠٢٠   CONTINUE
       V=٠
       DO ٤٠٤٠ I = ١, N
       DO ٤٠٣٠ J = ١, ١٢
       V = V + ١
       QL١(V) = QL٢(I, J)
٤٠٣٠   CONTINUE
٤٠٤٠   CONTINUE
       DO ٤٠٦٠ J = ١, ١٢
       SUM = ٠
       DO ٤٠٥٠ I = ١, N
       SUM = SUM + QL٢(I, J)
٤٠٥٠   CONTINUE
       QLV(J) = SUM / N
٤٠٦٠   CONTINUE
       DO ٤٠٨٠ J = ١, ١٢
       SUM = ٠
       DO ٤٠٧٠ I = ١, N
       SUM = SUM + (QL٢(I, J) - QLV(J)) ** ٢
٤٠٧٠   CONTINUE
       STL(J) = SQRT(SUM / (N - ١) )
٤٠٨٠   CONTINUE
       DO ٤١٠٠ I = ١, N
       DO ٤٠٩٠ J = ١, ١٢
       QZ٢(I, J) = (QL٢(I, J) - QLV(J)) / STL(J)
٤٠٩٠   CONTINUE
٤١٠٠   CONTINUE
```

```
      V = ٠
      DO ٤١٢٠ I = ١, N
      DO ٤١١٠ J = ١, ١٢
      V = V + ١
      QZ١(V) = QZ٢(I, J)
٤١١٠  CONTINUE
٤١٢٠  CONTINUE
      DO ٤١٤٠ J = ١, ١٢
      SUM = ٠
      DO ٤١٣٠ I = ١, N
      SUM = SUM + QZ٢(I, J)
٤١٣٠  CONTINUE
      QZV(J) = SUM / N
٤١٤٠  CONTINUE
      DO ٤١٦٠ J = ١, ١٢
      SUM=٠
      DO ٤١٥٠ I = ١, N
      SUM = SUM + (QZ٢(I, J) - QZV(J)) ** ٢
٤١٥٠  CONTINUE
      STZ(J) = SQRT(SUM / (N - ١) )
٤١٦٠  CONTINUE
      DO ٤١٧٠ J = ١, ١٢
      CVZ(J) = STZ(J) / QZV(J)
٤١٧٠  CONTINUE
      DO ٤١٩٠ J = ١, ١٢
      SM = ٠
      SM١ = ٠
      SM٢ = ٠
      DO ٤١٨٠ I = ١, (N-١)
      QZ٢(I, ١٣) = QZ٢(I + ١, ١)
      QZV(١٣) = QZV(١)
      SM = SM + (QZ٢(I, J) - QZV(J)) * (QZ٢(I, J + ١) - QZV(J + ١((
      SM١ = SM١ + (QZ٢(I, J) - QZV(J)) ** ٢
```

```
      SM٢ = SM٢ + (QZ٢(I, J + ١) - QZV(J + ١)) ** ٢
٤١٨٠  CONTINUE
      RZ(J) = SM / SQRT(SM١ * SM٢)
٤١٩٠  CONTINUE
      DO ٤٢٠٠ J = ١, ١١
      BZ(J) = (RZ(J) * STZ(J + ١) / STZ(J) )
٤٢٠٠  CONTINUE
      BZ(١٢) = RZ(١٢) * STZ(١) / STZ(١٢)
      DO ٤٢٢٠ J = ١, ١٢
      SUM = ٠.
      DO ٤٢١٠ I = ١, N
      SUM = SUM + (QZ٢(I, J) - QZV(J)) ** ٣
٤٢١٠  CONTINUE
      CSZ(J) = N * SUM/ (((STZ(J)) ** ٣) * ((N - ٢) * (N - ١) ) )
٤٢٢٠  CONTINUE
      DO ٤٢٣٠ J = ١, ١٢
C     WRITE (٤,*)'MONTLY PARAM=',QZV(J),STZ(J),CVZ(J),CSZ(J),RZ(J),BZ(J)
٤٢٣٠  CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٤٢٤٠ I=١,١٢*N١,٢
      AB=CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١(I + ١) = EB / DB + XB
```

```
٤٢٤٠  CONTINUE
      DYY = ١٢ * N١ - ١
      AN = ٨ * ATAN(١.٠)
      DO ٤٢٥٠ I=٢,DYY,٢
      AA = SQRT(-٢ * LOG(Q١(I) ) )
      SQI = Q١(I + ١)
      Q١(I) = AA * COS(AN * SQI)
      Q١(I + ١) = AA * SIN(AN * SQI)
٤٢٥٠  CONTINUE
      SM = ٠
      DO ٤٢٧٠ I=١,١٢*N١
      SM = SM + Q١(I)
٤٢٧٠  CONTINUE
      AV = SM / (١٢ * N١)
      SM = ٠
      DO ٤٢٨٠ I=١,١٢*N١
      SM = SM + (AV - Q١(I))**٢
٤٢٨٠  CONTINUE
      VAR = (SM / (١٢ * N١ - ١) )
      WRITE (٤,*)'VAR OF UN. RND IS:',VAR
      WRITE (٤,*)'MEAN OF RND IS:', AV
      QG٤(١) = QZV(١)
      DO ٤٣٠٠ I=١,(١٢*N١-١)
      M =I/١٢
      J=I-M*١٢
      IF (J.EQ.٠) THEN
      J=١٢
      GOTO ٤٢٩٠
      ELSE
      GOTO ٤٢٩٠
      ENDIF
٤٢٩٠  IF (J.EQ.١٢) THEN
      QG٤(I+١)=QZV(١)+BZ(١٢)*(QG٤(I)-QZV(١٢))+Q١(I)*STZ(١)*
```

```
*              SQRT(١-RZ(١٢)**٢)
      GOTO ٤٣٠٠
      ELSE
      QG٤(I+١)=QZV(J+١)+BZ(J)*(QG٤(I)-QZV(J))+Q١(I)*STZ(J+١)*
*              SQRT(١-RZ(J)**٢)
      GOTO ٤٣٠٠
      ENDIF
٤٣٠٠  CONTINUE
      DO ٤٣٢٠ I = ١, N١
      DO ٤٣١٠ J = ١, ١٢
      III=III+١
      Q(I,J)=QG٤(III)
٤٣١٠  CONTINUE
٤٣٢٠  CONTINUE
      DO ٤٣٤٠ I = ١, N١
      DO ٤٣٣٠ J = ١, ١٢
      Q(I, J) = Q(I, J) *  STL(J) + QLV(J)
٤٣٣٠  CONTINUE
٤٣٤٠  CONTINUE
      DO ٤٣٦٠ I = ١, N١
      DO ٤٣٥٠ J = ١, ١٢
      Q(I, J) = EXP(Q(I, J))-.٠١
٤٣٥٠  CONTINUE
٤٣٦٠  CONTINUE
      DO ٤٣٨٠ I = ١, N١
      DO ٤٣٧٠ J = ١, ١٢
      IF (Q(I, J).LT.٠) THEN
      Q(I,  J)=٠
      ELSE
      GOTO ٤٣٧٠
      ENDIF
٤٣٧٠  CONTINUE
٤٣٨٠  CONTINUE
```

```
      V=٠
      DO ٤٤٠٠ I = ١, N١
      DO ٤٣٩٠ J = ١, ١٢
      V=V+١
      Q١(V) = Q(I,J)
      WRITE (٤, *) Q١(V)
٤٣٩٠  CONTINUE
٤٤٠٠  CONTINUE
      GOTO ٢٤٠


C     ******* THIS PROGRAM FOR GENERATE DATA BY TWO-TIER MODEL *******

٥٠٠٠  CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٥٠١٠ I=١,N١,٢
      AB = CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١١(I + ١) = EB / DB + XB
٥٠١٠  CONTINUE
      DYY = N١ - ١
      AN = ٨ * ATAN(١.٠)
      DO ٥٠٢٠ I = ٢, DYY, ٢
      AA = SQRT(-٢ * LOG(Q١١(I) ) )
```

```
      SQI = Q١١(I + ١(
      Q١١(I) = AA * COS(AN * SQI)
      Q١١(I + ١) = AA * SIN(AN * SQI)
٥٠٢٠  CONTINUE
      YR(١) = QT٢
      DO ٥٠٣٠ I = ١, N١-١
      YR(I + ١) = QT٢ + RP*(YR(I) - QT٢) + Q١١(I)* STT* SQRT(١ - RP**٢)
٥٠٣٠  CONTINUE
      DO ٥٠٤٠ I = ١, N١
      IF (YR(I).LE.٠) YR(I) = ٠
C     WRITE (٤,*) YR(I)
٥٠٤٠  CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٥٠٥٠ I = ١, ١٢*N١, ٢
      AB = CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١(I + ١) = EB / DB + XB
٥٠٥٠  CONTINUE
      DYY = ١٢ * N١ - ١
      AN = ٨ * ATAN(١.٠)
      DO ٥٠٦٠ I = ٢, DYY, ٢
      AA = SQRT(-٢ * LOG(Q١(I) ) )
      SQI = Q١(I + ١)
```

```
      Q١(I) = AA * COS(AN * SQI)
      Q١(I + ١) = AA * SIN(AN * SQI)
٥٠٦٠  CONTINUE
      DO ٥٠٧٠ I = ١, ١٢*N١
C     WRITE (٢, *) Q١(I)
٥٠٧٠  CONTINUE
      SM = ٠
      DO ٥٠٨٠ I = ١, ١٢*N١
      SM = SM + Q١(I)
٥٠٨٠  CONTINUE
      AV = SM / (١٢ * N١)
      SM = ٠
      DO ٥٠٩٠ I = ١, ١٢*N١
      SM = SM + (AV - Q١(I)) ** ٢
٥٠٩٠  CONTINUE
      VAR = (SM / (١٢ * N١ - ١) )
      WRITE (٤, *)'VARIANCE OF NORMAL RANDOM NUMBER IS:',VAR
      WRITE (٤, *)'MEAN OF NORMAL RANDOM NUMBER IS:', AV
      DO ٥١٠٠ J = ١, ١٢
      IF (J.EQ.١٢) THEN
      CSLG(J) = (CS(١) - CS(١٢) * R(١٢)**٣) / ((١ - R(١٢)**٢)**(٣/٢) )
      ELSE
      CSLG(J) = (CS(J + ١) - CS(J) * R(J)**٣) / ((١ - R(J)**٢)**(٣/٢) )
      ENDIF
C     WRITE (٤, *) J, CSLG(J)
٥١٠٠  CONTINUE
      DO ٥١٢٠ I = ١, (١٢*N١-١)
      M = I / ١٢
      J = I - M * ١٢
      IF (J.EQ.٠) THEN
      J = ١٢
      ELSE
      GOTO ٥١١٠
```

```
      ENDIF
٥١١٠  Q١(I) = (٢/CSLG(J))*((١ + CSLG(J)*Q١(I)/٦ - CSLG(J)**٢/٣٦)**٣ - ١)
٥١٢٠  CONTINUE
      Q٤(١) = Q٢(١)
      DO ٥١٤٠ I = ١, (١٢*N١-١)
      M = I / ١٢
      J = I - M * ١٢
      IF (J.EQ.٠) THEN
      J = ١٢
      GOTO ٥١٣٠
      ELSE
      GOTO ٥١٣٠
      ENDIF
٥١٣٠  IF (J.EQ.١٢) THEN
      Q٤(I+١) = Q٢(١)+B(١٢)*(Q٤(I)-Q٢(١٢))+Q١(I)*ST(١)*SQRT(١-R(١٢)**٢)
      GOTO ٥١٤٠
      ELSE
      Q٤(I+١) = Q٢(J+١)+B(J)*(Q٤(I)-Q٢(J))+Q١(I)*ST(J+١)*SQRT(١-R(J)**٢)
      GOTO ٥١٤٠
      ENDIF
٥١٤٠  CONTINUE
      DO ٥١٥٠     I = ١, (١٢*N١)
      IF (Q٤(I).LT.٠) THEN
      Q٤(I) = ٠
      GOTO ٥١٥٠
      ELSE
      GOTO ٥١٥٠
      ENDIF
٥١٥٠  CONTINUE
      III = ٠
      DO ٥١٨٠ I = ١, N١
      DO ٥١٧٠ J = ١, ١٢
      III = III + ١
```

```
      Q(I, J) = Q٤(III)
C     WRITE (٤, *) Q(I, J)
٥١٧٠  CONTINUE
٥١٨٠  CONTINUE
      DO ٥٢٠٠ I = ١, N١
      Q٤(I) = ٠
      DO ٥١٩٠ J = ١, ١٢
      Q٤(I) = Q٤(I) + Q(I, J)
٥١٩٠  CONTINUE
٥٢٠٠  CONTINUE
      DO ٥٢٢٠ I = ١, N١
      DO ٥٢١٠ J = ١, ١٢
      Q(I, J) = Q(I, J) * YR(I) / Q٤(I)
C     WRITE (٤, *) Q(I, J)
٥٢١٠  CONTINUE
٥٢٢٠  CONTINUE
      N = N١
      V = ٠
      DO ٥٢٤٠ I = ١, N
      DO ٥٢٣٠ J = ١, ١٢
      V = V + ١
      Q١(V) = Q(I, J)
C     WRITE (٤, *) Q١(V)
٥٢٣٠  CONTINUE
٥٢٤٠  CONTINUE
      GOTO ٢٤٠


C     ***** THIS PROGRAM FOR GENERATE DATA BY MODIFIED TWO-TIER MODEL*****

٦٠٠٠  CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
```

```
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٦٠١٠ I = ١, N١, ٢
      AB = CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١١(I + ١) = EB / DB + XB
٦٠١٠  CONTINUE
      DYY = N١ - ١
      AN = ٨ * ATAN(١.٠)
      DO ٦٠٢٠ I = ٢, DYY, ٢
      AA = SQRT(-٢ * LOG(Q١١(I) ) )
      SQI = Q١١(I + ١(
      Q١١(I) = AA * COS(AN * SQI)
      Q١١(I + ١) = AA * SIN(AN * SQI)
٦٠٢٠  CONTINUE
      YR(١) = QT٢
      DO ٦٠٣٠ I = ١, N١-١
      YR(I + ١) = QT٢ + RP*(YR(I) - QT٢) + Q١١(I)* STT* SQRT(١ - RP**٢)
٦٠٣٠  CONTINUE
      DO ٦٠٤٠ I = ١, N١
      IF (YR(I).LE.٠) YR(I) = ٠
C     WRITE (٤, *) YR(I)
٦٠٤٠  CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
```

```
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٦٠٥٠ I = ١, ١٢*N١, ٢
      AB = CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١(I + ١) = EB / DB + XB
٦٠٥٠  CONTINUE
      DYY = ١٢ * N١ - ١
      AN = ٨ * ATAN(١.٠)
      DO ٦٠٦٠ I = ٢, DYY, ٢
      AA = SQRT(-٢ * LOG(Q١(I) ) )
      SQI = Q١(I + ١)
      Q١(I) = AA * COS(AN * SQI)
      Q١(I + ١) = AA * SIN(AN * SQI)
٦٠٦٠  CONTINUE
      DO ٦٠٧٠ I = ١, ١٢*N١
C     WRITE (٢, *) Q١(I)
٦٠٧٠  CONTINUE
      SM = ٠
      DO ٦٠٨٠ I = ١, ١٢*N١
      SM = SM + Q١(I)
٦٠٨٠  CONTINUE
      AV = SM / (١٢ * N١)
      SM = ٠
      DO ٦٠٩٠ I = ١, ١٢*N١
      SM = SM + (AV - Q١(I)) ** ٢
٦٠٩٠  CONTINUE
      VAR = (SM / (١٢ * N١ - ١) )
```

```
      WRITE (٤, *)'VARIANCE OF NORMAL RANDOM NUMBER IS:',VAR
      WRITE (٤, *)'MEAN OF NORMAL RANDOM NUMBER IS:', AV
      DO ٦١٠٠ J = ١, ١٢
      IF (J.EQ.١٢) THEN
      CSLG(J)=(CS(١) - CS(١٢) * R(١٢)**٣) / ((١-R(١٢)**٢)**(٣/٢) )
      ELSE
      CSLG(J)=(CS(J+١) - CS(J) * R(J)**٣) / ((١-R(J)**٢)**(٣/٢) )
      ENDIF
C     WRITE (٤, *) J, CSLG(J)
٦١٠٠  CONTINUE
      DO ٦١٢٠ I = ١, (١٢*N١-١)
      M = I / ١٢
      J = I - M * ١٢
      IF (J.EQ.٠) THEN
      J = ١٢
      ELSE
      GOTO ٦١١٠
      ENDIF
٦١١٠  Q١(I) = (٢/CSLG(J)) * ((١ + CSLG(J)*Q١(I)/٦ - CSLG(J)**٢/٣٦)**٣-١)
٦١٢٠  CONTINUE
      Q٤(١) = Q٢(١)
      DO ٦١٤٠ I = ١, (١٢*N١-١)
      M = I / ١٢
      J = I - M * ١٢
      IF (J.EQ.٠) THEN
      J = ١٢
      GOTO ٦١٣٠
      ELSE
      GOTO ٦١٣٠
      ENDIF
٦١٣٠  IF (J.EQ.١٢) THEN
      Q٤(I+١) = Q٢(١)+B(١٢)*(Q٤(I)-Q٢(١٢))+Q١(I)*ST(١)*SQRT(١-R(١٢)**٢)
      GOTO ٦١٤٠
```

```
      ELSE
      Q٤(I+١) = Q٢(J+١)+B(J)*(Q٤(I)-Q٢(J))+Q١(I)*ST(J+١)*SQRT(١-R(J)**٢)
      GOTO ٦١٤٠
      ENDIF
٦١٤٠  CONTINUE
      DO ٦١٥٠     I = ١, (١٢*N١)
      IF (Q٤(I).LT.٠) THEN
      Q٤(I) = ٠
      GOTO ٦١٥٠
      ELSE
      GOTO ٦١٥٠
      ENDIF
٦١٥٠  CONTINUE
      III = ٠
      DO ٦١٨٠ I = ١, N١
      DO ٦١٧٠ J = ١, ١٢
      III = III + ١
      Q(I, J) = Q٤(III)
C     WRITE (٤, *) Q(I,J)
٦١٧٠  CONTINUE
٦١٨٠  CONTINUE
      DO ٦٢٠٠ I = ١, N١
      Q٤(I) = ٠
      DO ٦١٩٠ J = ١, ١٢
      Q٤(I) = Q٤(I) + Q(I, J)
٦١٩٠  CONTINUE
٦٢٠٠  CONTINUE
      DO ٦٢١٠ I = ١, N١
      YRD(I) = YR(I)
٦٢١٠  CONTINUE
      DO ٦٢٥٠ J = ١, N١-١
      XX = YRD(١)
      DO ٦٢٤٠ I = ١, N١-١
```

```
      IF (XX.GE.YRD(I + ١)) THEN
      GOTO ٦٢٢٠
      ELSE
      GOTO ٦٢٣٠
      END IF
٦٢٢٠  XX = YRD(I + ١)
      YRD(I + ١) = YRD(I)
      YRD(I) = XX
٦٢٣٠  XX = YRD(I + ١)
٦٢٤٠  CONTINUE
٦٢٥٠  CONTINUE
      DO ٦٢٩٠ J = ١, N١-١
      XX = Q٤(١(
      DO ٦٢٨٠ I = ١, N١-١
      IF (XX.GE.Q٤(I + ١)) THEN
      GOTO ٦٢٦٠
      ELSE
      GOTO ٦٢٧٠
      END IF
٦٢٦٠  XX = Q٤(I + ١)
      Q٤(I + ١) = Q٤(I)
      Q٤(I) = XX
٦٢٧٠  XX = Q٤(I + ١)
٦٢٨٠  CONTINUE
٦٢٩٠  CONTINUE
      DO ٦٣١٠ I = ١, N١
      DO ٦٣٠٠ J = ١, ١٢
      Q(I, J) = Q(I, J) * YRD(I) / Q٤(I)
٦٣٠٠  CONTINUE
٦٣١٠  CONTINUE
      DO ٦٣٦٠ I = ١, N١
      DO ٦٣٤٠ SJ = ١, N١
      IF (YRD(I).EQ.YR(SJ)) THEN
```

```
      GOTO ٦٣٢٠
      ELSE
      GOTO ٦٣٤٠
      END IF
٦٣٢٠  DO ٦٣٣٠ J = ١, ١٢
      Q(SJ, J) = Q(I, J)
٦٣٣٠  CONTINUE
      GOTO ٦٣٥٠
٦٣٤٠  CONTINUE
٦٣٥٠  YRD(I) = ٠
٦٣٦٠  CONTINUE
      N = N١
      V = ٠
      DO ٦٣٨٠ I = ١, N
      DO ٦٣٧٠ J = ١, ١٢
      V = V + ١
      Q١(V) = Q(I, J)
C     WRITE (٤, *) Q١(V)
٦٣٧٠  CONTINUE
٦٣٨٠  CONTINUE
      GOTO ٢٤٠


C     ******** THIS PROGRAM FOR GENERATE DATA BY FRAGMENT MODEL ********

٧٠٠٠  DO ٧٠١٠ I = ١, N
      YRD(I) = YR(I)
٧٠١٠  CONTINUE
      DO ٧٠٣٠ I = ١, N
      DO ٧٠٢٠ J = ١, ١٢
      QF(I, J) = Q(I, J) / YR(I)
٧٠٢٠  CONTINUE
٧٠٣٠  CONTINUE
```

```
      DO ٧٠٧٠ J = ١, N-١
      XX = YRD(١)
      DO ٧٠٦٠ I = ١, N-١
      IF (XX.GE.YRD(I + ١)) THEN
      GOTO ٧٠٤٠
      ELSE
      GOTO ٧٠٥٠
      END IF
٧٠٤٠  XX = YRD(I + ١)
      YRD(I + ١) = YRD(I)
      YRD(I) = XX
٧٠٥٠  XX = YRD(I + ١)
٧٠٦٠  CONTINUE
٧٠٧٠  CONTINUE
      DO ٧٠٨٠ I = ١, N
C     WRITE (*, *) YRD(I)
٧٠٨٠  CONTINUE
      DO ٧١٢٠ I = ١, N
      DO ٧١١٠ YD = ١, N
      IF (YRD(I).EQ.YR(YD)) THEN
      GOTO ٧٠٩٠
      ELSE
      GOTO ٧١١٠
      END IF
٧٠٩٠  DO ٧١٠٠ J = ١, ١٢
      QF(I, J) = QF(YD, J)
٧١٠٠  CONTINUE
      YR(YD) = ٠
٧١١٠  CONTINUE
٧١٢٠  CONTINUE
      FRG(١) = ٠
      NUM(١) = ١
      NUM(N) = N
```

```
      DO ٧١٣٠ I = ٢, N-١
      NUM(I) = I
      FRG(I) = (YRD(I) + YRD(I - ١)) / ٢
٧١٣٠  CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٧١٤٠ I = ١, N١, ٢
      AB = CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١١(I + ١) = EB / DB + XB
٧١٤٠  CONTINUE
      DYY = N١ - ١
      AN = ٨ * ATAN(١.٠)
      DO ٧١٥٠ I = ٢, DYY, ٢
      AA = SQRT(-٢ * LOG(Q١١(I) ) )
      SQI = Q١١(I + ١(
      Q١١(I) = AA * COS(AN * SQI)
      Q١١(I + ١) = AA * SIN(AN * SQI)
٧١٥٠  CONTINUE
      YR(١) = QT٢
      DO ٧١٦٠ I = ١, N١-١
      YR(I + ١) = QT٢ + RP* (YR(I) - QT٢) + Q١١(I)* STT* SQRT(١ - RP**٢)
٧١٦٠  CONTINUE
      DO ٧١٧٠ I = ١, N١
```

```
      IF (YR(I).LE.٠) YR(I) = ٠
C     WRITE (٤, *) YR(I)
٧١٧٠  CONTINUE
      DO ٧١٨٠ I = ١, N١
C     WRITE (*, *) YR(I)
٧١٨٠  CONTINUE
      DO ٧٢٦٠ I = ١, N١
      DO ٧٢١٠ JT = ٢, N
      IF (YR(I).EQ.FRG(١)) GOTO ٧٢٢٠
      IF (YR(I).GE.FRG(N)) GOTO ٧٢٤٠
      IF (YR(I).LE.FRG(JT).AND.YR(I).GE.FRG(JT - ١)) THEN
      GOTO ٧١٩٠
      ELSE
      GOTO ٧٢١٠
      END IF
٧١٩٠  DO ٧٢٠٠ J = ١, ١٢
      Q(I, J) = YR(I) * QF(JT - ١, J)
٧٢٠٠  CONTINUE
٧٢١٠  CONTINUE
٧٢٢٠  DO ٧٢٣٠ J = ١, ١٢
      Q(I, J) = YR(I) * QF(١, J)
٧٢٣٠  CONTINUE
      GOTO ٧٢٦٠
٧٢٤٠  DO ٧٢٥٠ J = ١, ١٢
      Q(I, J) = YR(I) * QF(N, J)
٧٢٥٠  CONTINUE
٧٢٦٠  CONTINUE
      N = N١
      V = ٠
      DO ٧٢٨٠ I = ١, N
      DO ٧٢٧٠ J = ١, ١٢
      V = V + ١
      Q١(V) = Q(I, J)
```

```
C      WRITE (٤, *) Q١(V)
٧٢٧٠   CONTINUE
٧٢٨٠   CONTINUE
       GOTO ٢٤٠


C      * THIS PROG FOR GENE DATA BY THOMAS-FIERING MODEL WITH BOX-COX TRAN*


٨٠٠٠   BD=٠.٥
٨٠١٠   BD١ = BD + ٠.٠٠٠١
       AX=٠
       AY=٠
       AN=N
       SUM=٠
       DO ٨٠٢٠ I=١,١٢*N
       BCX(I) = (Q١(I)**BD١-١)/BD١
٨٠٢٠   CONTINUE
       DO ٨٠٣٠ I=١,١٢*N
       SUM=SUM+BCX(I(
٨٠٣٠   CONTINUE
       AV=SUM/(١٢*N(
       DO ٨٠٤٠ I=١,١٢*N
       AX=AX+(BCX(I)-AV)**٣
       AY=AY+(BCX(I)-AV)**٢
٨٠٤٠   CONTINUE
       AA = (١٢*AN/((١٢*AN-١)*(١٢*AN-٢)))*AX
       S١=(AY/(١٢*AN-١))**.٥
       SKW١=AA/S١**٣
       BD٢=BD-٠.٠٠٠١
       AX=٠
       AY=٠
       AN=N
```

```
      SUM=٠
      DO ٨٠٥٠ I=١,١٢*N
      BCX(I) = (Q١(I)**BD٢-١)/BD٢
٨٠٥٠  CONTINUE
      DO ٨٠٦٠ I=١,١٢*N
      SUM=SUM+BCX(I)
٨٠٦٠  CONTINUE
      AV=SUM/(١٢*N)
      DO ٨٠٧٠ I=١,١٢*N
      AX=AX+(BCX(I)-AV)**٣
      AY=AY+(BCX(I)-AV)**٢
٨٠٧٠  CONTINUE
      AA = (١٢*AN/((١٢*AN-١)*(١٢*AN-٢)))*AX
      S١=(AY/(١٢*AN-١))**.٥
      SKW٢=AA / S١**٣
      IF (ABS(SKW١).LT.ABS(SKW٢)) THEN
      BD=BD١
      SKW=SKW١
      IF (ABS(SKW١).LT.٠.٠٠٠٠٥) THEN
      GOTO ٨٠٨٠
      ELSE
      GOTO ٨٠١٠
      ENDIF
      ELSE
      BD=BD٢
      SKW=SKW٢
      IF (ABS(SKW٢).LT.٠.٠٠٠٠٥) THEN
      GOTO ٨٠٨٠
      ELSE
      GOTO ٨٠١٠
      ENDIF
      ENDIF
٨٠٨٠  WRITE (٤,*) BD, SKW
```

```
      DO ٨١٠٠ I = ١, N
      DO ٨٠٩٠ J = ١, ١٢
      QBX٢(I, J) = (Q(I, J)**BD-١)/BD
٨٠٩٠  CONTINUE
٨١٠٠  CONTINUE
      V=٠
      DO ٨١٢٠ I = ١, N
      DO ٨١١٠ J = ١, ١٢
      V = V + ١
      QBX١(V) = QBX٢(I, J)
٨١١٠  CONTINUE
٨١٢٠  CONTINUE
      DO ٨١٤٠ J = ١, ١٢
      SUM = ٠
      DO ٨١٣٠ I = ١, N
      SUM = SUM + QBX٢(I, J)
٨١٣٠  CONTINUE
      QBXV(J) = SUM / N
٨١٤٠  CONTINUE
      DO ٨١٦٠ J = ١, ١٢
      SUM = ٠
      DO ٨١٥٠ I = ١, N
      SUM = SUM + (QBX٢(I, J) - QBXV(J)) ** ٢
٨١٥٠  CONTINUE
      STBX(J) = SQRT(SUM / (N - ١) )
٨١٦٠  CONTINUE
      DO ٨١٨٠ I = ١, N
      DO ٨١٧٠ J = ١, ١٢
      QZ٢(I, J) = (QBX٢(I, J) - QBXV(J)) / STBX(J)
٨١٧٠  CONTINUE
٨١٨٠  CONTINUE
      V = ٠
      DO ٨٢٠٠ I = ١, N
```

```
      DO ٨١٩٠ J = ١, ١٢
      V = V + ١
      QZ١(V) = QZ٢(I, J)
٨١٩٠  CONTINUE
٨٢٠٠  CONTINUE
      DO ٨٢٢٠ J = ١, ١٢
      SUM = ٠
      DO ٨٢١٠ I = ١, N
      SUM = SUM + QZ٢(I, J)
٨٢١٠  CONTINUE
      QZV(J) = SUM / N
٨٢٢٠  CONTINUE
      DO ٨٢٤٠ J = ١, ١٢
      SUM=٠
      DO ٨٢٣٠ I = ١, N
      SUM = SUM + (QZ٢(I, J) - QZV(J)) ** ٢
٨٢٣٠  CONTINUE
      STZ(J) = SQRT(SUM / (N - ١) )
٨٢٤٠  CONTINUE
      DO ٨٢٥٠ J = ١, ١٢
      CVZ(J) = STZ(J) / QZV(J)
٨٢٥٠  CONTINUE
      DO ٨٢٧٠ J = ١, ١٢
      SM = ٠
      SM١ = ٠
      SM٢ = ٠
      DO ٨٢٦٠ I = ١, (N-١)
      QZ٢(I, ١٣) = QZ٢(I + ١, ١)
      QZV(١٣) = QZV(١)
      SM = SM + (QZ٢(I, J) - QZV(J)) * (QZ٢(I, J + ١) - QZV(J + ١) )
      SM١ = SM١ + (QZ٢(I, J) - QZV(J)) ** ٢
      SM٢ = SM٢ + (QZ٢(I, J + ١) - QZV(J + ١)) ** ٢
٨٢٦٠  CONTINUE
```

```
      RZ(J) = SM / SQRT(SM١ * SM٢)
٨٢٧٠  CONTINUE
      DO ٨٢٨٠ J = ١, ١١
      BZ(J) = (RZ(J) * STZ(J + ١) / STZ(J) )
٨٢٨٠  CONTINUE
      BZ(١٢) = RZ(١٢) * STZ(١) / STZ(١٢)
      DO ٨٣٠٠ J = ١, ١٢
      SUM = ٠.
      DO ٨٢٩٠ I = ١, N
      SUM = SUM + (QZ٢(I, J) - QZV(J)) ** ٣
٨٢٩٠  CONTINUE
      CSZ(J) = N * SUM/ (((STZ(J)) ** ٣) * ((N - ٢) * (N - ١) ) )
٨٣٠٠  CONTINUE
      DO ٨٣١٠ J = ١, ١٢
C     WRITE (٤,*)'MONTLY PARAM=',QZV(J),STZ(J),CVZ(J),CSZ(J),RZ(J),BZ(J)
٨٣١٠  CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
      DO ٨٣٢٠ I=١,١٢*N١,٢
      AB=CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(AB)) * DA
      Q١(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      Q١(I + ١) = EB / DB + XB
٨٣٢٠  CONTINUE
      DYY = ١٢ * N١ - ١
```

```
      AN = ٨ * ATAN(١.٠)
      DO ٨٣٣٠ I=٢,DYY,٢
      AA = SQRT(-٢ * LOG(Q١(I) ) )
      SQI = Q١(I + ١(
      Q١(I) = AA * COS(AN * SQI)
      Q١(I + ١) = AA * SIN(AN * SQI)
٨٣٣٠  CONTINUE
      DO ٨٣٤٠ I=١,١٢*N١
C     WRITE (٢,*) Q١(I)
٨٣٤٠  CONTINUE
      SM = ٠
      DO ٨٣٥٠ I=١,١٢*N١
      SM = SM + Q١(I)
٨٣٥٠  CONTINUE
      AV = SM / (١٢ * N١)
      SM = ٠
      DO ٨٣٦٠ I=١,١٢*N١
      SM = SM + (AV - Q١(I))**٢
٨٣٦٠  CONTINUE
      VAR = (SM / (١٢ * N١ - ١))
      WRITE (٤,*)'VAR OF UN. RND IS:',VAR
      WRITE (٤,*)'MEAN OF RND IS:', AV
      QG٤(١) = QZV(١)
      DO ٨٣٨٠ I=١,(١٢*N١-١)
      M =I/١٢
      J=I-M*١٢
      IF (J.EQ.٠) THEN
      J=١٢
      GOTO ٨٣٧٠
      ELSE
      GOTO ٨٣٧٠
      ENDIF
٨٣٧٠  IF (J.EQ.١٢) THEN
```

```
      QG٤(I+١)=QZV(١)+BZ(١٢)*(QG٤(I)-QZV(١٢))+Q١(I)*STZ(١)*
*                SQRT(١-RZ(١٢)**٢)
      GOTO ٨٣٨٠
      ELSE
      QG٤(I+١)=QZV(J+١)+BZ(J)*(QG٤(I)-QZV(J))+Q١(I)*STZ(J+١)*
*                SQRT(١-RZ(J)**٢)
      GOTO ٨٣٨٠
      ENDIF
٨٣٨٠  CONTINUE
      DO ٨٤٠٠ I = ١, N١
      DO ٨٣٩٠ J = ١, ١٢
      III=III+١
      Q(I,J)=QG٤(III)
٨٣٩٠  CONTINUE
٨٤٠٠  CONTINUE
      DO ٨٤٢٠ I = ١, N١
      DO ٨٤١٠ J = ١, ١٢
      Q(I, J) = Q(I, J) *  STBX(J) + QBXV(J)
٨٤١٠  CONTINUE
٨٤٢٠  CONTINUE
      DO ٨٤٤٠ I = ١, N١
      DO ٨٤٣٠ J = ١, ١٢
      Q(I, J) = (Q(I, J)*BD+١)**(١/BD)
٨٤٣٠  CONTINUE
٨٤٤٠  CONTINUE
      DO ٨٤٦٠ I = ١, N١
      DO ٨٤٥٠ J = ١, ١٢
      IF (Q(I, J).LT.٠) THEN
      Q(I,  J)=٠
      ELSE
      GOTO ٨٤٥٠
      ENDIF
٨٤٥٠  CONTINUE
```

```
٨٤٦٠  CONTINUE
      V=٠
      DO ٨٤٨٠ I = ١, N١
      DO ٨٤٧٠ J = ١, ١٢
      V=V+١
      Q١(V) = Q(I,J)
      WRITE (٤, *) Q١(V)
٨٤٧٠  CONTINUE
٨٤٨٠  CONTINUE
      GOTO ٢٤٠

٨٥٠٠  STOP
      END
```

```
C     THIS PROGRAM IS FOR EVALUATING THE P.O.F. OF RESERVOIR BY SEQUENT
PEAK ALGORITHIM METHOD

      DIMENSION QG٢(١٠٠٠٠,١٢), QG١(١٢٠٠٠٠), Q(١٠٠٠٠,١٢), Q٢(١٠٠٠٠,١٢),
      *Q١(١٢٠٠٠٠), Q٨(١٢٠٠), Q٩(٢٤٠١), MON(١٢), QH(١٢٠٠٠٠), QD(١٢٠٠٠٠),
*     QM(١٢٠٠٠٠), QNET(١٢٠٠٠٠), RAN(١٢٠٠٠٠), WHT(١٢٠٠٠٠), CAP(١٢٠٠٠٠),
*     QLVM(١٢), STLM(١٢), CSLM(١٢), RLM(١٢), QH٢(٧٠,١٢), QH١(٨٤٠),
*     QHV(١٣), STH(١٢), CSH(١٢), RH(١٢), QL٢(٧٠,١٢), QL١(٨٤٠), QLV(١٢),
*     STL(١٢), CSS(١٢), QZ٢(٧٠,١٢), QZ١(٨٤٠), QZV(١٣), STZ(١٢), CSZ(١٢),
*     RZ(١٢)

      DOUBLE PRECISION  DA, Q٩

      READ *, N, N١, RELSE, POF, TYP
```

```
      OPEN (UNIT=١, FILE='D\:WAEL PROGRAM\HISTORICAL-DATA.IN')
      OPEN (UNIT=٢, FILE='D\:WAEL PROGRAM\MONTHS.IN')
      OPEN (UNIT=٣, FILE='D\:WAEL PROGRAM\RESULT.OUT')

      DO ٢٠ I = ١, N
      DO ١٠ J = ١, ١٢
      READ (١, *) QH٢(I, J)
١٠    CONTINUE
٢٠    CONTINUE
      V = ٠
      DO ٤٠ I = ١, N
      DO ٣٠ J = ١, ١٢
      V = V + ١
      QH١(V) = QH٢(I, J)
٣٠    CONTINUE
٤٠    CONTINUE
      DO ٦٠ J = ١, ١٢
      SUM = ٠
      DO ٥٠ I = ١, N
      SUM = SUM + QH٢(I, J)
٥٠    CONTINUE
      QHV(J) = SUM / N
٦٠    CONTINUE
      DO ٨٠ J = ١, ١٢
      SUM = ٠
      DO ٧٠ I = ١, N
      SUM = SUM + (QH٢(I, J) - QHV(J)) ** ٢
٧٠    CONTINUE
      STH(J) = SQRT(SUM / (N - ١))
٨٠    CONTINUE
      DO ١٠٠ J = ١, ١٢
      SM = ٠
      SM١ = ٠
```

```
      SM٢ = ٠
      DO ٩٠ I = ١, (N-١)
      QH٢(I, ١٣) = QH٢(I + ١, ١)
      QHV(١٣) = QHV(١(
      SM = SM + (QH٢(I, J) - QHV(J)) * (QH٢(I, J + ١) - QHV(J + ١))
      SM١ = SM١ + (QH٢(I, J) - QHV(J)) ** ٢
      SM٢ = SM٢ + (QH٢(I, J + ١) - QHV(J + ١)) ** ٢
٩٠    CONTINUE
      RH(J) = SM / SQRT(SM١ * SM٢)
١٠٠   CONTINUE
      DO ١٢٠ J = ١, ١٢
      SUM = ٠.
      DO ١١٠ I = ١, N
      SUM = SUM + (QH٢(I, J) - QHV(J)) ** ٣
١١٠   CONTINUE
      CSH(J) = N * SUM / ((N - ٢) * (N - ١) * (STH(J)) ** ٣)
١٢٠   CONTINUE
      IF (TYP.EQ.١) THEN
      GOTO ١٥٠
      ELSE
      IF (TYP.EQ.٢) THEN
      GOTO ٥٩٠
      ELSE
      GOTO ١٠٠٠
      ENDIF
      ENDIF


C     ***************** LIKE GAMA DISTRIBUTION MODEL *****************


١٥٠   DO ١٧٠ I = ١, N
      DO ١٦٠ J = ١, ١٢
      QZ٢(I, J) = (QH٢(I, J) - QHV(J)) / STH(J)
```

```
١٦٠   CONTINUE
١٧٠   CONTINUE
      V = ٠
      DO ١٩٠ I = ١, N
      DO ١٨٠ J = ١, ١٢
      V = V + ١
      QZ١(V) = QZ٢(I, J)
١٨٠   CONTINUE
١٩٠   CONTINUE
      DO ٢١٠ J = ١, ١٢
      SUM = ٠
      DO ٢٠٠ I = ١, N
      SUM = SUM + QZ٢(I, J)
٢٠٠   CONTINUE
      QZV(J) = SUM / N
٢١٠   CONTINUE
      DO ٢٣٠ J = ١, ١٢
      SUM = ٠
      DO ٢٢٠ I = ١, N
      SUM = SUM + (QZ٢(I, J) - QZV(J)) ** ٢
٢٢٠   CONTINUE
      STZ(J) = SQRT(SUM / (N - ١))
٢٣٠   CONTINUE
      DO ٢٥٠ J = ١, ١٢
      SM = ٠
      SM١ = ٠
      SM٢ = ٠
      DO ٢٤٠ I = ١, (N-١)
      QZ٢(I, ١٣) = QZ٢(I + ١, ١)
      QZV(١٣) = QZV(١(
      SM = SM + (QZ٢(I, J) - QZV(J)) * (QZ٢(I, J + ١) - QZV(J + ١))
      SM١ = SM١ + (QZ٢(I, J) - QZV(J)) ** ٢
      SM٢ = SM٢ + (QZ٢(I, J + ١) - QZV(J + ١)) ** ٢
```

```
٢٤٠    CONTINUE
       RZ(J) = SM / SQRT(SM١ * SM٢)
٢٥٠    CONTINUE
       DO ٢٧٠ J = ١, ١٢
       SUM = ٠
       DO ٢٦٠ I = ١, N
       SUM = SUM + (QZ٢(I, J) - QZV(J)) ** ٣
٢٦٠    CONTINUE
       A = N * SUM / ((N - ١) * (N – ٢))
       CSZ(J) = A / (STZ(J) ** ٣)
٢٧٠    CONTINUE
       LAG = ١
       DO ٢٨٠ I = ١, ١٢*N-LAG
       SUMC = SUMC + QZ١(I) * QZ١(I + LAG)
       SUMD = SUMD + QZ١(I(
       SUME = SUME + QZ١(I + LAG)
       SUMF = SUMF + QZ١(I) ** ٢
       SUMG = SUMG + QZ١(I + LAG) ** ٢
٢٨٠    CONTINUE
       NI = ١٢ * N - LAG
       AB = (SUMC / NI) - (SUMD * SUME / (NI ** ٢))
       UN=SQRT((SUMF/NI)-(SUMD**٢/NI**٢))*SQRT((SUMG/NI)-(SUME**٢/NI**٢))
       COR١ = AB / UN
       CA = ٥ ** ٥
       CB = ٧ ** ٥
       DA = ٣٤٣٥٩٧٣٨٣٣٧.
       DB = ٢١٤٧٤٨٣٦٤٧.
       XA = ١ / (٢ * DA)
       XB = ١ / (٢ * DB)
       EA = ١٠٠٠٥٦٧
       EB = ٢٢٥٧٣٣٣
       EA = (CA * EA)
       DO ٢٩٠ I = ١, ١٢*N١,٢
```

```
      TA= CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(TA)) * DA
      RAN(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      RAN(I + ١) = EB / DB + XB
٢٩٠   CONTINUE
      AN = ٨ * ATAN(١.٠)
      DO ٣٠٠ I = ٢, (١٢*N١-١), ٢
      AA = SQRT(-٢ * ALOG(RAN(I)))
      SQI = RAN(I + ١)
      RAN(I) = AA * COS(AN * SQI)
      RAN(I + ١) = AA * SIN(AN * SQI)
٣٠٠   CONTINUE
      SUM=٠
      DO ٣١٠ I = ١, ١٢*N١
      SUM=SUM+RAN(I)
٣١٠   CONTINUE
      AV=SUM/(١٢*N١)
      SUM = ٠
      DO ٣٢٠ I = ١, ١٢*N١
      SUM = SUM + (AV-RAN(I))**٢
٣٢٠   CONTINUE
      VAR = (SUM / (١٢ * N١ - ١))
C     WRITE (٣, *)'VAR OF UN. RND IS:',VAR
C     WRITE (٣, *)'MEAN OF RND IS:', AV
      DO ٣٣٠ J = ١, ١٢
      IF (J.EQ.١٢) THEN
      CSS(J) = (CSZ(١) - CSZ(١٢) * RZ(J)**٣) / ((١ - RZ(J)**٢)**(٣/٢))
      ELSE
      CSS(J) = (CSZ(J+١) - CSZ(J) * RZ(J)**٣) / ((١ - RZ(J)**٢)**(٣/٢))
      ENDIF
٣٣٠   CONTINUE
      DO ٣٥٠ I = ١, ١٢*N١
```

```
      M = I / ١٢
      J = I - M * ١٢
      IF (J.EQ.٠) THEN
      J = ١٢
      ELSE
      GOTO ٣٤٠
      ENDIF
٣٤٠   WHT(I) = (٢/CSS(J))*((١ + CSS(J)*RAN(I)/٦ - CSS(J)**٢/٣٦)**٣ - ١)
٣٥٠   CONTINUE
      QG١(١) = QZV(١)
      DO ٣٦٠ I = ١, (١٢*N١-١)
      QG١(I+١) = COR١ * QG١(I) + (SQRT(١ - COR١ ** ٢)) * WHT(I+١)
٣٦٠   CONTINUE
      DO ٣٨٠ I = ١, N١
      DO ٣٧٠ J = ١, ١٢
      III = III + ١
      QG٢(I, J) = QG١(III)
٣٧٠   CONTINUE
٣٨٠   CONTINUE
      DO ٤٠٠ I = ١, N١
      DO ٣٩٠ J = ١, ١٢
      Q(I, J) = QG٢(I, J) * STH(J) + QHV(J)
٣٩٠   CONTINUE
٤٠٠   CONTINUE
      DO ٤٢٠ I = ١, N١
      DO ٤١٠ J = ١, ١٢
      IF (Q(I, J).LT.٠) THEN
      Q(I,  J)=٠
      ELSE
      GOTO ٤١٠
      ENDIF
٤١٠   CONTINUE
٤٢٠   CONTINUE
```

```
      WRITE (*, *) 'LIKE GAMA DISTRIBUTION MODEL':
      GOTO ١٤٩٠

C       ************* TWO PARAMETER LOG-NORMAL DISTRIBUTION *************

٥٩٠   DO ٦١٠ I = ١, N
      DO ٦٠٠ J = ١, ١٢
      QL٢(I, J) = LOG(QH٢(I, J) + ٠.٠١)
٦٠٠   CONTINUE
٦١٠   CONTINUE
      V=٠
      DO ٦٣٠ I = ١, N
      DO ٦٢٠ J = ١, ١٢
      V = V + ١
      QL١(V) = QL٢(I, J)
٦٢٠   CONTINUE
٦٣٠   CONTINUE
      DO ٦٥٠ J = ١, ١٢
      SUM = ٠
      DO ٦٤٠ I = ١, N
      SUM = SUM + QL٢(I, J)
٦٤٠   CONTINUE
      QLV(J) = SUM / N
٦٥٠   CONTINUE
      DO ٦٧٠ J = ١, ١٢
      SUM = ٠
      DO ٦٦٠ I = ١, N
      SUM = SUM + (QL٢(I, J) - QLV(J)) ** ٢
٦٦٠   CONTINUE
      STL(J) = SQRT(SUM / (N - ١))
٦٧٠   CONTINUE
      DO ٦٩٠ I = ١, N
```

```
      DO ٦٨٠ J = ١, ١٢
      QZ٢(I, J) = (QL٢(I, J) - QLV(J)) / STL(J)
٦٨٠   CONTINUE
٦٩٠   CONTINUE
      V = ٠
      DO ٧١٠ I = ١, N
      DO ٧٠٠ J = ١, ١٢
      V = V + ١
      QZ١(V) = QZ٢(I, J)
٧٠٠   CONTINUE
٧١٠   CONTINUE
      LAG = ١
      DO ٧٢٠ I = ١, ١٢*N-LAG
      SUMC = SUMC + QZ١(I) * QZ١(I + LAG)
      SUMD = SUMD + QZ١(I)
      SUME = SUME + QZ١(I + LAG)
      SUMF = SUMF + QZ١(I) ** ٢
      SUMG = SUMG + QZ١(I + LAG) ** ٢
٧٢٠   CONTINUE
      NI = ١٢ * N - LAG
      AB = (SUMC / NI) - (SUMD * SUME / (NI**٢))
      UN=SQRT((SUMF/NI)-(SUMD**٢/NI**٢))*SQRT((SUMG/NI)-(SUME**٢/NI**٢))
      COR١ = AB / UN
      DO ٧٤٠ J = ١, ١٢
      SUM = ٠
      DO ٧٣٠ I = ١, N
      SUM = SUM + QZ٢(I, J)
٧٣٠   CONTINUE
      QZV(J) = SUM / N
٧٤٠   CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
```

```
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA(
      DO ٧٥٠ I = ١, ١٢*N١, ٢
      TA= CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(TA)) * DA
      RAN(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      RAN(I + ١) = EB / DB + XB
٧٥٠   CONTINUE
      AN = ٨ * ATAN(١.٠)
      DO ٧٦٠ I = ٢, (١٢*N١-١), ٢
      AA = SQRT(-٢ * ALOG(RAN(I)))
      SQI = RAN(I + ١)
      RAN(I) = AA * COS(AN * SQI)
      RAN(I + ١) = AA * SIN(AN * SQI)
٧٦٠   CONTINUE
      SUM=٠
      DO ٧٧٠ I = ١, ١٢*N١
      SUM=SUM+RAN(I)
٧٧٠   CONTINUE
      AV=SUM/(١٢*N١)
      SUM = ٠
      DO ٧٨٠ I = ١, ١٢*N١
      SUM = SUM + (AV-RAN(I))**٢
٧٨٠   CONTINUE
      VAR = (SUM / (١٢ * N١ - ١))
C     WRITE (٤,*)'VAR OF UN. RND IS:',VAR
C     WRITE (٤,*)'MEAN OF RND IS:', AV
      QG١(١) = QZV(١)
```

```
      DO ٧٩٠ I = ١, (١٢*N١-١)
      QG١(I + ١) = COR١ * QG١(I) + (SQRT(١ - COR١ ** ٢))*RAN(I + ١)
٧٩٠   CONTINUE
      DO ٨١٠ I = ١, N١
      DO ٨٠٠ J = ١, ١٢
      III = III + ١
      QG٢(I, J) = QG١(III)
٨٠٠   CONTINUE
٨١٠   CONTINUE
      DO ٨٣٠ I = ١, N١
      DO ٨٢٠ J = ١, ١٢
      Q(I, J) = QG٢(I, J) *  STL(J) + QLV(J)
٨٢٠   CONTINUE
٨٣٠   CONTINUE
      DO ٨٥٠ I = ١, N١
      DO ٨٤٠ J = ١, ١٢
      Q(I, J) = EXP(Q(I, J)) - ٠.٠١
٨٤٠   CONTINUE
٨٥٠   CONTINUE
      DO ٨٧٠ I = ١, N١
      DO ٨٦٠ J = ١, ١٢
      IF (Q(I, J).LT.٠) THEN
      Q(I,  J)=٠
      ELSE
      GOTO ٨٦٠
      ENDIF
٨٦٠   CONTINUE
٨٧٠   CONTINUE
      WRITE (*, *) 'TWO PARAMETER LOG-NORMAL DISTRIBUTION':
      GOTO ١٤٩٠


C       ************* THREE PARAMETER LOG-NORMAL DISTRIBUTION *************
```

```
١٠٠٠  DO ١٠٣٠ J = ١, ١٢
      A١ = ١
      DO ١٠١٠ I = ١, ١٠٠٠٠
      F١ = EXP(٣ * A١) - ٣ * EXP(A١) + ٢ - CSH(J) * (EXP(A١) - ١) ** ١.٥
      F٢ = ٣*EXP(٣*A١) -٣*EXP(A١) -١.٥*CSH(J)*(SQRT(EXP(A١) -١))*EXP(A١)
      A٢ = A١ - (F١ / F٢)
      IF (ABS(A١ - A٢).LT.٠.٠٠٠٠٠٠١) THEN
      GOTO ١٠٢٠
      ELSE
      A١ = A٢
      GOTO ١٠١٠
      ENDIF
١٠١٠  CONTINUE
١٠٢٠  STLM(J) = SQRT(A٢)
١٠٣٠  CONTINUE
      DO ١٠٤٠ J = ١, ١٢
      QLVM(J) = ٠.٥*LOG(STH(J)**٢ /(EXP(٢*STLM(J)**٢) -EXP(STLM(J)**٢)))
١٠٤٠  CONTINUE
      DO ١٠٥٠ J = ١, ١٢
      CSLM(J) = QHV(J) - EXP(٠.٥ * STLM(J) ** ٢ + QLVM(J))
١٠٥٠  CONTINUE
      DO ١٠٦٠ J = ١, ١٢
      IF (J.EQ.١٢) THEN
      RLM(J) = LOG(RH(١٢) * ((EXP(STLM(١٢) **٢) - ١) * (EXP(STLM(١) **٢)
      ) / (١ + ٠.٥ ** ((١ - *STLM(١٢) * STLM(١)))
      GOTO ١٠٦٠
      ELSE
      RLM(J) = LOG(RH(J) * ((EXP(STLM(J)**٢) - ١) * (EXP(STLM(J + ١)**٢)
      ) / (١ + ٠.٥ ** ((١ - *STLM(J) * STLM(J + ١))
      GOTO ١٠٦٠
      ENDIF
١٠٦٠  CONTINUE
```

```
      DO ١٠٨٠ I = ١, N
      DO ١٠٧٠ J = ١, ١٢
      QL٢(I, J) = LOG(QH٢(I, J) - CSLM(J))
١٠٧٠  CONTINUE
١٠٨٠  CONTINUE
      V=٠
      DO ١١٠٠ I = ١, N
      DO ١٠٩٠ J = ١, ١٢
      V = V + ١
      QL١(V) = QL٢(I, J)
١٠٩٠  CONTINUE
١١٠٠  CONTINUE
      DO ١١٢٠ J = ١, ١٢
      SUM = ٠
      DO ١١١٠ I = ١, N
      SUM = SUM + QL٢(I, J)
١١١٠  CONTINUE
      QLV(J) = SUM / N
١١٢٠  CONTINUE
      DO ١١٤٠ J = ١, ١٢
      SUM = ٠
      DO ١١٣٠ I = ١, N
      SUM = SUM + (QL٢(I, J) - QLV(J)) ** ٢
١١٣٠  CONTINUE
      STL(J) = SQRT(SUM  / (N – ١))
١١٤٠  CONTINUE
      DO ١١٦٠ I = ١, N
      DO ١١٥٠ J = ١, ١٢
      QZ٢(I, J) = (QL٢(I, J) - QLV(J)) / STL(J)
١١٥٠  CONTINUE
١١٦٠  CONTINUE
      V = ٠
      DO ١١٨٠ I = ١, N
```

```
      DO ١١٧٠ J = ١, ١٢
      V = V + ١
      QZ١(V) = QZ٢(I, J)
١١٧٠  CONTINUE
١١٨٠  CONTINUE
      LAG = ١
      DO ١١٩٠ I = ١, ١٢*N-LAG
      SUMC = SUMC + QZ١(I) * QZ١(I + LAG)
      SUMD = SUMD + QZ١(I)
      SUME = SUME + QZ١(I + LAG)
      SUMF = SUMF + QZ١(I) ** ٢
      SUMG = SUMG + QZ١(I + LAG) ** ٢
١١٩٠  CONTINUE
      NI = ١٢ * N - LAG
      AB = (SUMC / NI) - (SUMD * SUME / (NI ** ٢))
      UN=SQRT((SUMF/NI)-(SUMD**٢/NI**٢))*SQRT((SUMG/NI)-(SUME**٢/NI**٢))
      COR١ = AB / UN
      DO ١٢١٠ J = ١, ١٢
      SUM = ٠
      DO ١٢٠٠ I = ١, N
      SUM = SUM + QZ٢(I, J)
١٢٠٠  CONTINUE
      QZV(J) = SUM / N
١٢١٠  CONTINUE
      CA = ٥ ** ٥
      CB = ٧ ** ٥
      DA = ٣٤٣٥٩٧٣٨٣٣٧.
      DB = ٢١٤٧٤٨٣٦٤٧.
      XA = ١ / (٢ * DA)
      XB = ١ / (٢ * DB)
      EA = ١٠٠٠٥٦٧
      EB = ٢٢٥٧٣٣٣
      EA = (CA * EA)
```

```
      DO ١٢٢٠ I = ١, ١٢*N١, ٢
      TA= CA * EA / DA
      EA = ((CA * EA) / DA - IFIX(TA)) * DA
      RAN(I) = (EA / DA) + XA
      EB = ((CB * EB) / DB - IFIX(CB * EB / DB)) * DB
      RAN(I + ١) = EB / DB + XB
١٢٢٠  CONTINUE
      AN = ٨ * ATAN(١.٠(
      DO ١٢٣٠ I = ٢, (١٢*N١-١), ٢
      AA = SQRT(-٢ * ALOG(RAN(I)))
      SQI = RAN(I + ١(
      RAN(I) = AA * COS(AN * SQI)
      RAN(I + ١) = AA * SIN(AN * SQI)
١٢٣٠  CONTINUE
      SUM = ٠
      DO ١٢٤٠ I = ١, ١٢*N١
      SUM = SUM + RAN(I)
١٢٤٠  CONTINUE
      AV = SUM / (١٢ * N١)
      SUM = ٠
      DO ١٢٥٠ I = ١, ١٢*N١
      SUM = SUM + (AV - RAN(I)) ** ٢
١٢٥٠  CONTINUE
      VAR = (SUM / (١٢ * N١ - ١))
C     WRITE (٣, *)'VAR OF UN. RND IS:',VAR
C     WRITE (٣, *)'MEAN OF RND IS:', AV
      QG١(١) = QZV(١)
      DO ١٢٦٠ I = ١, (١٢*N١-١)
      QG١(I + ١) = COR١ * QG١(I) + (SQRT(١ - COR١ ** ٢)) * RAN(I + ١)
١٢٦٠  CONTINUE
      DO ١٢٨٠ I = ١, N١
      DO ١٢٧٠ J = ١, ١٢
      III = III + ١
```

```
      QG٢(I, J) = QG١(III)
١٢٧٠  CONTINUE
١٢٨٠  CONTINUE
      DO ١٣٠٠ I = ١, N١
      DO ١٢٩٠ J = ١, ١٢
      Q(I, J) = QG٢(I, J) * STLM(J) + QLVM(J)
١٢٩٠  CONTINUE
١٣٠٠  CONTINUE
      DO ١٣٢٠ I = ١, N١
      DO ١٣١٠ J = ١, ١٢
      Q(I, J) = EXP(Q(I, J)) + CSLM(J)
١٣١٠  CONTINUE
١٣٢٠  CONTINUE
      DO ١٣٤٠ I = ١, N١
      DO ١٣٣٠ J = ١, ١٢
      IF (Q(I, J).LT.٠) THEN
      Q(I, J) = ٠
      ELSE
      GOTO ١٣٣٠
      ENDIF
١٣٣٠  CONTINUE
١٣٤٠  CONTINUE
      WRITE (*, *) 'THREE PARAMETER LOG-NORMAL DISTRIBUTION':


C     *** THE P.O.F. OF RESERVOIR BY SEQUENT PEAK ALGORITHIM METHOD ***


١٤٩٠  DO ١٥٠٠ J = ١, ١٢
      READ (٢, *) MON(J)
١٥٠٠  CONTINUE
      SUM = ٠
      DO ١٥٢٠ I = ١, N
      DO ١٥١٠ J = ١, ١٢
```

```
      SUM = SUM + QH٢(I, J) * ٠.٢٤ * ٠.٣٦ * MON(J)
١٥١٠  CONTINUE
١٥٢٠  CONTINUE
      SUM = SUM / (١٢ * N)
      DT = SUM * RELSE / ١٠٠
      DO ١٥٤٠ I = ١, N١
      DO ١٥٣٠ J = ١, ١٢
      Q٢(I, J) = ٠.٣٦٠٠ * ٠.٢٤ * MON(J) * Q(I, J)
١٥٣٠  CONTINUE
١٥٤٠  CONTINUE
      III = ٠
      DO ١٥٦٠ I = ١, N١
      DO ١٥٥٠ J = ١, ١٢
      III = III + ١
      Q١(III) = Q٢(I, J)
١٥٥٠  CONTINUE
١٥٦٠  CONTINUE
      NOP = N١ / ١٠٠
      Z = ٠
      DO ١٦٩٠ K = ١, NOP
      WRITE (٣, *) K
      DO ١٥٧٠ M = ١, ١٢٠٠
      Q٨(M) = Q١((K - ١) * ١٢٠٠ + M)
١٥٧٠  CONTINUE
      DO ١٥٨٠ M = ١, ٢*١٢*١٠٠
      IF (M.GT.١٢ * ١٠٠) THEN
      Q٨(M) = Q٨(M - ١٢ * ١٠٠)
      ELSE
      GOTO ١٥٨٠
      ENDIF
١٥٨٠  CONTINUE
      DO ١٥٩٠ M = ١, ٢*١٢*١٠٠
      Q٨(M) = Q٨(M) - DT
```

```
١٥٩٠ CONTINUE
      Q٩(١) = ٠
      SUM = ٠
      DO ١٦٠٠ M = ٢, ٢*١٢*١٠٠+١
      SUM = SUM + Q٨(M - ١)
      Q٩(M) = SUM
١٦٠٠ CONTINUE
      B = ٠
      IF (Q٩(١).GT.Q٩(٢)) THEN
      T = ١
      QH(T) = Q٩(١)
      M = ٢
      GOTO ١٦٣٠
      ELSE
      GOTO ١٦١٠
      ENDIF
١٦١٠ DO ١٦٢٠ I = ٢, ٢*١٢*١٠٠+١
      IF (Q٩(I).GT.Q٩(I - ١).AND.Q٩(I).GT.Q٩(I + ١)) THEN
      T = ١
      QH(T) = Q٩(I)
      M = I + ١
      GOTO ١٦٣٠
      ELSE
      GOTO ١٦٢٠
      ENDIF
١٦٢٠ CONTINUE
١٦٣٠ DO ١٦٦٠ I = ٢, ٢*١٢*١٠٠+١
      IF (Q٩(I).GT.Q٩(I-١).AND.Q٩(I).GT.Q٩(I+١).AND.Q٩(I).GT.QH(T)) THEN
      T = T + ١
      QH(T) = Q٩(I)
      DO ١٦٤٠ J = M, I - ١
      IF (Q٩(J).LT.Q٩(J - ١).AND.Q٩(J).LT.Q٩(J + ١)) THEN
      B = B + ١
```

```
      QM(B) = Q٩(J)
      ELSE
      GOTO ١٦٤٠
      ENDIF
١٦٤٠  CONTINUE
      QMMIN = QM(١)
      DO ١٦٥٠ L = ٢, B
      IF (QMMIN.LT.QM(L)) THEN
      GOTO ١٦٥٠
      ELSE
      QMMIN = QM(L)
      ENDIF
١٦٥٠  CONTINUE
      QD(T - ١) = QMMIN
      B = ٠
      M = I + ١
      ELSE
      GOTO ١٦٦٠
      ENDIF
١٦٦٠  CONTINUE
      DO ١٦٧٠ I = ١, T-١
      QNET(I) = QH(I) - QD(I)
١٦٧٠  CONTINUE
      QMAX = QNET(١)
      DO ١٦٨٠ I = ٢, T
      IF (QMAX.GT.QNET(I)) THEN
      GOTO ١٦٨٠
      ELSE
      QMAX = QNET(I)
      ENDIF
١٦٨٠  CONTINUE
      Z = Z + ١
      CAP(Z) = QMAX
```

```
      WRITE (٣, *) CAP(Z)
١٦٩٠  CONTINUE
      SUM = ٠
      DO ١٧٠٠ J = ١, NOP
      SUM = SUM + CAP(J)
١٧٠٠  CONTINUE
      AVC = SUM / NOP
      SUM = ٠
      DO ١٧١٠ J = ١, NOP
      SUM = SUM + (CAP(J) - AVC) ** ٢
١٧١٠  CONTINUE
      STC = SQRT(SUM / (NOP - ١    ))
      ALFA = (٣.١٤١٦ / SQRT(٦.٠)) / STC
      BETA = AVC - (٠.٥٧٧٢١ / ALFA)
      CAPACITY = ((-LOG(-LOG( POF / ١٠٠ ))) / ALFA ) + BETA
      WRITE (*, *) 'PROBABILITY OF FAILURE OF RESERVOIR IS:', POF
      WRITE (*, *) 'CAPACITY OF RESERVOIR IS:', CAPACITY

      STOP
      END
```

CHAPTER ONE

Introduction

١.١ General

Water-resources systems should be designed and operated for the most effective and efficient accomplishment of overall objective. A water-resources system usually consists of one or more reservoirs, power plant, diversions, and canals that are each constructed for specific objectives and operated according to a certain pre-organized policy. The general function of a system is to control and regulate the water for flood control, irrigation, hydroelectric power, industrial water supply, recreation, water quality, and navigation. Although the water stored in lakes, reservoirs, and streams is less than a half of one percent of the earths fresh water, its easy accessibility and frequent replenishment make it the most important source of supply for the needs of mankind.

When the required diversion rate from a river exceeds the natural flow rate, the excess demand can only be met from an alternative supply, e.g., ground-water or from surface storage. The storage required on a river to meet a specific demand depends preliminary on three factors, namely, the magnitude and variability of the river flow, the size of the demand, and the degree of reliability of this demand being met.

There are two aspects in building reservoirs, the capacity and the operation. The design of a reservoir is concerned with determining the storage capacity required to maintain a yield with a given probability of failure. This is very important as the cost of building the reservoir increases exponentially with the height of the dam (Rajab et al., ٢٠٠١). On the other hand, a reservoir which is too small will not serve its purpose and there will be a shortage of water on a regular basis.

System performance can be described from three different viewpoints: (١) how often the system fails (reliability), (٢) how quickly the system returns to a satisfactory state once a failure has occurred (resiliency), and (٣) how significant the likely consequences of failure may be (vulnerability). The present research aims mainly at assessing the above criteria of Bekhme reservoir in Iraq.

١.٢ Methodology of the Research

In the present research, three reservoir capacity-yield procedures are used for estimating the probability of reservoir failure. These three procedures are behavior procedure, Gould’s procedure, and sequent peak algorithm method using sequences of historical and synthetic monthly flows. Synthetic data are generated by using six approaches of data generation techniques, namely, Thomas-Fiering with log transformation, Thomas-Fiering with Box-Cox transformation, Two-tier model, Modified two-tier model, Fragment model, and First order Markov model. The results of the three aforementioned models are compared in order to select the best model for representing the Bekhme Dam inflow. Moreover, two additional measures of risk are also estimated. These are vulnerability and resilience.

١.٣ Objectives of the Research

The objectives of the research are:

(١) Estimating the reliability, vulnerability and resilience of Bekhme reservoir for the design storage capacity by behavior, Gould's probability matrix and sequent peak algorithm methods. Both historical and generated monthly inflow data are used in the analysis.

(٢) Developing of general capacity-yield relationship for all Iraqi reservoirs to provide a preliminary design capacity or yield estimate for storage reservoir.

١.٤ Organization of the Thesis

The present thesis consists of seven chapters:

- Chapter One (Introduction) which includes a general introduction, Methodology, objectives and organization of the research.
- Chapter Two (Review of Literature) presents brief description of previous studies on reservoir capacity-yield procedures and stochastic data generation techniques.
- Chapter Three (Theoretical Background) is devoted to the methods of reservoir capacity-yield in use for estimating the reliability, vulnerability and resilience.
- Chapter Four (Data Generation Techniques) summarizes the models of stochastic data generation techniques.
- Chapter Five (Application of Capacity-Yield Procedures to Bekhme Reservoir) consists of the application of reservoir capacity-yield procedure to Bekhme reservoir and analysis of results.
- Chapter Six (Development of General Capacity-Yield Relationship) includes development of general relationships for Iraqi reservoirs.

- Chapter Seven (Conclusions and Recommendations) involves the conclusions abstracted from the results of the research and recommendations suggested for further research work.

CHAPTER TWO

Review of Literature

٢.١ General

Capacity - yield procedures are used by water resources engineers to determine the required capacity of reservoir to maintain a pre-specified reservoir release. Reservoir capacity-yield procedures can be classified into three main groups (figure ٢.١). The first group includes critical period techniques while the methods based on Moran’s Dam theory and similar procedures are included in the second group. The third group consists of those procedures which are based on generated data.

Briefly, the critical period techniques include methods in which a sequence (or sequences) of flows for which demand exceeds inflow is used to determine the storage size as classified into many approaches in figure (٢.١).

The second group of procedures is considered to be a development of Moran’s theory of storage (١٩٥٤, ١٩٥٥, and ١٩٥٩). Moran considered time and flow to be discontinuous variables and showed how reservoir capacity, release, and inflow could be related to each other by a system of simultaneous equations. Sequently, Gould (١٩٦١) modified the simultaneous Moran’s model by using the transition matrix with a yearly time period to account for both seasonality and auto-correlation of monthly inflows (Srikanthan and McMahon, ١٩٨٥b).

Although stochastic methods were first used more than sixty years ago, it was not until the advent of high-speed digital computers in the ١٩٦٠'s that such procedures became established in engineering hydrology.

Finally, the sequent peak algorithm which have special features or which considers other aspects of storage and yield is developed by Thomas and Burden (١٩٦٣). Vogel and Stedinger (١٩٨٧) employed the double-cycling algorithm as opposed to the single-cycling algorithm used by Burges and Linsley (١٩٧١), Troutman (١٩٧٨), and Bayazit (١٩٨٢) (Vogel and Stedinger, ١٩٨٧).

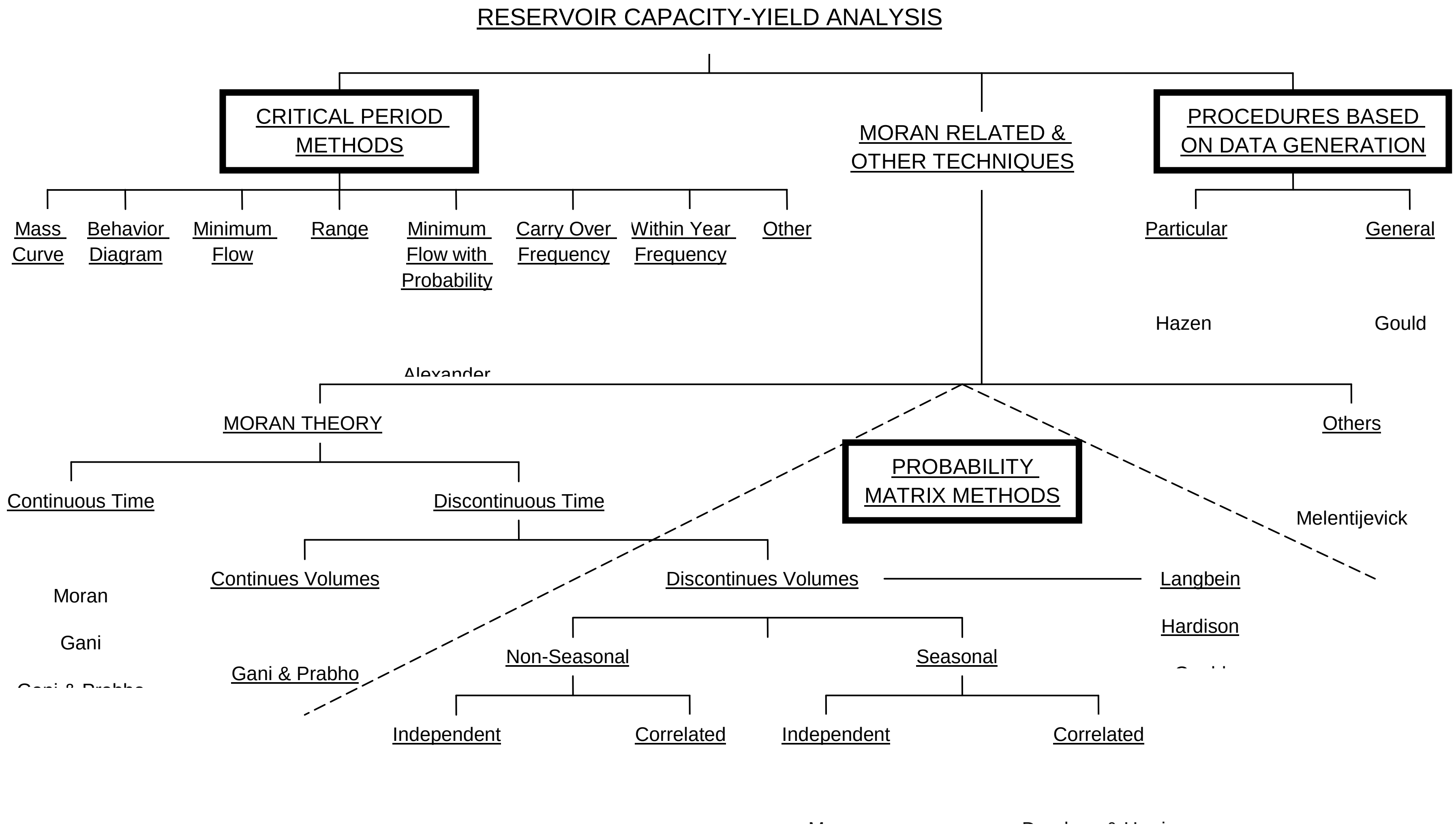

Figure ٢.١: A theoretical Classification of Methods for Reservoir Capacity-Yield Analysis

(McMahon and Mein, ١٩٨٦)

٢.٢ Review of Literature on Reservoir Capacity - Yield Procedures

Harris (١٩٦٥) applied both Moran's steady state probability method and Gould's probability method for determining the probability of failure for Alwen reservoir in Wales. It is assumed that the distribution of the historical season inflow to Alwen reservoir is approximately normal. He found the flows to be seasonal and independent, and prepared wet and dry season transition matrices which were multiplied together to give the annual transition matrix.

McMahon et al. (١٩٧٢) examined the behaviour approach and Gould's method for determining reservoir storage size by analysing representative sequences of monthly flows generated by a Thomas and Fiering model for six Australian rivers. Both procedures exhibited large variations in storage estimates; however, the behaviour estimates were also affected by the initial storage conditions. They found that the storage variations resulting from the Gould analysis were smaller than those found using the behaviour technique.

Codner and McMahon (١٩٧٣) examined several important aspects in the use of lognormal Markov model for stream flow generation, including the variations between the two-parameter and three-parameter lognormal seasonal models, the number and length of traces required to adequately specify storage size, and the technique to determine the size of a single reservoir. The results of the application of three models, skewed, LN٢, and LN٣ to several Australian rivers showed that no one model satisfactorily produced both storage and flow parameters estimates. Storage estimates from the two-parameter lognormal model were found to be lower than those estimated using the three-parameter lognormal model.

Doran (١٩٧٥) used ٢-parameter lognormal distribution to test the efficiency of the divided interval technique. A computer program was prepared to find the effect of number of storage states on the probability of failure. He found that the use of ١٠ states with the divided interval technique would give a sufficiently accurate solution of reservoir capacity.

McMahon (١٩٧٦) compared the Gould model output with that of a behavior analysis for some ١٥٦ Australian streams and derived empirical correction factors for serial correlation based on the variance of annual stream flows.

Teoh (١٩٧٧) analyzed ten streams with coefficient of variation varying between ٠.١٩ and ١.٧٩. He suggested the following table (see Table ٢.١), as a general rule in choosing the number of zones (Srikanthan and McMahon, ١٩٨٥a).

Table ٢.١: Teoh's Suggestion for the

Coefficient of Variation (Cv)	Number of Zones
Cv < ٠.٥	١٠
٠.٥ ≤ Cv < ١.٠	٢٠
١.٠ ≤ Cv < ١.٥	٣٠
Cv ≥ ١.٥	٤٠

Hoshi et al. (١٩٧٨) used the sequent peak algorithm (SPA) to determine the necessary reservoir size to meet a given demand schedule. Storage probability distributions were determined as follows: ٥٠٠ synthetic monthly flow traces, each trace having a length of ٤٠ years were generated. Each of these synthetic traces was routed through the (SPA) to yield a value of the required storage. The monthly flow generated by Thomas-Fiering model and disaggregation model (annual Markov and ARMA generator). The results of the three cases examined for different monthly flow generators showed significant differences in the probability distributions of required storage when determined from the normal and ٣PLN distribution procedures; the ٣PLN distributed monthly sequences yield lesser storage requirements for every case than normally distributed monthly flows.

Srikanthan (١٩٧٨) suggested a possible modification to the disaggregation scheme proposed by Valencia and Schaake to generate skewed monthly stream flows. The modified procedure was applied to two Australian streams and the results were compared with those of the two-tier model of Harms and Campbell. The storage estimates were obtained by using the sequent peak algorithm for ٥٠, ٧٠ and ٩٠٪ draft.

He concluded that any one of the methods can be used to generate stream flows sequentially.

Hoshi and Burges (١٩٧٩) developed alternative models, which preserve all relevant correlations, and accommodate skewed marginal distributions by approximating them with general log-normal distributions. The Mejia-Rousselle (MR) model was modified to model skewed marginal distributions and compared with the model developed by them (HB). The MR method achieved a better result than the HB method in terms of the over-year correlation between September and October. However, the standard deviations were more biased in these two months than those by the HB method.

Panu and Unny (١٩٨٠) tested the synthetic realizations of monthly stream flows obtained by utilizing a feature synthesis model from statistical and hydrological view points for several rivers. The model results suggested that the synthesis of stream flows based on concepts of pattern recognition is potentially viable approach and warrants further investigation.

Simonovic and Marino (١٩٨٠) presented the application of reliability programming techniques to a multipurpose reservoir. This approach, in allowing reliabilities to be considered as decision variables, explicitly considered the tradeoff between benefits and risk. The solution was obtained for a reservoir with few purposes and random inflow and demands. The output of the program gave the optimal values of reservoir releases and the optimal risk levels (flood risk and draught risk) which are valuable information for decision makers.

Abdul-Rasoul (١٩٨١) generated monthly stream flow data by appling Thomas-Fiering model, in addition to Wilson-Hilferty and Kirby's modifications (to avoid high skewness coefficient) at four stations, three on the Tigres river and one on the Euphrates river. She concluded that this model has a good agreement if the skewness of data is treated by Wilson-Hilferty method.

Hashimoto et al. (١٩٨٢) discussed three criteria for evaluating the possible performance of water resources systems. These measures are called reliability, resilience, and vulnerability. Their work explained the using of these criteria to assist in the evaluation and selection of alternative design and operating policies for a wide variety of water resources projects. They showed that one can not have both the maximum possible reliability and minimum possible vulnerability.

Srikanthan and McMahon (١٩٨٢) used two stream flow generation models to generate monthly flows for Australian streams. In one model, seasonalities and periodicities in the monthly flows were removed and the resulting weekly stationary series was modeled. The second approach used the Thomas-Fiering monthly model. The results of these models were compared. They recommended that a modified two-tier model be used for less variable streams and the method of fragments be used for highly variable streams.

Stedinger and Taylor (١٩٨٢b) illustrated the impact of incorporating the uncertainty in the statistic parameters of the distribution of annual flows on estimates of monthly reservoir system reliability. They used non informative prior distributions, with the ٥٠-year flow record available for the upper Delaware River basin. They concluded that the uncertainty in the mean, variance, and correlation of the annual flows had a major impact on estimate of the reliability.

Phatarfod (١٩٨٤) compared between two simulation procedures and three probability procedures-one numerical and two analytical for determining the size and the probability of failure of a reservoir. A case study of the River Yarra in Australia was given. The aspects of comparison were easiness of application, flexibility, and the amount of effort required. He concluded that the behavior procedure was the best.

Srikanthan and McMahon (١٩٨٥a and b) prepared two studies based on an analysis of historical and synthetic stream flows for nine Australian rivers. In the first paper, the effect of starting month on storage size was examined. In the second paper, the error involved in ignoring annual autocorrelation in Gould’s procedure was examined and correction factors were presented [as given in figure (٢.٢)]. They concluded that the starting month for annual routes should coincide with the minimum mean monthly flow in the first paper. The second paper concluded that Gould’s transition probability matrix method is not a suitable procedure for rivers with significant annual autocorrelation coefficients. However, Gould’s procedure may be used for small annual autocorrelation coefficient (say, ٠.٢) so long as the correction factor is not greater than ١.٥.

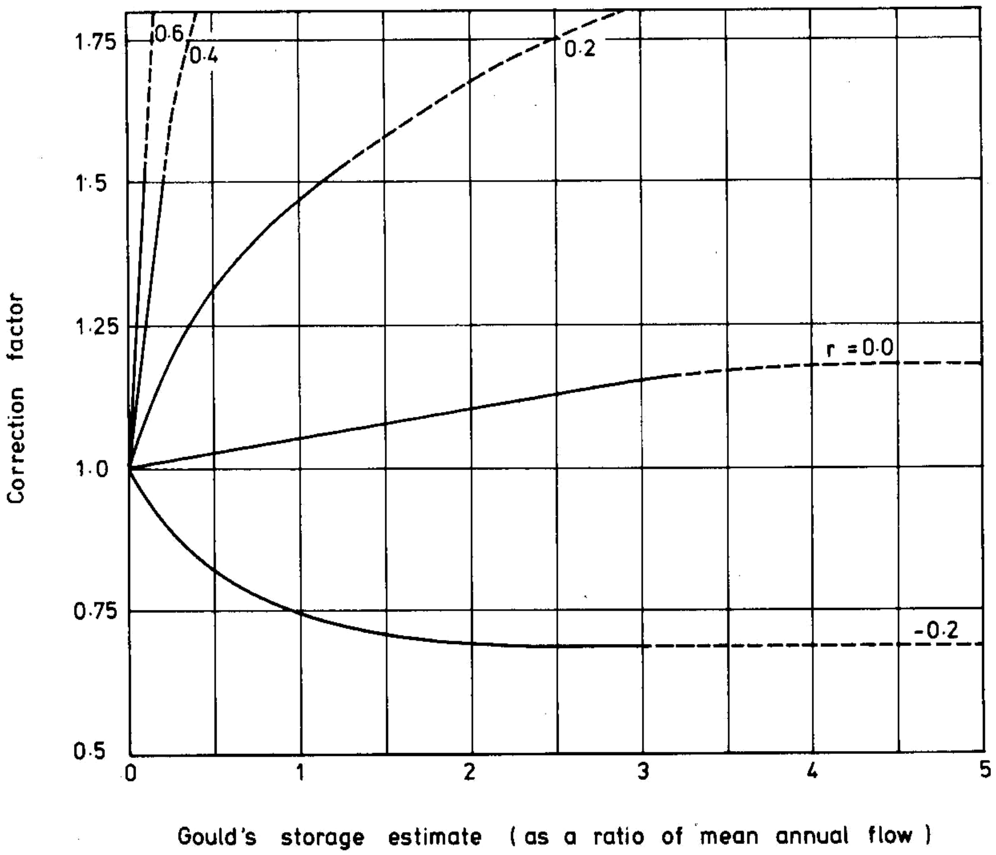

Figure ٢.٢: Factor of Adjust Storage Size Calculated by Gould's Probability Matrix Method for Annual Serial Correlation Coefficient

(Srikanthan and McMahon, ١٩٨٥b)

Vogel (١٩٨٥) provided a comparison of the impact of using the single-versus the double-cycling sequent peak algorithm; he documents situations in which the two procedures yield substantially different results (Vogel and Stedinger, ١٩٨٧).

Moy et al. (١٩٨٦) suggested operational measures of reliability, vulnerability, and resilience in water supply reservoir performance. Using multi objective mixed-integer linear programming, they optimized these measures and traded them off one against the other. It was found that as reliability was increased or as the maximum length of consecutive shortfalls decreases (resilience increases), the vulnerability of the water system to larger deficits increased.

Phatarfod (١٩٨٦) investigated the effect of the serial correlation coefficient of the inflows on the reservoir size, when large reservoirs were involved. When the reservoir was operated on an annual basis, it was shown that for low drafts the ratio is dependent on the inflow model, where as for the limiting case when the draft ratio approaches the value ١.٠, the ratio was approximately (١+ρ)/(١-ρ), irrespective of the inflow model, where ρ is the annual serial coefficient. Where the reservoir was operated on a seasonal basis, the ratio considered was that of the reservoir size when all the serial correlations were present to the size when year-end seasonal correlation was neglected. He showed that for large reservoirs this ratio was mainly dependent on the annual flow parameters irrespective of the within-year pattern of inflows.

Vogel (١٩٨٦) developed a new probability plot correlation coefficient test for the normal, log-normal and Gumbel distributional hypothesis. He extended Flliben's test for samples of length ١٠٠ to ١٠,٠٠٠ because many water resources research applications required a test of normality for samples of length greater than ١٠٠.

Vogel and Stedinger (١٩٨٨) illustrated the variability of required reservoir storage capacity estimates based on ٢٠-٨٠ year stream flow record. Stochastic stream flow models: AR(١) lognormal, AR(١) normal, AR(١) Gamma, and an ARMA(١,١) lognormal model were applied. Their results showed that the use of stochastic stream flow models can lead to improvement in the precision of the reservoir design capacity estimates. In their experiments, an AR(١) lognormal model was fit to historical flow sequences generated with four different stochastic stream flow models.

Kheder (١٩٩٠) generated the monthly hydrological series in an arid region by using modified Thomas-Fiering model for ١٠٠ years. This model required using random numbers which have different distributions. The comparison of the monthly mean and standard deviation of the historical and synthetic data indicated a good agreement between the two series.

Wurbs and Bergman (١٩٩٠) considered that yield versus reliability relationships and firm yield estimates are fundamental to water supply planning and management. The factors affecting estimates of reservoir yield are classified as follows:

(١) Compilation and development of basic data representing basin hydrology;

(٢) Simulation of physical characteristics and operating policies of the reservoir; and

(٣) Modeling the impacts of basin wide water management.

Moore and Smith (١٩٩٢) developed a computer program to compare the Gould probability matrix model with the behavior analysis for the hydrologic design of offstream irrigation storages. The models were applied to three case studies for the Darling Downs region of Queensland. The Gould model produced results which were comparable to the behavior analysis. He concluded that the differences between the models were found to be smaller if serial correlation effects were neglected.

Al-Shareef (١٩٩٦) used the Moran model to estimate the probability of failure of Al-Adhaim reservoir. Only two probability distributions were used, namely, the normal and log-normal distributions. It was found that the probabilities of failure were ٢.٩٪ and ٦.٣٪ respectively.

Pretto et al. (١٩٩٧) investigated the dependence of estimates of reservoir storage capacity derived using behavior analysis on the length of inflow sequence used for over year reservoir simulation. The results showed that it may take sequence lengths as much as ١٠٠٠ years or more for the mean of the distribution of storage capacity estimates to approach a stationary value (figure ٢.٣).

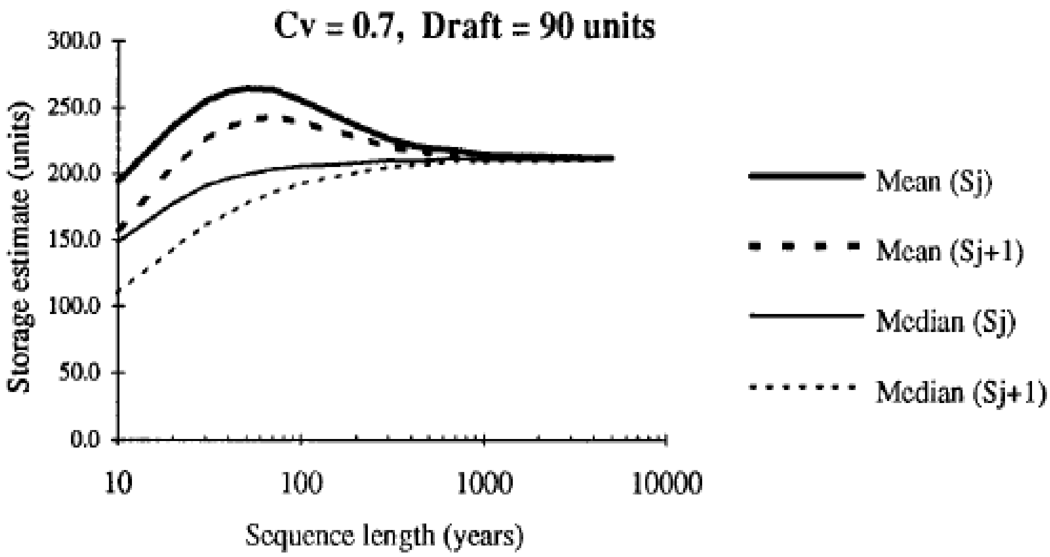

Figure ٢.٣: Comparison of Mean and Median Storage Estimates for $S_{j+١}$ and S_j, for Concatenated Behavior Analysis and Reliability = ٩٠٪, $r_١$ = ٠

(Pretto et al., ١٩٩٧)

Bojilova (٢٠٠٠) applied the original extended Mejia and Rouselle model and the corrected extended Lin model into two forms, one and two-stage disaggregation to the stream flow data of the chosen rivers in Bulgaria. He made a comparison between the three models for single and multi-site disaggregation. The results showed that the three approaches are suitable for disaggregation of the river flows. Furthermore, the best results were obtained from the corrected extended model, two-stage disaggregation for both single and multi-site approaches.

Jenkins and Lund (٢٠٠٠) developed a new framework that integrates traditional yield simulation modeling with accost-minimizing shortage management model. The framework was used to examine integrated resource planning decisions for urban water supply reliability from an economic and risk-based perspective.

Madhloom (٢٠٠٠) applied two procedures from reservoir capacity yield groups to estimate the probability of failure for Al-Adhaim reservoir. Those procedures were behavior procedure and Gould's procedure. Also the synthetic data were generated by using Thomas-Fiering monthly model and used the sequences of monthly synthetic data to estimate the probability of failure. The logarithmic transformation was found to be the best one that suits the inflow distribution of Adhaim River among the like Gamma transformations. Madhloom concluded that Gould's procedure could estimate reliability accurately based only on historical data, while the behavior procedure needs the synthetic data.

Ragab et al. (٢٠٠١) calculated the probability of failure on a monthly basis for different starting months of the year by using the HYDROMED model (figure ٢.٤). They applied modified Gould probability matrix method on El-Gouazine catchment's in Tunisia. They concluded that the HYDROMED model has successfully implemented a modified Gould probability matrix method.

Rugumayo (٢٠٠١) developed analytical approach in the process of determining the initial capacity of the storage required, using the mass curve technique and compared the results of the behaviour analysis method with application of the mass curve analytical technique to two rivers in Uganda. Mass curve analytical technique gave the same result as the mass curve graphical technique. He concluded that the behavior analysis gives a more specified estimate with a known reliability which can be used in final designs.

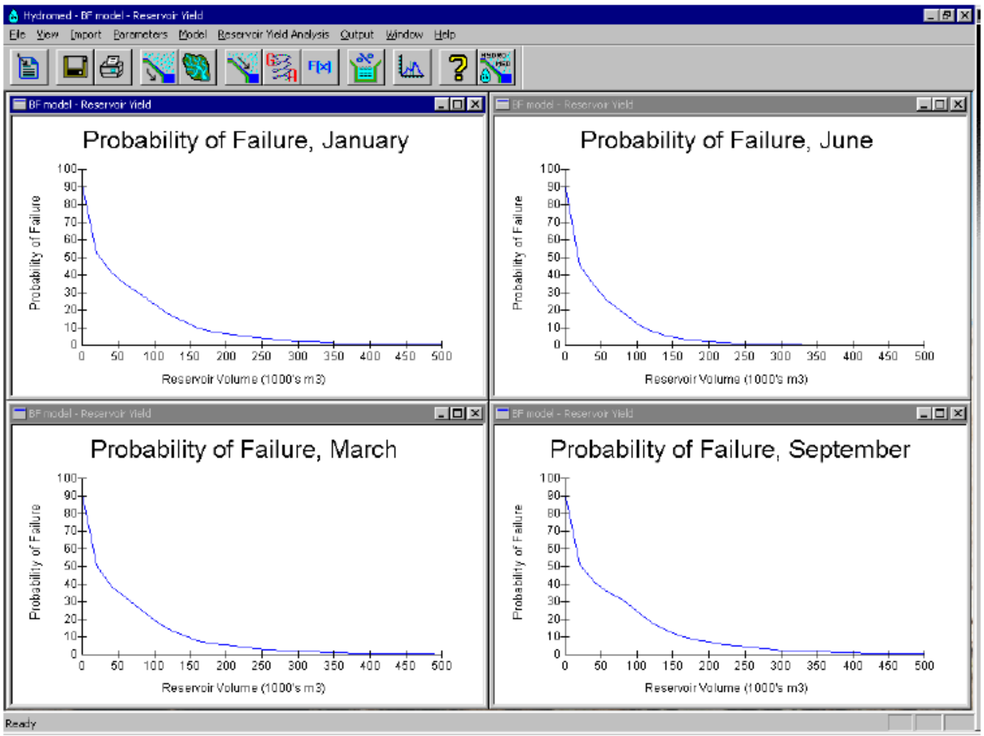

Figure ٢.٤: Reservoir Probability of Failure at El-Gouazine, Tunisia for Different Times of the Year (Ragab et al., ٢٠٠١)

Al-Fatlawi (٢٠٠٣) applied the behavior analysis to Haditha reservoir for evaluating the reliability, vulnerability, and resilience, where Gould's procedure was used for evaluating reliability. Data generation techniques were also used for estimating the above three measures of risk. The synthetic data were generated by using five approaches, namely, Thomas-Fiering model with log transformation, Thomas-Fiering model with Box-Cox transformation, two-tier model, modified two-tier model, and fragment model. These approaches were tested and used to find the probability of failure by behavior and Gould's techniques. The modified two-tier model and the two-tier model were found to be the best for representing the Haditha dam inflow.