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A FLOOD CONTROL OPERATION OF A RESERVOIR

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CONTENTS

LIST OF FIGURES

ABSTRACT

Reservoirs which are constructed for the purpose of conservation and flood control have to be operated for flood control during monsoon season in order to safeguard the downstream control points and the dam against damaging floods. Though flood forecasting models have been developed for some basins yet their utilisation during heavy down pour is in its infancy as they are dependent on communications that are subject to failure or on expert analysis that might not be available at the time. Thus it is necessary to have a guideline to the spillway operator at the reservoir site that will earmark the flood cushion requirement considering the importance of conservation and the restrainment to be shown towards the downstream damaging centres. A methodology based on U.S.Army Corps of Engineers for the preparation of a spillway regulation curve is presented here.

1.0 INTRODUCTION

The degree of flood protection assured by a multi purpose reservoir that is operated for conservation and flood control may vary seasonally with varying hydrologic conditions. When flood control requirements conflict seriously with conservation needs it may be necessary to compromise and reduce the degree of flood protect subjected to non-damaging releases in respect of downstream control points. A complete evaluation of a plan of operation could theretically be made if regulation of the reservoir were studied with a specific forecasting model. In order to evaluate any plan of operation, it is necessary to integrate the effects of all combination of conditions and flood magnitude that can prevail. The normal method of evaluation is to route all observed, and estimated floods through the reservoir for different stipulated initial levels which may be varying on a tendaily or monthly basis.

Flood forecasting using rainfall-runoff modelling and the required data is yet to be introduced for most of the Indian basins. Even in those systems where forecasting models are developed and used the performance of the models are not satisfactory because of the failure due to :

i) Communication system to convey the upstream reading during monsoon,

ii) Gauging during monsoon floods,

iii) Unaccounting of contribution of innumerable streams which directly enter into the artificial Lake and

iv) Unaccounting of direct precipitation over lake in the case of heavy downpour.

Hence a procedure is identified and programmed here to route the flood of different magnitudes at different elevation. The theory is based on the recession storage procedure(suggested by the U.S.Army Corps of Engineers). While no forecasting is adopted the inflow is extrapolated as per the slope of the hydrograph of the previous period and corrected towards the end of the period. Maximum safe release is included as a constraint to the spillway discharge.

1.1 Purpose and Capabilities

At present no generalised procedure for flood routing through reservoir are available. Whenever occassions arised flood regulation studies were made on a system specific basis and and often revised. And in certain cases where detail studies were not made routing have been carried out on the basis of outflow equal to inflow without making use of the potential created.

Here a procedure is programmed for the construction of spillway gate regulation curve which would assure that the reservoir operation to comply with the required conditions. This procedure can be used both in the planning and operation stage of a reservoir to analyse the spillway capacity required and the difrerent level that should be maintained during high flood period. During operation period a spillway regulation curve which shows the releases for different flood magnitudes at different levels can be evaluated for the ready reference to the spillway operator. It is capable of coping with both FPS and MKS units.

1.2 Terminology

Recession Storage

Recession storage is defined as the volume of water that will be brought by the flood during its recession limb of flood hydrograph.

Recession Constant

It is a constant having units of time and indicates the rate of exponential decay of the flood.

FRL

The FRL is termed as the maximum conservation pool level that will be maintained in a reservoir.

MWL

The MWL is termed as the top of surcharge - water level.

Induced surcharge storage

Induced surcharge is the storage above the FRL(static pool level) and below MWL.

1.3 Scope

The reservoir storage meant for flood control should not cause damage either to the structure or the downstream centres. In the case of projects, which are completed, this space can be utilised even when there is no forecasting of flood to assure the protection for downstream centres. Depending upon the magnitude and frequency of flood during monsoon , the degree of protection to the down stream will vary. The scope of the study is to provice a methodology to the spillway operator at the reservoir site for the operation of the gates to release the flood as to ensure the least possible damage considering the conservation as well as flood control.

2.0 METHODOLOGY

2.1 Formulation

The flood cushion space required by any reservoir is determined by routing a specific observed or hypothetical design flood. The initial level and the reservoir can be chosen either from the maximum storage that could reasonably be anticipated as per the working table of the reservoir or a compromise of the above and the anticipated flood. Normally this initial level for flood computations would be the top of conservation pool (FRL) or slightly below FRL with minor seasonal variations (which includes storage required for all purposes other than flood control). The releases made during flood are bounded generally by outlet capacity of the spillway and the maximum feasible target flows that do not produce serious flood damage at the downstream control points. Here a methodology for flood regulation based on U.S.Army corps of Engineers is programmed to help the designers and operators during pre and post reservoir conditions.

Assumption

The assumptions made while evaluating the procedure for flood regulation through the spillway are :

i) The slope of the flood hydrograph for the period under consideration is the same as the previous period.

ii) At no stage the water level in the reservoir shall exceed MWL

iii) Releases are made to allow gradual opening of gates to their full capacity (corresponding to non damaging release)

iv) Reservoir space provided for flood control would be held empty during flood potential periods.

v) Releases are restricted to the current inflow (when the flood rises), the maximum downstream channel capacity and the spillway free flow capacity.

Induced surcharge operation is adopted to exercise partial control over outflow rates after the reservoir has filled to the top of conservation pool level. Regulation is accomplished by raising all gates by small increments, forcing the inflow in excess of the discharge capacity of the specific gate openings as induced surcharge. and volume of induced surcharge will vary with the volume and rate of inflow and schedule of gate operation during individual floods. The maximum elevation of induced surcharge that is practicable to provide in the design of projects involving gated spillways is limited to the MWL.

The step by step procedure to be followed to decide the releases (Q_2) are as follows:

Case 1 :

When the flood raises i.e. when the water level is in between FRL and MWL.

i) construct an induced surcharge envelope curve within the range of the non-damaging release as well as at whithin the maximum permissible induced surcharge elevation (Fig.1 shows a typical induced surcharge envelope curve). The curve would permit lower release rate in the lower surcharge ranges. Once it reaches the maximum safe release the curve becomes a straight line parallel to the ordinate.

$\underline{Q_2}$

ii) Assume the initial release (Q_2) to be zero or equal to the down stream minimum requirement.

iii) Compute the expected inflow (Q_1) as per assumption i form the flood hydrograph.

iv) Compute the amount of water that goes, into storage (ΔQ) i.e. $\Delta Q = Q_1 - Q_2$

v) Determine the elevation corresponding to the amount of water retained in storage (ΔQ)

vi) From the induced surcharge enveloping curve, find the amount of water to be released corresponding to the level computed in step (V)

vii) Compute the recession constant as follows

The recession constant T_s may be obtained by plotting the recession curve as a straightline on a semilog paper with the flow on a logarithmic scale and time on arithmetic scale. For this purpose the historical flood hydrographs must be used. According to unit hydrograph theory, this recession constant has to be the same for all the floods for a particular basin. However, it is observed that there will be variation for

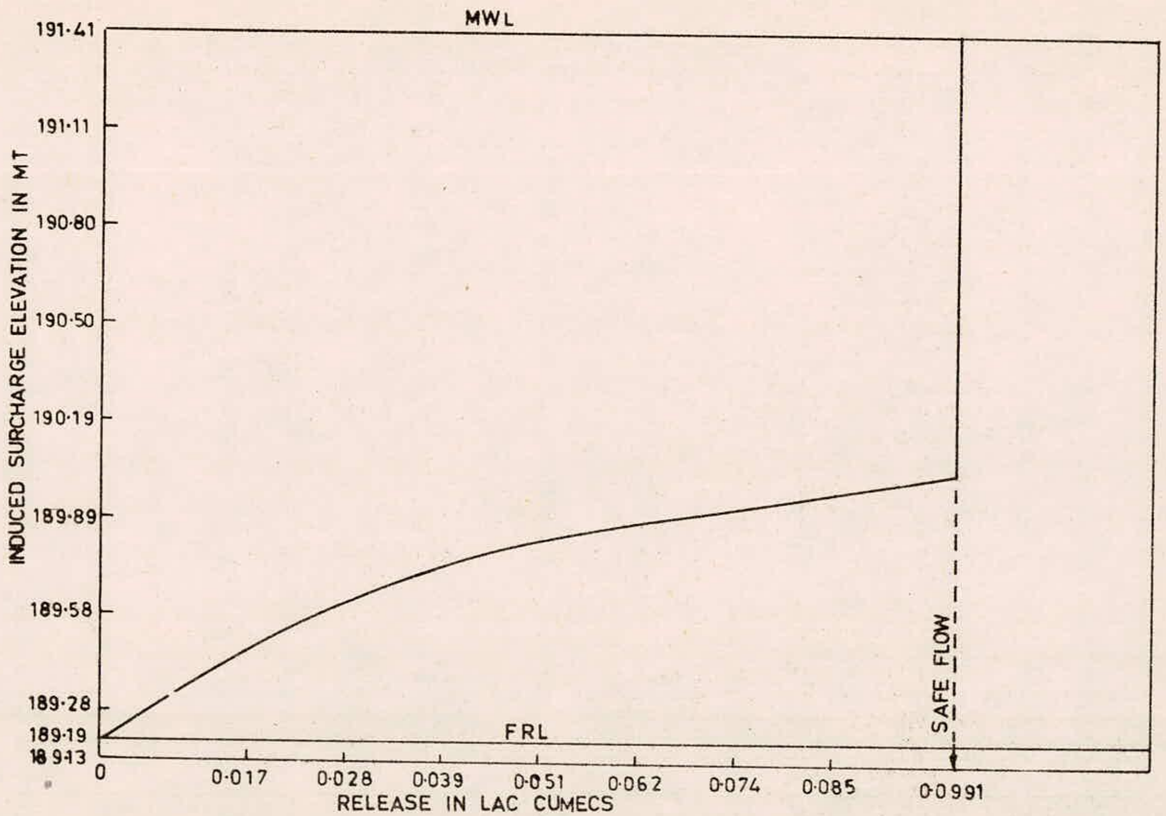

FIG.1 A TYPICAL INDUCED SURCHARGE ENVELOPE CURVE FOR A RESERVOIR 189·19 MT FRL AND MWL 191·41 MT

different floods and it is preferable to use the maximum value of T_s, thus computed for different floods.

viii) By knowing the inflow(Q_1) outflow (Q_2) as per step No.6 and recession constant (T_s), compute the recession storage 'SA' from the equation given below :

$$SA = C\, T_s \left[Q_1 - Q_2 \quad (1 + \log_e \frac{Q_1}{Q_2}) \right] \qquad \ldots(1)$$

where,

SA = recession storage in volume unit

Q_1 = inflow rate in flow units

Q_2 = outflow in flow units

T_s = recession constant, giving rate of logarithmic decay of the flood with time(hours) as the unit

C = conversion constant

Releases have to be decided on the basis of the recession storage that would have brought by the flood during its recession limb, reservoir level and the rate of inflow at the moment. The volume of recession that must be stored for a hydrograph receeded from an initial inflow to a constant outflow is derived by the U.S.Army Corps of Engineers as given in Equation 1.

ix) Compute the difference between Q_1 and the Q_2 obtained from Step No. (vi) (ΔQ_1)

x) Compare ΔQ_1 with SA

xi) If Q_1 is comparable with SA (0.5%) then the computed Q_2 from Step No.(vi) be retained.

xii) If Q_1 is either higher or lower than SA, repeat step no. (vi) to (x)

Case 2 a. When the flood receeds: but when the water level is inbetween M W L and F R L.
Retain the maximum gate opened until the pool elevation falls below the top of conservation (F R L)

Case 2 b. When the flood receeds and when the water level is below FRL. Decide the release on the basis of the average of the previous release and the expected in flow as per assumption (i).
In the above two cases releases are subjected to, the maximum safe release (FMAX).

Case 3. When the reservoir level raises above MWL. Decide release on the basis of storage indication routing (i.e. spillway free flow).

2.2 Data Requirement

The data required for the computer programme are induced surcharge envelope curve as a table of releases and levels spillway discharge for different levels at full gate opening, the flood hydrograph and different operation levels like F R L, M W L and starting level.

2.3 Analysis

Reservoirs which are operated for both conservation and flood are normally filled step by step during monsoon and full level is maintained towards the end of monsoon. For an expected flood of given magnitude, this method could be used to ascertain the initial level of reservoir that must be maintained from the known maximum safe release or vice-versa. Thus a reservoir requires different induced surcharge envelope curve for different periods of the monsoon/initial level, which will be of great help for an operator. For different inflows and levels reservoir releases could be computed through the step by step method explained above. Hence it is possible to construct a spillway regulation curve to find out release based on various inflow rates and reservoir levels. Figure 2 shows a typical spillway regulation curve corresponding to the induced surcharge curve given in Figure 1. Thus, it can be used to decide upon the spillway capacity for reservoirs during planning stage and after construction it serves as a ready reckner to the spillway operation.

2.4 Advantages and Limitations

The computational procedure and structuring of the programme is very simple. It is advantageous to use this method where spillway operation must not be dependent on communications which are likely to fail. The resultant spillway regulation curve will be handy even if the spillway operator is inexperienced. However, the programme does not consider the local runoff that may occur between the reservoir and the downstream control point, while computing the maximum safe release.

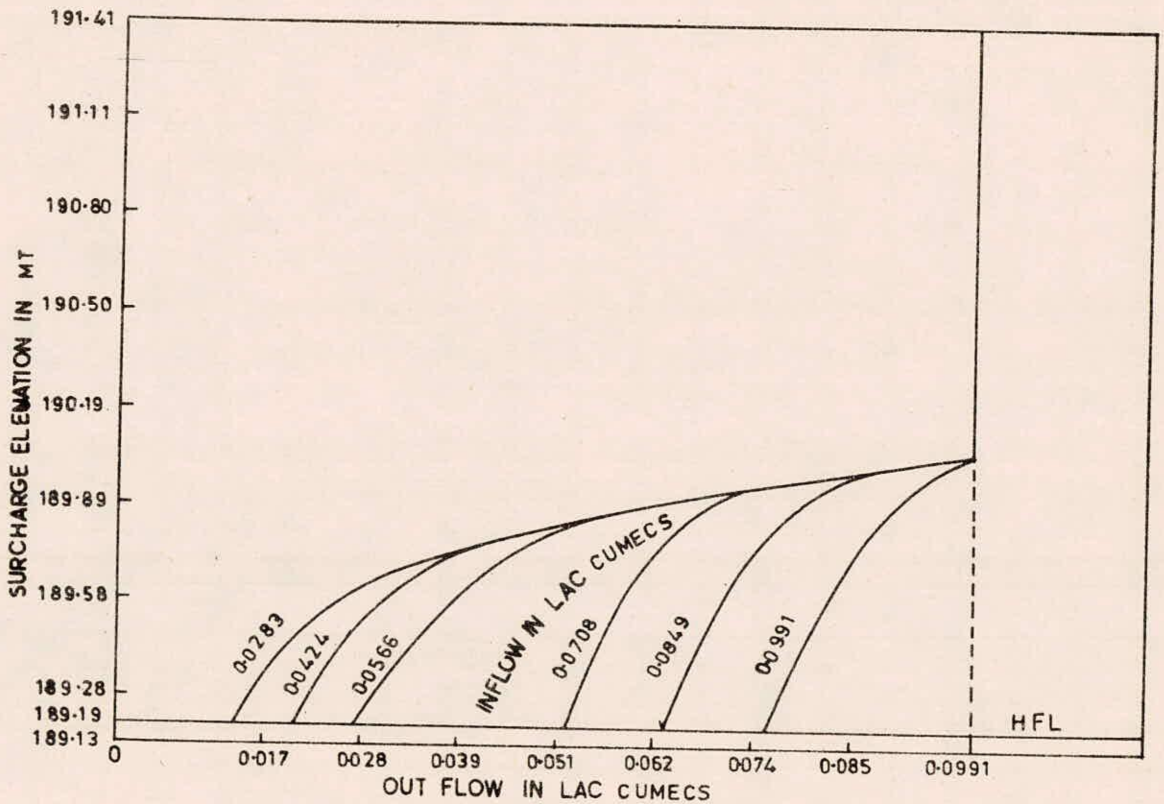

FIG 2 A TYPICAL SPILLWAY REGULATION CURVE FOR A RESERVOIR OF 181·19 MT FRL AND 191·41 MT MWL

3.0 RECOMMENDATIONS

This procedure is recommended for reservoirs where either forecasting is not available or subjected to failure. Alternative spillway capacities can be analysed for variable flood magnitudes and levels in a short interval of time.

REFERENCES

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2. Boopathy Dhason,S.R.(1984),' Reservoir Operation Study for Bhakra-Beas system' Case Study-4, National Institute of Hydrology,Roorkee.

3. Hydrological Engineering Center (1966),' Spillway Rating and Flood Routing', Sacremento,USA.

4. Hydrological Engineering Center,(1975),' Flood Control by Reservoirs', Davis,USA.

a) Computer Programme

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C       FLOOD ROUTING THROUGH GATTED RESERVOIR
      DIMENSION ELEV(40),Q(50)
      DIMENSION CT(40),IPERSR(10),IPERDQ(10),ZINFL(120)
        OPEN(UNIT=1,FILE='SPILL.DAT',STATUS='OLD')
 10   FORMAT(40A2)
        DO 20 I=1,3
      READ (1,10)(Q(N), N= 1, 40)
 20   PRINT 10,  (Q(N),N=1,40)
      PRINT 200
30    FORMAT(1X,I7,9I8)
 40   FORMAT (1X,F7.0,9F8.0)
      READ(1,50)(IPERSR(N), N= 1, 10)
      READ(1,50)(IPERDQ(N), N= 1, 10)
 50   FORMAT(10I8)
      READ(1,30) NUMQ,METRIC
      IF(METRIC)60,60,70
 60   CON1=64.4
      CON2=5.67
      CON3=12.1
      CON4=1.9835
      CON5=.005
      CON6=1.0
      GO TO 80
 70   CON1=19.64
      CON2=(9.82)**.5
      CON3=.278
      CON4=86.5
      CON5=1.235*.005
      CON6=.5523
 80   READ (1,100) NUMEL, NUMIN
      IF(NUMEL)90,90,110
 90   STOP
 100  FORMAT (1X,I7,I8)
 110   READ(1,40) (ELEV(I), CT(I), I=1,NUMEL)
      ELMAX=ELEV(NUMEL)
      READ(1,40)(Q(N),N=1,NUMQ)
      READ(1,40)(ZINFL(I), I=1, NUMIN )
      READ(1,40)ELTOP, ELTFC, STFC, ELST, PER, TIME, CHCAP
      TTIME=TIME
      READ(1,40)ELTSUR, ELSURO, QSURO, TS
      READ(1,120)NGATES,SPWID,FMAX,ELSPI
 120    FORMAT(1X,I7,9F8.0)
      TTS=TS
        IF(METRIC) 140,140,160
 140    PRINT 150,ELSURO,ELTSUR,ELSPI,ELST,PER,TS
 150    FORMAT(2X,'FULL RESERVOIR LEVEL IN FEET =',F7.2,5X,'MAXIMUM WATER
     1 LEVEL IN FEET ',F7.2//
     12X,'CREST LEVEL IN FEET            =',F7.2,5X,'STARTING LEVEL IN FE
     2ET  =',F7.2//
     32X,'ROUTING INTERVAL IN HOURS      =',F7.2,5X,'RECESSION CONSTANT I
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```
   4N HOURS=',F7.2//)
      GO TO 180
160   PRINT 170,ELSURO,ELTSUR,ELSPI,ELST,PER,TS
170   FORMAT(2X,'FULL RESERVOIR LEVEL IN METER=',F7.2,5X,'MAXIMUM WATER
   1 LEVEL IN METER',F7.2//
   12X,'CREST LEVEL IN METER          =',F7.2,5X,'STARTING LEVEL IN ME
   2 =',F7.2//
   32X,'OUTING INTERVAL IN HOURS      =',F7.2,5X,'RECESSION CONSTANT IN
   4 HOURS=',F7.2//)
180   DO 190 I=1,NUMQ
190   Q(I)=Q(I)*NGATES
200  FORMAT (1H0)
210  FORMAT (8F10.2)
     PRINT 200
     ISTPUL=10
     TIME=TTIME
     TS=TTS
     PQC=1.
     N=1
     I=1
     ZMAXWS=0.0
     QIN=0.0
     A=0.0
     PEL=0.0
     PQIN=0.0
      PPQIN=0.00
     QCAVE=0.0
     PQAV=0.0
     FINSUR=10.
     TRYTOP=0.0
     PQPGO=0.0
     ICASE=0
     ELAS=ELST
     IXY=0
     QFREE=999999.
     PQFREE=999999.
     INDPGO=0
     MXQPGO=0
       FINSUR=0.0
     TS=TS/24.
     X=ELSURO
220  DO 230 N=1,NUMEL
     IF(ELEV(N)-X)230,230,240
230  CONTINUE
240  RATIO=(X-ELEV(N-1))/(ELEV(N)-ELEV(N-1))
     QTOPSR=RATIO*(Q(N)-Q(N-1))+Q(N-1)
     STGTSR=RATIO*(CT(N)-CT(N-1))+CT(N-1)
     IF(X-ELSURO)250,250,260
250  TQBSR=QTOPSR
     X=ELTSUR
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      CTNSRO=STGTSR
      GO TO 220
260   PRINT 200
270   TRACE=1.
      IF(ELAS-ELEV(1))280,300,300
280   PRINT 290
290   FORMAT ( 10H STOP  730)
      PRINT 210,    ELAS,ELEV(1)
      GO TO 1660
300   IF(ELTOP-ELAS)310,320,320
310   PRINT 200
      GO TO 1660
320   DO 330 N=1,NUMEL
      IF(ELAS-ELEV(N))340,330,330
330   CONTINUE
340   X=ELEV(N)
      Y=ELEV(N-1)
      RATIO=(ELAS-Y)/(X-Y)
      STG=(CT(N)-CT(N-1))*RATIO+CT(N-1)
      IF(Y-ELSPI)360,350,350
350   QN=Q(N)
      QNM1=Q(N-1)
      GO TO 400
360   IF(X-ELSPI)350,350,370
370   IF(ELAS-ELSPI)380,390,390
380   QN=CQELSP
      QNM1=Q(N-1)
      X=ELSPI
      GO TO 400
390   QN=Q(N)
      QNM1=CQELSP
      Y=ELSPI
400   IF(FINSUR)430,410,430
410   IF(I-1)420,420, 990
420   PQC=QSURO
      QC=QSURO
      GO TO 440
430   RATIO=(ELAS-Y)/(X-Y)
      QC=(QN-QNM1) *RATIO+QNM1
      STIND=QC*.5+STG*CON3/PER
      NSTIND = N
      IF(I-1)440,440,800
440   INDSTR=0
      IF(ZINFL(I)-QC)470,470,450
450   QIN=0.0
      TIME=TIME-PER
      GO TO 490
460   TIME=TIME+PER
470   QIN=ZINFL(I)
      I=I+1
```

```
      IF(I-NUMIN)480,480,1660
 480  IF(ZINFL(I)-QC)460,460,490
 490  CUMSTG=STG
      QCAVE=0.0
      SA=0.0
      CSA=0.0
      ELAS=0.0
      STG=0.0
      ELEVC=ELST
      IF(FINSUR)1150, 980,500
 500  PRINT 510
      PRINT 520
      PRINT 530
      ISTPUL=0
 510  FORMAT(' TIME  AC.INFLOW  AS.INFLOW OUTFLOW  OUTFLOW')
 520  FORMAT(' HOURS     AV         AV        AV    END PER  S+Q/2   CAPAC
     1TY  POLL.EL  AS.STORAGE     ACTUAL')
 530  FORMAT(10X,' CFS        CFS        CFS     CFS    END PER  END PER  E
     1ND PER                POLL.EL')
      IF(INDSTR)720,720,540
 540  PQC=PQFREE
      ELAS=PEL
      GO TO 270
 550  INDPGO=0
 560  CUMSTG=PCUMST+(QIN-QCAVE)*PER/CON3
      DO 570 N=1,NUMEL
      IF(CT(N)-CUMSTG)570,570,590
 570  CONTINUE
      PRINT 580
 580  FORMAT (13H EXTEND TABLE)
      XN=N
      PRINT 210,  ELAS,XN,CT(N),CUMSTG
      GO TO 1660
 590  RATIO=(CUMSTG-CT(N-1))/(CT(N)-CT(N-1))
      ELEVC=(ELEV(N)-ELEV(N-1))*RATIO+ELEV(N-1)
      QFREE=(Q(N)-Q(N-1))*RATIO+Q(N-1)
      QAFREE=(QFREE+PQFREE)*.5
        IF(QAFREE.GT.FMAX) QAFREE=FMAX
      IF(INDPGO)1150,600,1090
 600  IF(ELEVC-ELTSUR-.001)630,630,610
 610  TRYTOP=TRYTOP+1.
      IF(TRYTOP-3.)620,620,650
 620  QCAVE=QIN+(PCUMST-STGTSR)*CON3/PER
      QC=QCAVE
      ICASE= 6
      GO TO 550
 630  IF(QAFREE-QCAVE)640,660,660
 640  QC=QAFREE
      QCAVE=QAFREE
      ICASE=7
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```
      GO TO 560
650   FINSUR=10.
      INDSTR=10
      PRINT 200
      PRINT 200
      GO TO 490
660   TIME=TIME+PER
670   FORMAT(I4,3F9.0,3F10.0,2X,F10.0,2X,F9.2,I6,2X,2F10.2)
680   IT=TIME
        ACUMSTG=CUMSTG
        CUMSTG=CUMSTG+(((AQIN-QIN)*PER)/CON3)
        DO 690 N=1,NUMEL
        IF(CT(N)-CUMSTG) 690,690,700
690     CONTINUE
700    RATIO=(CUMSTG-CT(N-1))/(CT(N)-CT(N-1))
      ELEVA=(ELEV(N)-ELEV(N-1))*RATIO+ELEV(N-1)
      PRINT 670,IT,AQIN,QIN,QCAVE,STG,SA,CSA,CUMSTG,ELEVC,ICASE,ACUMSTG
     1,ELEVA
      GO TO 760
710   TIME=TIME+PER
720   IT=TIME
        ACUMSTG=CUMSTG
        CUMSTG=CUMSTG+(((AQIN-QIN)*PER)/CON3)
        DO 730 N=1,NUMEL
        IF(CT(N)-CUMSTG) 730,730,740
730     CONTINUE
740   RATIO=(CUMSTG-CT(N-1))/(CT(N)-CT(N-1))
      ELEVA=(ELEV(N)-ELEV(N-1))*RATIO+ELEV(N-1)
      PRINT 750,IT,AQIN,QIN,QCAVE,QC,STIND,CUMSTG,ELEVC,ACUMSTG,ELEVA
      ISTPUL=10
750   FORMAT (I4,2X,4F9.0,2F10.0,F9.2,F9.0,F9.2)
760   PCUMST=CUMSTG
      PQC=QC
        PPQIN=PQIN
        IF(I.LE.2) PPQIN=ZINFL(I)
        PQIN=AQIN
      ELAS=ELEVA
      TRIAL=1.
      PQFREE=QFREE
      GUESS=0.0
      PQAV=QCAVE
      PEL=ELEVC
      TRYTOP=0.0
      INDPGO=0
      NSTIND=0
      IF(ZMAXWS-ELEVC)770,780,780
770   ZMAXWS=ELEVC
780   IF(I-NUMIN)790,790,1660
790   QIN=PQIN+(((PQIN-PPQIN)/PPQIN)*PQIN)
        IF(I.EQ.2) QIN=ZINFL(1)
```

```
      AQIN=ZINFL(I)
     I=I+1
     IF(FINSUR)270,270,800
800  TEMP=STIND
     STIND=STIND-QC+QIN
     IF(STIND-TEMP) 820, 810, 810
 810  N=NSTIND
     GO TO  830
 820  N=NSTIND-3
 830  IF(N-1) 840, 840, 850
 840  N=2
 850  XSIND =.5*Q(N-1)+CT(N-1)*12.1/PER
 860  PXSIND=XSIND
     XSIND=.5*Q(N)+CT(N)*CON3/PER
     IF(XSIND-STIND)870,870, 880
870  N=N+1
     IF(N-NUMQ) 860, 860, 900
880  IF(PXSIND-STIND) 920, 920, 890
 890 N=1
     GO TO  860
 900 PRINT  910
 910 FORMAT(/20H RATING EXTRAPOLATED/)
     N=NUMQ
 920 RATIO=(STIND-PXSIND)/(XSIND-PXSIND)
     NSTIND=N
     QC= Q(N-1)+RATIO*(Q(N)-Q(N-1))
     ELEVC=ELEV(N-1)+RATIO*(ELEV(N)-ELEV(N-1))
     QCAVE=.5*(QC+PQC)
     CUMSTG=CT(N-1)+RATIO*(CT(N)-CT(N-1))
     IF(PEL-ELTSUR) 930,710,710
 930 IF(ISTPUL)710,710, 940
 940 FINSUR=0.0
     INDSTR =10
     PRINT  200
     GO TO  980
 950 FORMAT(' TIME AC.INFLOW AS.INFLOW  OUTFLOW  STG-IND  STORAGE   ST
    1ORAGE     RESER.  RESERVOIR',10X,7HASSUMED)
 960 FORMAT(' HOURS     AV          AV          AV          SUR     AVAIL.     A
    1VAIL.     CAPAC.  POOL ELEV  ICASE',2X,9HRESERVOIR)
 970 FORMAT(9X,' CFS        CFS        CFS       CURVE    ASSUM.     COMP.
    1  END  PD.  END  PD ',10X,7HSTORAGE)
 980 PRINT  950
     PRINT  960
     PRINT  970
     PRINT 200
     IF(INDSTR)260,680,260
 990 ITRY=1
     IF(QIN-PQAV)1000,1170,1170
1000 IF(ELEVC-ELTFC)1110,1110,1140
1010 IF(QCAVE-PQAV)1020,550,550
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1020 IF(QIN-PQIN)1050,1030,1040
1030 IF(PQPGO)1050,1040,1050
1040 IF(PQAV-CHCAP)550,1120,1050
1050 IF(INDPGO)550,1060,550
1060 HEAD=ELEVC-ELSPI-2.0
     N=1
     STG=0.
1070 XD=PQAV/(((CON1*HEAD)**.5)*SPWID)
     HEAD=ELEVC-ELSPI-.5*XD
     N=N+1
     IF(N-5)1070,1080,1080
1080  N=1
     INDPGO=10
     ICASE=3
     QCAVE=PQAV
     GO TO 560
1090 H=ELEVC-ELSPI-.5*XD
     QCAVE=((H/HEAD)**.5)*PQAV
     PQPGO=QCAVE
     N=N+1
     IF(N-5)560,1100,1100
1100 IF(ELEVC-ELTFC)1110,1110,1130
1110 QCAVE=(QIN +PQAV)*.5
     ICASE=4
     IF(QCAVE-CHCAP)1120,1120,1130
1120 QCAVE=CHCAP
     ICASE=5
1130 QC=QCAVE
     SA=0.0
     CSA=0.0
     STG=0.0
     GO TO 550
1140 SA=0.
     CSA=0.
     GO TO 1060
1150 PRINT 1160
1160        FORMAT ( 11H STOP 11777)
            GO TO 1660
1170 GUESS=0.0
     QSUR=0.0
     IF(PEL-ELTSUR)1180,1610,1610
1180 IF(QIN-QSURO)1610,1610,1190
1190 QCAVE=QSURO
     ICASE=0
     NTRY=0
     STG=0.0
     ITRY=1
     GO TO 1340
1200 X=CSA+PCUMST
     FTSUR=ELTSUR-ELSURO
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```
      QCAVE=PQAV
1210  N=1
1220  A = IPERDQ(N)
      QSUR = A*.0001*(QTOPSR-QSURO)+QSURO
      IF(QSUR-QCAVE)1230,1230,1280
1230  N=N+1
      IF(N-10)1240,1240,1250
1240  XQSUR=QSUR
      GO TO 1220
1250  QCAVE=QTOPSR
      ICASE=1
      NTRY=NTRY+1
      IF(NTRY-5)1210,1210,1260
1260  SA=0.
      CSA=0.
      STG=0.
1270  IF(QCAVE-QIN)1010,1010,1610
1280  IF(N-1)1290,1290,1300
1290  QCAVE=QSURO
      GO TO 1210
1300  RATIO=(QCAVE-XQSUR)/(QSUR-XQSUR)
      A = IPERSR(N)
      B = IPERSR(N-1)
      SURPER = RATIO*(A-B) + B
      ELSUR=FTSUR*.0001*SURPER+ELSURO
      N=1
1310  IF(ELEV(N)-ELSUR)1320,1330,1330
1320  N=N+1
      IF(N-NUMEL)1310,1310,1270
1330  RATIO=(ELSUR-ELEV(N-1))/(ELEV(N)-ELEV(N-1))
      STG=(CT(N)-CT(N-1))*RATIO+CT(N-1)
      ITRY=ITRY+1
      SA=STG-PCUMST
1340    Q1=(.5-.5/PER)*(QIN-PQIN)+PQIN
      IF(Q1)1350,1350,1360
1350  CSA=0.0
      GO TO 1390
1360  IF(QCAVE)1370,1370,1380
1370  CSA=CON4*TS*Q1
      GO TO 1390
1380  CSA=CON4*TS*(Q1-QCAVE*(1.+ALOG(Q1/QCAVE)))
1390  IF(ITRY-1)1400,1200,1400
1400  X=CSA-SA
      IF(X)1410,1420,1420
1410  X=-X
1420  Y=SA
      IF(Y)1430,1440,1440
1430  Y=-Y
1440  L=X-CON5*Y
      IF(L)1450,1450,1460
```

```
1450 ICASE=2
     GO TO 1270
1460 IF(ITRY-2)1630,1470,1480
1470 XSA=SA
     XCSA=CSA
     XQCAVE=QCAVE
     GO TO 1560
1480 TEMP=QCAVE
     IG=SA
     IF(IG)1510,1490,1510
1490 IF(Q1-QCAVE)1500,1500,1530
1500 ICASE=8
      QCAVE=Q1
     GO TO 1620
1510 IXS=XSA
     IF(IXS)1520,1530,1530
1520 QCAVE=XQCAVE-((XSA*(XQCAVE-QCAVE))/(XSA-SA))
     GO TO 1550
1530 A=(XQCAVE-QCAVE)*(CSA-SA)
     B=(CSA-SA)-(XCSA-XSA)
     QCAVE=A/B+QCAVE
     IF(QCAVE)1540,1540,1550
1540 QCAVE=1.0
1550 XQCAVE=TEMP
     XSA=SA
     XCSA=CSA
     GO TO 1590
1560 IF(QCAVE)1570,1570,1580
1570 QCAVE=1.0
     GO TO 1590
1580 QCAVE=1.1*QCAVE
1590 IF(QCAVE-Q1 )1210,1600,1600
1600 GUESS=GUESS+1.
     IF(GUESS-5.0)1210,1210,1610
1610 QCAVE=Q1
     ICASE=8
1620 SA=0.0
     CSA=0.0
     STG=0.0
     GO TO 1010
1630 PRINT 1640
1640    FORMAT ( 10H STOP STOP)
1660    STOP
     END
*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/*/
```

b) Input Specification

Card No.	Variable	Format	Description
1-3	Q	40 A2	Three heading cards
4	IPERSR	10 I8	Percents of surcharge head in the induced surcharge envelope curve
5	IPERDQ	10 I8	Percents of discharge corresponding to IPERSR in the induced surcharge envelop curve
6	NUMQ	I8	Number of gate discharges
	METRIC	I8	Discharge and storage units 0-For F P S system 1-For M K S system
7	NUMEL	I8	Number of elevation to be read
8	ELEV	F 8.0	Elevation
	CT	F 8.0	Capacity corresponding to ELEV
9	Q	10 F 8.0	Discharge per gate corresponding to ELEV for a total of NUMQ
10	ZINFL	10 F 8.0	Inflow to cusec/cumec as per METRIC A total of NUMIN to be read
11	ELTOP	F 8.0	Maximum elevation for which Q is available
	ELTFC	F 8.0	Elevation of top of flood control pool
	STFC	F 8.0	Storage at ELTFC
	ELST	F 8.0	Starting elevation for the routing

	PER	F 8.0	Period of flood routing in hours
	TIME	F 8.0	Starting time in hours
	CHACAP	F 8.0	Minimum discharge when pool,elevation is receeding
12	ELTSUR	F 8.0	Elevation of top of induced surcharge (M W L)
	ELSURO	F 8.0	Elevation of bottom of induced surcharge (top of conservation sotrage(FRL)
	QSRO	F 8.0	Discharge at ELSURO
	TS	F 8.0	Recession constant in hours
13	NGATES	F 8.0	Number of gates
	SPWID	F 8.0	Spillway apron width
	FMAX	F 8.0	Maximum safe channel carrying capacity
	ELSPI	F 8.0	Spillway crest elevation

c) Output Description

All important reservoir parameters are printed out. Details of inflow, outflow, reservoir levels and storage are printed at the end of every time period as shown in the output example problem. Under the head ICASE different type of routings are coded. The codings and their details are as given below :

Case	Release criteria
1.	Release based on top of induced surcharge pool since spillway capacity to satisfy induced surcharge envelope curve is slightly greather than the former.
2.	Release based on induced surcharge envelope curve.

3) Release based on discharge resulting from maintaining maximum gate opening until top of conservation pool is reached since flood receeds.

4) Release based on average of previous periods release and current inflow since pool elevation is below top of conservation pool (F R L) and is falling.

5) Release based on minimum down stream requirement since inflow is less than CHCAP and pool level is below (FRL) top of conservation pool.

6) Release based on bringing pool elevation down to top of induced surcharge pool (MWL) exactly at the end of the period.

7) Release based on free flow subjected to a maximum of FMAX discharge since gate regulation release is greater than free flow.

8) Release based on not exceeding the average inflow for the last one hour.

d) Example application

The example problem given here shows flood regulation through a multipurpose reservoir that operates for conservation and flood control. The top of conservation storage (FRL) that is also the bottom of induced surcharge is at an elevation of 189.19 mt (620.70 ft). The top of induced surcharge (MWL) is an elevation of 191.41 (628.00 ft). The objective is to moderate a incoming flood hydrograph with a peak of 0.142 laccumea (5 lac cusecs) to 0.0991 cumecs (3.5 lac cusecs) to the down stream from an starting elevation of 189.13 mt (620.66 ft).

The final induced surcharge envelope curve between pool levels 189.19 mt(620.70 ft) and 191.41 mt (628.00 ft) that routs the incoming flood to the down stream subjected to a maximum of 0.0991 lac cumecs (3.5 lac cusecs) and at the same time not allowing the pool level above MWL (628.00 ft) is shown in Figure 1. The curve would permit lower release rate in the lower surcharge ranges. Once it reached the maximum safe release the curve is asymptotic to the elevation axis. It means after this corresponding surcharge elevation no more increase in releases are permitted to any further rise of routings at various levels and trends of inflow are printed in the output shown. The routing is performed on an hourly basis with a recession constant of 13 hours.

e) Example Problem input and output

```
                 NATIONAL  INSTITUTE OF   HYDROLOGY ** ROORKEE
                      EXAMPLE  RESERVOIR  FLOOD STUDY
                 12  GATES OF 49'*35'   CREST LEVEL AT 587
      0     600    1500    2100    2500    3124    3600    3900    3900    4000
      0    1000    2000    3000    4000    6000    8000   10000   10000   10000
     22       0
     29      85
    560   45000     580  120000     590  191000     594  230000     600  299000
    605  373000     610  462000     615  565000     617  610000  618.31  641118
 619.38  668460  619.69  676219     620  682000  620.41  694378  620.70  703676
    622  736000     623  760000     624  788000     625 0815000     626  840000
    627  870000     628  900000     629  930000     630  962000     631  994000
    632 1026000     633 1059000     634 1092000     635 1125000
     00      00    1200    3200    7800   13020   19250   26300   29900   31927
  33773   34321   34870   35482   35941   37600   39360   41120   42890   44670
  46560   48440
 13077.  17066.  21054.  27200.  33346.  39656.  45966.  51981.  57997.  64143.
 70354.  76337.  82320.  87943.  93566.  98535. 103505. 107951. 112397. 116124.
119851. 124134. 128416. 133484. 138551. 142409. 146267. 154538. 162809. 169282.
175755. 189061. 202367. 216719. 231071. 252910. 274748. 324278. 373807. 419413.
465019. 481104. 497188. 498594. 500000. 491500. 483000. 468942. 454884. 435171.
415457. 391493. 367530. 343076. 318622. 293808. 268994. 246600. 224206. 203380.
182555. 164084. 145613. 134072. 122532. 108997.  95462.  84151.  72839.  65843.
 58847.  51981.  45116.  37959.  30803.  26223.  21642.  19746.  17850.  16444.
 15039.  14450.  13862.  13469.  13077.
    628     622  736000  620.66       1       1     000
 628.00  620.70     000      13
     12     588  350000     587
```

NATIONAL INSTITUTE OF HYDROLOGY ** ROORKEE
EXAMPLE RESERVOIR FLOOD STUDY
12 GATES OF 49'*35' CREST LEVEL AT 587

0

FULL RESERVOIR LEVEL IN FEET = 620.70   MAXIMUM WATER LEVEL IN FEET 628.00

CREST LEVEL IN FEET = 587.00   STARTING LEVEL IN FEET = 620.66

ROUTING INTERVAL IN HOURS = 1.00   RECESSION CONSTANT IN HOURS= 13.00

0
0

TIME HOURS	AC.INFLOW AV CFS	AS.INFLOW AV CFS	OUTFLOW AV CFS	STG-IND SUR CURVE	STORAGE AVAIL. ASSUM.	ST ORAGE AVAIL. COMP.	RESER. CAPAC. END PD.	RESERVOIR POOL ELEV END PD ASSU	ICASE	ASSUMED RESERVOIR STORAGE	RESERVOIR POOL ELEV END PD ACT
0											
0	0.	0.	0.	0.	0.	0.	702392.	620.66	0	702392.44	620.66
1	13077.	0.	0.	0.	0.	0.	703473.	620.66	8	702392.44	620.69
2	17066.	13077.	7377.	705059.	1585.	1587.	704274.	620.71	2	703944.31	620.72
3	21054.	22272.	10793.	705698.	1424.	1426.	705122.	620.76	2	705222.63	620.76
4	27200.	25974.	14433.	706380.	1258.	1259.	706177.	620.80	2	706075.81	620.80
5	33346.	35140.	19769.	707381.	1203.	1206.	707299.	620.85	2	707447.50	620.85
6	39656.	40881.	25342.	708425.	1125.	1126.	708482.	620.90	2	708583.44	620.89
7	45966.	47160.	31211.	709523.	1041.	1043.	709702.	620.95	2	709800.38	620.94
8	51981.	53280.	37239.	710653.	951.	953.	710920.	621.00	2	711027.44	620.99
9	57997.	58783.	43188.	711768.	848.	848.	712144.	621.04	2	712208.94	621.04
10	64143.	64709.	49218.	712897.	753.	753.	713377.	621.09	2	713424.25	621.09
11	70354.	70940.	55370.	714051.	673.	676.	714616.	621.14	2	714664.25	621.14
12	76337.	77166.	60867.	715336.	720.	720.	715894.	621.19	2	715962.88	621.19
13	82320.	82829.	65782.	716719.	824.	823.	717261.	621.25	2	717303.13	621.25
14	87943.	88772.	70900.	718156.	895.	893.	718670.	621.31	2	718738.06	621.30
15	93566.	93950.	75992.	719587.	917.	915.	720122.	621.36	2	720153.69	621.36
16	98535.	99549.	81182.	721045.	923.	922.	721556.	621.42	2	721639.81	621.42
17	103505.	103768.	86127.	722435.	879.	877.	722992.	621.48	2	723014.00	621.48
18	107951.	108726.	91086.	723829.	836.	835.	724386.	621.54	2	724450.06	621.53
19	112397.	112588.	95797.	725154.	767.	764.	725758.	621.59	2	725773.69	621.59
20	116124.	117026.	100467.	726466.	708.	706.	727052.	621.64	2	727126.38	621.64
21	119851.	119975.	104759.	727671.	619.	618.	728299.	621.69	2	728309.31	621.69
22	124134.	123698.	108950.	728850.	551.	550.	729554.	621.74	2	729517.94	621.74
23	128416.	128570.	113320.	730078.	524.	521.	730802.	621.79	2	730814.38	621.79
24	133484.	132846.	118141.	731256.	454.	454.	732070.	621.84	2	732016.88	621.84
25	138551.	138752.	124332.	732417.	347.	345.	733245.	621.89	2	733261.31	621.89
26	142409.	143810.	130227.	733520.	276.	274.	734252.	621.93	2	734367.31	621.93
27	146267.	146374.	135195.	734452.	201.	200.	735167.	621.97	2	735175.44	621.97
28	154538.	150230.	139836.	735322.	155.	154.	736382.	622.00	2	736025.50	622.02
29	162809.	163277.	146755.	736596.	215.	214.	737708.	622.07	2	737747.00	622.07
30	169282.	171523.	154266.	737954.	246.	245.	738949.	622.13	2	739134.56	622.12
31	175755.	176012.	160997.	739171.	222.	221.	740169.	622.17	2	740190.25	622.17
32	189061.	182476.	167646.	740374.	205.	204.	741939.	622.22	2	741394.63	622.25

33	202367.	203374.	179469.	742205.	266.	266.	743831.	622.33	2	743914.56	622.33
34	216719.	216609.	194379.	744002.	171.	172.	745678.	622.40	2	745668.50	622.40
35	231071.	232089.	209392.	745813.	135.	135.	747469.	622.48	2	747553.31	622.48
36	252910.	246373.	224084.	747584.	115.	115.	749852.	622.55	2	749311.31	622.58
37	274748.	276813.	246696.	749934.	82.	83.	752170.	622.68	2	752340.50	622.67
38	324278.	298472.	270797.	752201.	31.	31.	756590.	622.77	2	754456.94	622.86
39	373807.	382737.	318137.	756653.	63.	63.	761191.	623.07	2	761928.50	623.04
40	419413.	430901.	350000.	761213.	23.	23.	766927.	623.28	7	767876.50	623.25
41	465019.	470583.	350000.	0.	0.	0.	776433.	623.60	7	776892.63	623.59
42	481104.	515584.	350000.	0.	0.	0.	787268.	624.08	7	790117.38	623.97
43	497188.	497745.	350000.	0.	0.	0.	799432.	624.43	7	799478.13	624.42
44	498594.	513810.	350000.	0.	0.	0.	811713.	624.92	7	812970.06	624.88
45	500000.	500004.	350000.	0.	0.	0.	824109.	625.36	7	824109.56	625.36
46	491500.	501410.	350000.	0.	0.	0.	835804.	625.86	7	836622.50	625.83
47	483000.	483145.	350000.	0.	0.	0.	846795.	626.23	7	846807.19	626.23
48	468942.	474647.	350000.	0.	0.	0.	856625.	626.57	7	857096.63	626.55
49	454884.	455293.	350000.	0.	0.	0.	865293.	626.84	7	865327.06	626.84
50	435171.	441247.	350000.	0.	0.	0.	872332.	627.09	7	872834.38	627.08
51	415457.	416312.	350000.	0.	0.	0.	877742.	627.26	7	877812.56	627.26
52	391493.	396636.	350000.	0.	0.	0.	881171.	627.39	7	881596.13	627.37
53	367530.	368911.	350000.	0.	0.	0.	882620.	627.42	7	882734.00	627.42
54	343076.	345034.	349910.	0.	0.	0.	882055.	627.41	3	882216.88	627.40
55	318622.	320249.	349463.	0.	0.	0.	879506.	627.32	3	879640.75	627.32
56	293808.	295911.	348680.	0.	0.	0.	874971.	627.17	3	875145.25	627.17
57	268994.	270927.	347544.	0.	0.	0.	868480.	626.95	3	868639.44	626.95
58	246600.	246276.	346071.	0.	0.	0.	860259.	626.67	3	860232.25	626.68
59	224206.	226070.	344354.	0.	0.	0.	850329.	626.35	3	850483.50	626.34
60	203380.	203846.	342257.	0.	0.	0.	838852.	625.96	3	838890.50	625.95
61	182555.	184488.	339500.	0.	0.	0.	825881.	625.44	3	826041.13	625.44
62	164084.	163862.	336439.	0.	0.	0.	811637.	624.87	3	811618.81	624.88
63	145613.	147482.	333342.	0.	0.	0.	796122.	624.31	3	796276.81	624.30
64	134072.	129221.	329993.	0.	0.	0.	779931.	623.70	3	779529.69	623.71
65	122532.	123446.	326741.	0.	0.	0.	763054.	623.11	3	763129.31	623.11
66	108997.	111985.	322743.	0.	0.	0.	745389.	622.40	3	745635.88	622.39
67	95462.	96957.	209850.	0.	0.	0.	735935.	622.00	4	736058.94	622.00
68	84151.	83608.	146729.	0.	0.	0.	730764.	621.79	4	730718.75	621.79
69	72839.	74180.	110454.	0.	0.	0.	727655.	621.67	4	727765.75	621.66
70	65843.	63048.	86751.	0.	0.	0.	725927.	621.59	4	725696.00	621.59
71	58847.	59519.	73135.	0.	0.	0.	724746.	621.55	4	724801.69	621.55
72	51981.	52594.	62865.	0.	0.	0.	723847.	621.51	4	723897.31	621.51
73	45116.	45916.	54390.	0.	0.	0.	723080.	621.48	4	723146.25	621.48
74	37959.	39158.	46774.	0.	0.	0.	722352.	621.46	4	722450.69	621.45
75	30803.	31937.	39356.	0.	0.	0.	721645.	621.43	4	721738.56	621.42
76	26223.	24996.	32176.	0.	0.	0.	721153.	621.40	4	721051.44	621.40
77	21642.	22324.	27250.	0.	0.	0.	720689.	621.39	4	720745.69	621.38
78	19746.	17861.	22556.	0.	0.	0.	720457.	621.37	4	720301.38	621.37
79	17850.	18016.	20286.	0.	0.	0.	720256.	621.37	4	720269.56	621.37
80	16444.	16136.	18211.	0.	0.	0.	720110.	621.36	4	720084.31	621.36
81	15039.	15149.	16680.	0.	0.	0.	719974.	621.36	4	719983.19	621.36
82	14450.	13754.	15217.	0.	0.	0.	719911.	621.35	4	719853.25	621.35

83	13862.	13884.	14551.	0.	0.	0.	719854.	621.35	4	719855.69	621.35
84	13469.	13298.	13924.	0.	0.	0.	719816.	621.35	4	719802.13	621.35
85	13077.	13087.	13506.	0.	0.	0.	719781.	621.35	4	719781.69	621.35