REUSE DRAINAGE WATER PROJECT

A SIMPLIFIED APPROACH TO CALCULATE THE DRAINABLE QUANTITY IN
IRRIGATION PRACTICE

ir. D. Boels

nota

institut voor cultuurtechniek en waterhuishouding, wageningen

REUSE DRAINAGE WATER PROJECT

A SIMPLIFIED APPROACH TO CALCULATE THE DRAINABLE QUANTITY IN IRRIGATION PRACTICE

# C O N T E N T

# 1. INTRODUCTION

To calculate the quantity of water that could potentially be drained it is essential to be informed on the infiltration function and the infiltration opportunity time. The latter is a time period that water infiltrates into the soil. Once knowing the infiltrated quantity. the drainable quantity is that quantity that infiltrates additionally to the quantity required to bring the soil at its field capacity. The infiltration opportunity time resembles the time period from the moment that a surface flow arrives at a certain location untill the standing water layer recedes.

That time period should be short enough as to prevent an anaerobic condition in the rootzone that has an adverse effect on crop growth. This period is called the maximum admissable infiltration opportunity time or ponding period. When more irrigation water is available, the excess quantity is supposed to be drained through a surface system into a drainage canal. That quantity does not effectively contribute to the leaching process.

Irrigation water is conveyed by on-farm channels from an irriga- tion tool to the field plot. Losses could occur due to infiltration.

The latter quantity will contribute to the leaching of the sub- soil.

Rice fields will be treated in a some what different way. Rice is grown while the soil is submerged and that condition should be main- tained.

## 2. APPROACH FOR NON-RICE FIELDS

A known quantity of irrigation water is available. This quantity
is lifted by an irrigation tool with a known capacity and conveyed to
the field. The rate of conveyance losses is known. In the field a
basin or furrow irrigation is practized. This means that the irriga-
tion water is supplied at the head of the field and is allowed to flow
over the soil surface to the tail of the field. In basin irrigation
the soil is submerged at any location, where as in furrow irrigation
only a part of the area is submerged.

The advance speed of the waterfront depends on the nett stream-
size, the surface roughness, the infiltration rate and the rate of
soil cracking.

For the description of the advance speed it is assumed that a
dynamic wave approach is applicable and that accelleration forces can
be neglected. So the sole determinant factor is the waterdepth.

The streamsize is kept constant at any location and equal to some
average.

$$\bar{q} = q_0 - \tfrac{1}{2}.I.L \tag{1}$$

where: $\bar{q}$ = average streamsize, $m^2.sec^{-1}$

$q_0$ = nett streamsize at head of field, $m^2.sec^{-1}$

$I$ = the long term infiltration rate $m.sec^{-1}$

$L$ = length of the field

With a capacity of $Q_0$ $m^3.sec^{-1}$ of the irrigation tool, conveyance
losses of $Q_1$ $m^3.sec^{-1}$ and a width of the field, W, the net streamsize
is defined as:

$$q_0 = \frac{Q_0 - Q_1}{W} \tag{2}$$

The maximum length of a field should be less then:

$$L < \frac{q_0}{I} \tag{3}$$

The infiltration rate normally is high during the first stage where as it decreases rapidly with respect to time.

The cumulative infiltration function shows that a big quantity infiltrates in a short time while later on the additional infiltrated quantity is small but shows an almost linear relationship with respect to time. The cumulative infiltration function is described with:

$$V(t) = c1 + I.t \qquad\qquad (4)$$

where: $V(t)$ = infiltrated quantity at time t, (m)

$\qquad c1$ = constant $\qquad\qquad$ m

On cracking soils the constant c1 is almost equal to the crack-volume per unit area.

The advance speed of the water front can be described with:

$$V = \frac{\bar{q}}{\bar{h} + c1} \qquad\qquad (5)$$

where: $\bar{h}$ = the average waterdepth

The average waterdepth is calculated from:

$$\bar{h} = \left[ \bar{q} \cdot \frac{N}{\sqrt{S_o}} \right]^{3/5} \qquad\qquad (6)$$

with: $N$ = Mannings coefficient

$\qquad S_o$ = slope of energy line.

Now the time moment that the water front advances a certain distance is calculated from:

$$T_{a.x} = \frac{X}{V} \qquad\qquad (7)$$

The recession time is calculated as the sum of the operation time and the time to allow to infiltrate the quantity present at the soil surface when irrigation stops. Calling the operation time To, the above mentioned quantity is:

$$VSO = To.q_o - (To - \tfrac{1}{2} Ta,L + cl) . L \tag{8}$$

and the recession time is now:

$$Tr = To + \frac{VSO}{I.L} \tag{9}$$

To prevent the infiltration opportunity time to exeed the admissable ponding period, Tp, the operation time is restricted to:

$$To < Tr - \frac{VSO}{I.L} \tag{10}$$

or:

$$To \leqslant \frac{I.L}{q_o} (Tp - \tfrac{1}{2} Ta,L) \tag{11}$$

When a quantity Vi is available per unit area, the net quantity available is:

$$Vi.n = Vi \left(1 - \frac{Q_1}{Q_o}\right) . L \tag{12}$$

per unit plot width.

The actual supplied quantity per unit plot width is:

$$Va = Min (Vi.n : (Tp - \tfrac{1}{2} Ta,L) . I . L + cl L) \tag{13}$$

and the operation time is:

$$To = \frac{Va}{q_o} \tag{14}$$

The surface drainage, per unit area is:

$$Vsdr = \frac{Vi,n - Va}{L} + \frac{Q_1}{Q_o} \cdot Vi - \frac{Q_1}{LW} \cdot To \qquad (15)$$

while the conveyance losses are:

$$Vc = To \cdot \frac{Q_1}{W.L} \qquad (16)$$

The saturation deficit preceding the irrigation is denoted by SD and the saturation deficit at field capacity by MF. Drainage occurs when the total infiltration V(t) exceeds the quantity SD-MF so when:

$$V(t) = c1 + I.L > SD - MF \qquad (17)$$

or when:

$$T > \frac{SD - MF - c1}{I} = Tcrit \qquad (18)$$

When the fields are at dead level, the infiltration opportunity time at the head and at the tail of the field have to be examined only.

The infiltration opportunity time is:

at the head of the field $Toh = To + \frac{VSO}{I.L}$ $\qquad (19)$

at the tail of the field $Tot = Toh - Ta,L$ $\qquad (20)$

Three cases can be considered:

case 1: no drainage when Toh < Tcrit and Vd=0

case 2: drainage at any location when Tot > Tcrit

$$Vd = \frac{Va}{L} - SD + MF \qquad (21)$$

case 3: drainage occurs on $0 \leqslant X \leqslant Xd < L$

   when Toh > Tcrit and Tot < Tcrit

The quantity Xd is calculated from:

$$Xd = (Toh - Tcrit) \, V \qquad (22)$$

(V - advance speed water front) and the drainage from:

$$Vd = \tfrac{1}{2} (Toh - Tcrit) \, . \, I \, . \, \frac{Xd}{L} \qquad (23)$$

## 3. DRAINAGE CALCULATION FOR RICE FIELDS

Normally a standing waterlayer is present when irrigation starts. The saturation deficit is then zero by definition. The depth of the standing water layer after irrigation is restricted to a maximum value. Under water shortage conditions, however. no water is left behind on the soil surface and the rice crop will with draw water from the soil. Then a non zero saturation deficit is found preceeding an irrigation.

A surface salt reservoir is defined. containing the salts present in the standing water layer.

When irrigation starts three cases will be distinguished.

case 1. The net quantity of available irrigation water is equal or more then to create a standing water layer of maximum depth. A standing water layer is present.

In this situation the present water layer is drained completely. Then a new water layer is made and the remaining irrigation water is drained too. The surface salt reservoir contains a quantity equal to the depth times the concentration of irrigation water.

case 2. The net quantity of available irrigation water is less than to make a new water layer with maximum depth. A standing water layer is present.

In this case the available net quantity of irrigation water is added to the present standing water layer. A new salt concentration as a result of complete mixing occurs. A quantity is drained to reach at a maximum depth. No drainage occurs when together with the present waterlayer the maximum depth is not obtained.

case 3: there is no standing water layer present preceeding irriga-
    tion. The saturation deficit is greater than zero.

When the net quantity of irrigation water is less or equal to the
saturation deficit, a non rice field condition is met.

Is, however, this quantity more than the saturation deficit, a
standing water layer results after a complete saturation of the soil.
Drainage occurs when the new waterdepth exceeds the maximum depth.


## 4. SIMPLIFIED METHOD TO CALCULATE CRACKVOLUME

On clay soils swelling and shrinkage occurs due to a changing
moisture content. With a saturation deficit SD, a groundwatertable at
a depth G below soil surface when the soil would be fully saturated,
and a subsidence ratio $\epsilon$ the saturation deficit equals:

$$SD = (\Delta\theta + \epsilon) \cdot G \tag{3.1}$$

with: $\Delta\theta$ = average air content $\qquad$ $(m^3 \cdot m^{-3})$

$\qquad \epsilon$ = relative isotropic shrinkage (m/m)

The shrinkage, due to moisture chances is:

$$\epsilon = 1 - \left[\frac{\rho_o}{\rho_o - \Delta\theta \frac{d\rho}{d\theta}}\right]^{1/3} \tag{3.2}$$

with: $\rho_o$ = dry bulk density at saturation $kg \cdot m^{-3}$

$\qquad \frac{d\rho}{d\theta}$ = ratio change dry bulk density and change of moisture
        content

Substituting e.q. 3.2 into e.q. 3.1 results after rearranging:

$$f(\Delta\theta) = 0 = \left(1 + \Delta\theta - \frac{SD}{G}\right)^3 \left(\rho_o - \Delta\theta \frac{DP}{d\theta}\right) - \rho_o \tag{3.3}$$

and $0 < \Delta\theta \leqslant \frac{SD}{G}$

From e.q. 3.3 $\Delta\theta$ is solved, following Newtons method. This method includes that having the value of a function $f(x)$ in x, the function in $x + \Delta x$ is estimated from:

$$f(x+\Delta x) \simeq f(x) + \Delta x \ . \ f'(x)$$

where $f'(n)$ is the first derivative of the function $f(n)$ in x.

If, however, a value of a function is known, but not the related x, an iteration procedure is applied. An estimation of x is made and the value of $\Delta x$ is calculated to obtain the wanted value of the function. F, so:

$$\Delta x \simeq \frac{F - f(x)}{f'(x)}$$

and a better estimation of the root of the function is obtained:

$$x' = x + \Delta x$$

This new estimation is used for an improved estimation.

In one case we have $f(\Delta\theta)$ instead $f(x)$ and $\Delta\theta$ instead of x. Starting with a first estimation of $\Delta\theta=\frac{1}{2}.\frac{SD}{G}$ the improved estimation is calculated from:

$$\Delta\theta' = \Delta\theta + \frac{\rho_0 - (1 + \Delta\theta - \frac{SD}{G})^3 (\rho_0 - \Delta\theta \frac{d\rho}{d\theta})}{3(\rho_0 - \Delta\theta \frac{d\rho}{d\theta})(1 + \Delta\theta - \frac{SD}{G})^2 - \frac{d\rho}{d\theta}(1 + \Delta\theta - \frac{SD}{G})}$$

A solution is acceptable when:

$$\left|\frac{\Delta\theta'-\Delta\theta}{\Delta\theta}\right| < 0.001$$

Once found Δθ, the value for ε if solved from e.q. 3.2 and the crack volume is calculated from:

$$CRACK = \{(1-\epsilon) - (1-\epsilon)^3\} \ G$$

(see e.q. 58a, p 21, BOELS 1986, Nota 1697 ICW).

## 5. VERIFICATION OF THE METHODS

To check the validity of the simplified method a comparison with the more detailed one is presented below.

Three characteristics are compared: the advance time, the total infiltration and the calculated crackvolume.



Fig. 1. Comparison advance time calculated with simplified and detailed approach

a - The advance time

The advance time is calculated for different plot length with both methods. From fig. 1 it can be read that there are no significant differences.

total
Infiltr.

\*

detailed approach,M^2



simplified approach,M^2

Fig. 2. Comparison simplified method with detailed approach for infiltration

b - The total infiltration

The infiltrated quantity per unit plot width is calculated as would occur during the advance time. Fig. 2 shows that no significant differences exists between results obtained from different methods.

Fig. 3. Crack volume calculated with exact and simplified method

c - The crack volume

As the crack volume is related to the third power of the anistropic shrinkage a deviation might be expected when a uniform water distribution is assumed as is done in the simplified method. This distribution is assumed lineair with respect to depth in the more correct method.

The simplified method yields a ± 10% lower crack volume than the more correct method (see fig. 3).

## 6. PROGRAM SET UP

### 6.1. The input

The input comprises time dependent and time independent input data.

#### 6.1.1. Time independent data

This type of data depends probably on crop and soil type.

Table 1. Time independent input

| Variable name | Description | Dimension |
|---|---|---|
| RICECOD | code, tells if crop is rice code=0 then no rice code =1 then rice | - |
| TPO | maximum admissable infiltration opportunity time | days |
| HMAX | maximum depth standing water layer in rice fields | m |
| LP | length field plot | m |
| WDTH | width field plot | m |
| So | plot slope or slope energy line | m/m |
| NMAN | Mannings coefficient for surface roughnes | $(m^{1/3}.sec)^{-1}$ |
| RHO | dry bulk density of the soil at saturation | $kg.m^{-3}$ |
| DRHO | ratio change dry bulk density and change moisture content | $kg.m^{-3}$ |
| MF | saturation deficit at field capacity | m |
| RINFL | long term infiltration rate | m/day |
| CS | capacity irrigation pump | $m^3/sec$ |
| CNL | onfarm conveyance losses | $m^3/sec$ |
| ALFA | factor for furrow or basin irrigation, gives relative wetted during irrigation ALFA=1. - basin irrigation ALFA≈0.7 - furrow irrigation | - |
| DD | draindepth in m below soil surface | m |

## 6.1.2. Time dependent input

The time dependent input data are summarized in table 2.

| Variable name | Description | Dimension |
|---|---|---|
| IGROSS | depth of available irrigation water | m |
| CIRR | salinity of irrigation water | $[EC, ppm.$ $eq.m^{-3}]$ |
| SD | saturation deficit preceeding irrigation | m |
| HSTI | depth standing water layer (RICECODE=1) | m |
| INFSALT | quantity of salt in standing water layer (RICECOD=1) | $[EC.m, ppm.$ $M.eq.m^{-2}]$ |
| H | depth groundwatertable above drainlevel | m |

## 6.2. The output

Table 3. The time dependent output

| Variable name | Description | Dimension |
|---|---|---|
| IGROSS | the net irrigation depth | m |
| VSDR | surface drainage | m |
| VC | conveyance losses (on farm) | m |
| VD | drainage to open field drains or subsurface drains | m |
| HSTI | depth standing water (RICECOD=1) | m |
| INFSALT | quantity of salts in standing waterlayer (RICECOD=1) | $[EC.m, ppm.m$ $eq.m^{-2}]$ |
| QSALT | quantity of surface drained salt | $[EC.m, ppm.m$ $eq.m^{-2}]$ |
| CRACK | crackvolume preceeding irrigation | $m^3.m^{-2}$ |

## 6.3. The program

### 6.3.1. Controlling routine IREFF

The program comprises a controlling routine and several subrou-
tines. The controlling routine, IRREFF, transforms the dimensions of
the infiltration rate into m per sec and of the maximum infiltration
opportunity time in sec. It calculates the depth of the groundwater-
table below soil surface and it sets the crackvolume to zero.

When the RICECOD=1, the conditions for ricefields are met and the
subroutine RICE is called. In other cases the crackvolume is calcula-
ted by subroutine CRVOL, only when it concerns a soil that shows swel-
ling and shrinkage (DRHO<0), and then the surface drainage and drai-
nage to field drains or subsurface drains is calculated by subroutine
IRRAPL.

### 6.3.2. Subroutine RICE

Subroutine RICE first checks if a standing water layer is present.
If not then the saturation deficit is more then zero. When the avai-
lable quantity of irrigation water is equal or more then the satura-
tion deficit, it is assumed that the deficit is replenished and with
the remaining quantity of irrigation water a new standing water layer
is created. If, however, the available quantity of irrigation water is
insufficient for full saturation of the soil, this case is treated
similar to non-ricefields.

When HSTI>0, it is checked if the availabe irrigation water quan-
tity, HR, is more then the maximum standing water layer, HMAX. If so,
the present water layer is drained fully preceeding irrigation. A new
standing water layer with depth of HMAX is created and the excess
irrigation water is drained to the surface drainage system.

If, however, the available quantity of irrigation water is less
then HMAX, the total quantity is added to the present quantity. A com-
plete mixing of irrigation water and present water in the standing
water layer is assumed. All the water is drained to the surface system,
that is present above the quantity present when the depth of the
standing water layer equals HMAX. The salinity is that of the mixed
irrigation water and standing water layer.

### 6.3.3. Subroutine CRVOL

The subroutine CRVOL starts with a first estimation of the average air content in the soil above the groundwatertable (= XKM). Then through an iterative methode the improved estimation of that aircontent (= XKM1) is calculated. When the ratio between the absolute difference between the two successive estimations and the old estimation (ERROR = $\left| \frac{XKM - XKM1}{XKM} \right|$ ) is less than 0.001 the solution is satisfactory.

This generally occurs after three estimations. Then the crackvolume CRACK is calculated.

### 6.3.4. Subroutine IRRAPL

Subroutine IRRAPL starts to calculate the apparent net streamsize, QO. and the infiltration rate, RI. The maximum plotlength, Xe is calculated that might be irrigated. Then the advance time, TADV, is calculated.

The net applied quantity irrigation water, VA, per unit width of the fieldplot is calculated, following e.q. 13. The on farm conveyance losses are simply the results of a multiplication of the time to provid the required irrigation water quantity and the conveyance losses rate.

The surface drainage quantity, VSDR, is the difference between the gross quantity available irrigation water, the net applied irrigation water quantity (eg. Va/LP) and the conveyance losses.

The quantity of drainage to the on farm open drainage of subsurface drainage system, VD, depends on the cases, distinghuished in chapter 1. TINFM coincides with Toh, e.q. 19, and TINF with Tot in e.q. 20.

XD in case 3 (TINFM>TCRIT and TINF<TCRIT) is calculated acc. e.q. 22.

APPENDIX A. Program IRREFF

```
****************************************************************************
*                    IRRIGATION EFFICIENCY PROGRAMME                     *
*                    --------------------------------                    *
* PROGRAMME FOR THE CALCULATION OF IRRIGATION EFFICIENCIES               *
*                                                                        *
* DEFINITIONS                                                            *
* -----------                                                           *
* IGROSS=WATER SUPPLY TO A CROP              M**3/M**2                   *
* WDTH  =PLOT WIDTH                          M                          *
* SO    =ENERGY LINE SLOPE                   M/M                        *
* LP    =PLOT LENGTH                         M                          *
* NMAN  =MANNING'S COEFFICIENT                                          *
* ALFA  =RELATIVE WETTED AREA                                           *
* SD    =SATURATION DEFICIT                  M**3/M**2                  *
* MF    =SATURATION DEFICIT AT FIELD CAPACITY M**3/M**2                 *
* CRACK =CRACK VOLUME                        M**3/M**2                  *
* TPO   =MAXIMUM PONDING TIME                D                         *
* RINFL =INFILTRATION RATE                   M/D                       *
* CS    =IRRIGATION CAPACITY                 M**3/SEC                   *
* CNL   =CONVEYANCE LOSSES                   M**3/SEC                   *
* VSDR  =SURFACE DRAINAGE                    M**3/M**2                  *
* VC    =ON-FARM CONVEYANCE LOSSES           M**3/M**2                  *
* VD    =DRAINABLE QUANTITY                  M**3/M**2                  *
****************************************************************************
        REAL NMAN.MF.LP,INFSALT,MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX
          REAL IGROSS
        INTEGER RICECOD.CROPCOD,SOILCOD
        COMMON /PLOT  / WDTH,LP,SO,NMAN,CS,CNL
        COMMON /MOIST / MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,SD,MF
        COMMON /TIME  / TINTER,TPO,TO
        COMMON /CODE  / CROPCOD,SOILCOD,RICECOD
        COMMON /LEVEL / HSTAND,H,HSTI,HI,HMAX
          COMMON /LENGTH/ DD,RZD,HAQ,DU,DS,DAQ
```

```
        COMMON /RES    / DRSALT,INFSALT,DRWA
        COMMON /IRR    / CRACK,IGROSS,CIRR,DRAIN,VC,VSDR,VD,QSALT
        COMMON /INFL   / ALFA,RINFL,RHO,DRHO
        OPEN (10,FILE='INPUT1.TXT')
          OPEN(20,FILE='OUTPUT1.TXT',STATUS='NEW')
*----------------------------------*
*  READ THE INPUT DATA             *
*----------------------------------*
10      READ (10,100,END=20) IGROSS,CIRR,SD,MF,TPO,RICECOD,HSTI,HMAX,
       /INFSALT,WDTH,LP,SO,NMAN,ALFA,RHO,DRHO,H,DD,RINFL,CS,CNL
100      FORMAT(5F6.4,I6,3F7.4,2F6.2,2F6.4,F4.2,2F7.1,2F5.2,3F7.4)
         RINFL=RINFL/86400
         TPO=TPO*86400
         G=DD-H
         CRACK=0.
        IF (RICECOD .EQ. 1) THEN
                CALL RICE
        ELSE
                IF(DRHO.LT.0.) CALL CRVOL
                CALL IRRAPL
        ENDIF
        WRITE(20,200) IGROSS,VSDR,VC,VD,QSALT,HSTI,INFSALT
200      FORMAT(7F6.4)
         GOTO 10
20       CLOSE (10)
         CLOSE(20)
C        RETURN
        STOP
        END
```

APPENDIX B. Subroutine IRRAPL

```
******************************************************************************
*                          SUBROUTINE IRRAPL                                *
*                          -------------------                              *
* SUBROUTINE FOR THE CALCULATION OF NET APPLICATION VOLUME (VA).            *
* ONFARM CONVEYANCE LOSSES (VC) AND SURFACE DRAINAGE VOLUME (VSDR)          *
******************************************************************************
      SUBROUTINE IRRAPL
      REAL NMAN,MF,LP,INFSALT,MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,
     /IGROSS
      INTEGER RICECOD,CROPCOD,SOILCOD
      COMMON /PLOT   / WDTH,LP,SO,NMAN,CS,CNL
      COMMON /MOIST  / MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,SD,MF
      COMMON /TIME   / TINTER,TPO,TO
      COMMON /CODE   / CROPCOD,SOILCOD,RICECOD
      COMMON /LEVEL  / HSTAND,H,HSTI,HI,HMAX
      COMMON /LENGTH/ DD,RZD,HAQ,DU,DS,DAQ
      COMMON /RES    / DRSALT,INFSALT,DRWA
      COMMON /IRR    / CRACK,IGROSS,CIRR,DRAIN,VC,VSDR,VD,QSALT
      COMMON /INFL   / ALFA,RINFL,RHO,DRHO
C   --------------------------------------------------------------------
      QO=(CS-CNL)/(ALFA*WDTH)
      RI=ALFA*RINFL
      XE=QO/RI
      IF (XE .GT. LP)     XE=LP
        QAVER=QO-.5*RI*XE
        RNSQSO=NMAN/SQRT(SO)
C
C   CALCULATE MAXIMUM OPERATION TIME (TO)
C
      TO=IGROSS*LP*WDTH/CS
        AHSD=(QAVER*RNSQSO)**.6
        ADVSPD=QAVER/(AHSD+CRACK)
        TADV=XE/ADVSPD
```

```
        IF(TO.LT.TADV) THEN
                XE=XE*TO/TADV
                TADV=TO
        ENDIF
        IF(TPO.LT.TADV) THEN
                XE=XE*TPO/TADV
                TADV=TPO
        ENDIF


C  CALCULATE NET APPLICATION VOLUME PER UNIT AREA (VA)
C  ---------------------------------------------------------
C
        Y1=TO*ALFA*QO
        Y2=((TPO-.5*TADV)*RI+CRACK)*XE
        VA=AMIN1(Y1,Y2)
        TO1=VA/(ALFA*QO)
        IGROSS=VA/LP
C  CALCULATE CONVEYANCE LOSSES PER UNIT AREA (VC)
C  ---------------------------------------------------
        VC=TO1*CNL/(WDTH*LP)
C
C  CALCULATE IRRIGATION LOSSES PER UNIT AREA (VSDR)
C  ---------------------------------------------------
        VSDR=(Y1-Y2)/LP +(TO-TO1)*CNL/(LP*WDTH)
        IF(VSDR.LT.0.) VSDR=0.
        QSALT=VSDR*CIRR
C
C  CALCULATE DRAINABLE QUANTITY THROUGH SUBSURFACE DRAINAGE(VD)
C
        TCRIT=(SD-MF-CRACK)/RI
        VSO=TO1*ALFA*QO-((TO1-.5*TADV)*RI+CRACK)*XE
        DT=VSO/(XE*RI)
        TINFM=TO1+DT
        TINF=TINFM-TADV
```

```
    IF(TINFM.LE.TCRIT) THEN
            VD=0.
    ELSEIF(TINF.GE.TCRIT) THEN
            VD=VA/LP-SD+MF
    ELSE
            XD=(TINFM-TCRIT)*ADVSPD
            VD=.5*(TINFM*RI-SD+MF+CRACK)*XD/LP
    ENDIF
RETURN
END
```

APPENDIX C. Subroutine RICE

```
*******************************************************************
*                        SUBROUTINE RICE                         *
*                        ---------------                         *
*  THIS SUBROUTINE IS USED WHERE RICE FIELD CONDITION EXISTS.    *
*  THE SUBROUTINE CALCULATES:-IRRIGATION LOSSES    (VSDR)        *
*                          -QUANTITY OF SALTS THAT WILL BE DRAINED *
*                           TO THE DRAINAGE SYSTEM   (QSALT)      *
*                          -INITIAL STANDING WATER LAYER AFTER    *
*                           IRRIGATION                           *
*                                                                *
*  DEFINITIONS                                                   *
*  -----------                                                   *
*  HSTI    =INITIAL STANDING WATER LAYER IN RICE FIELD      M    *
*  HMAX    =MAXIMUM STANDING WATER LAYER IN RICE FIELD      M    *
*  INFSALT =QUANTITY OF SALTS IN THE STANDING WATER LAYER   Eq/M**2 *
*  CIRR    =CHLORIDE CONCENTRATION OF IRRIGATION WATER      Eq/M**3 *
*  QSALT   =SALTLOAD RELEASED BY SURFACE DRAINAGE           Eq/M**2 *
*******************************************************************
       SUBROUTINE RICE
       REAL NMAN,MF,LP,INFSALT,MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,
      /IGROSS
       INTEGER RICECOD,CROPCOD,SOILCOD
       COMMON /PLOT   / WDTH,LP,SO,NMAN,CS,CNL
       COMMON /MOIST  / MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,SD,MF
       COMMON /TIME   / TINTER,TPO,TO
       COMMON /CODE   / CROPCOD,SOILCOD,RICECOD
       COMMON /LEVEL  / HSTAND,H,HSTI,HI,HMAX
         COMMON /LENGTH/ DD,RZD,HAQ,DU,DS,DAQ
       COMMON /RES    / DRSALT,INFSALT,DRWA
       COMMON /IRR    / CRACK,IGROSS,CIRR,DRAIN,VC,VSDR,VD,QSALT
       COMMON /INFL   / ALFA,RINFL,RHO,DRHO
```

```
C
C   START CALCULATION
C   *****************
        VD=0.
        QSALT=0.
      HR=IGROSS*(1.0-CNL/CS)
        VC=IGROSS-HR
      IF (HSTI .LE. 0.0)    GO TO 5
      IF (HR .LT. HMAX)     GO TO 10
      VSDR=HSTI+HR-HMAX
      QSALT=INFSALT+(HR-HMAX)*CIRR
      HSTI=HMAX
        INFSALT=HMAX*CIRR
        IGROSS=HR
      GO TO 50
C
   10 HT=HSTI+HR
      IF (HT .LT. HMAX)     GO TO 20
      VSDR=HT-HMAX
      INFSALT=INFSALT+HR*CIRR
      QSALT=VSDR*INFSALT/HT
        INFSALT=INFSALT-QSALT
      HSTI=HMAX
        IGROSS=HR
        GOTO 50
C
   20 VSDR=0.0
      INFSALT=INFSALT+HR*CIRR
      HSTI=HSTI+HR
        IGROSS=HR
        GOTO 50
```

```
C
   5 IF (HR .LT. SD)        GO TO 30
     HSTI=HR-SD
     IF (HSTI .GT. HMAX)  GO TO 40
     INFSALT=HSTI*CIRR
     VSDR=0.0
        IGROSS=HR
     GO TO 50
C
  40 INFSALT=HMAX*CIRR
     VSDR=HSTI-HMAX
     QSALT=VSDR*CIRR
     HSTI=HMAX
        IGROSS=HR
     GO TO 50
C
  30 CRACK=0.
        IF(DRHO.LT.0.) CALL CRVOL
     CALL IRRAPL
C
  50 RETURN
     END
```

APPENDIX D. Subroutine CRVOL

```
****************************************************************************
*                        SUBROUTINE CRVOL                                 *
*                        ------------------                               *
* SUBROUTINE FOR THE CALCULATION OF CRACK VOLUME                          *
****************************************************************************
      SUBROUTINE CRVOL
      REAL NMAN,MF,LP,INFSALT,MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,
     /IGROSS
      INTEGER RICECOD,CROPCOD,SOILCOD
      COMMON /PLOT  / WDTH,LP,SO,NMAN,CS,CNL
      COMMON /MOIST / MOI,MOIWP,MOIFC,MOISAT,MOIO,MOIMAX,SD,MF
      COMMON /TIME  / TINTER,TPO,TO
      COMMON /CODE  / CROPCOD,SOILCOD,RICECOD
      COMMON /LEVEL / HSTAND,H,HSTI,HI,HMAX
        COMMON /LENGTH/ DD,RZD,HAQ,DU,DS,DAQ
      COMMON /RES   / DRSALT,INFSALT,DRWA
      COMMON /IRR   / CRACK,IGROSS,CIRR,DRAIN,VC,VSDR,VD,QSALT
      COMMON /INFL  / ALFA,RINFL,RHO,DRHO
*-------------------------------------------------------------------------
*  DEFINITIONS:
*  ------------
*  RHO  = MINIMUM DRY BULK DENSITY
*  THEO = MOISTURE CONTENT AT WHICH RHO OCCURS
*  THEA = AIR CONTENT AT MOISTURE CONTENT THEO
*  G    = DEPTH OF GROUNDWATER BELOW SOIL SURFACE
*-------------------------------------------------------------------------
C
C DETERMINATION OF AVERAGE AIR CONTENT,XKM,WITH NEWTONS METHODE
C A FIRST ESTIMATION IS THE SATURATION DEFICIT DEVIDED BY THE
C THE DEPTH OF WATER TABLE BELOW SOIL SURFACE
C
C -----------------------------------------------------------------------
```

```
          G=DD-H

          SDDG=SD/G

          XKM=.5*SDDG

10      A=1.+XKM-SDDG

          B=RHO-XKM*DRHO

          A2=A**2

          A3=A2*A

          XKM1=XKM+(RHO-A3*B)/(3.*B*A2-DRHO*A3)

          ERROR=(XKM1-XKM)/XKM

          IF(ABS(ERROR).GT..001) THEN

                  XKM=XKM1

                  GOTO 10

          ENDIF
C     ---------------------------------------------------------------------
C  DETERMINATION OF CRACK VOLUME   (CRACK)
C     ---------------------------------------------------------------------
          ONMEPS=(RHO/B)**.3333

          ONMEP3=ONMEPS**3

          CRACK=(ONMEPS-ONMEP3)*G

      RETURN

      END
```