User’s Guide to *CIRFLE* vs 2.0

CONCEPTUAL IRRIGATION RETURN FLOW HYDROSALINITY MODEL

Prepared by:

D. Quílez, D. Isidoro, R. Aragüés

(CITA – Government of Aragón, Spain)

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1. INTRODUCTION

CIRFLE is a computer model that estimates the volume of water and the salt concentrations and loads in irrigation return flows. The model *CIRFLE* focuses on the crop's root zone and considers only the main flow-paths of water and salts in the system. The model assumes that the masses of water and salt are conservative and that steady state conditions can model long-term transient conditions approximately.

CIRFLE is based in a mass balance approach for water and salts, and considers only the most important inputs and outputs from the system. Inputs to the system are irrigation, precipitation, and inflows from rim areas; outputs from the system are evapotranspiration, irrigation and precipitation runoff, subsurface drainage and deep percolation. The changes in soil storage are considered as the difference between the initial and final states, with special attention to the leaching efficiency of salts and the calcite and gypsum dissolution-precipitation processes. *CIRFLE* does not model individual ions, only salts as a lumped parameter, and thus cation exchange reactions or adsorption are not considered.

The model has been designed to be applied to large systems and for long periods, such as an irrigation season, a hydrologic year, or a series of consecutive years. The model should not be applied for short periods as, in general, steady state conditions do not hold. The model's variables and parameters are spatial and temporal averages. Thus, *CIRFLE* must be applied to spatially homogeneous areas or the results can be misleading.

The conceptual Irrigation Return Flow hydrosalinity model was developed by Tanji (1977), revised by Aragüés et al. (1985, 1990) with the name *CIRF*, and updated by Quílez (1998) with the name *CIRFLE* (**C**onceptual **I**rrigation **R**eturn **Fl**ow hydrosalinity model with consideration for the **L**eaching **E**fficiency of salts). The model has been revised, updated and rewritten in the object-oriented programming language C-sharp (C#).

2. MATHEMATICAL DESCRIPTION of *CIRFLE*

CIRFLE consists of a hydrologic submodel coupled to a salinity submodel. In the hydrologic submodel the volume of water Q is considered. In the salinity submodel, the salt concentration (C) expressed as total dissolved solids (TDS), and the load or mass of salts (M) are considered. Salt load is obtained as the product of water volume, salt concentration and an adequate unit conversion factor (SMCF) that depends on the units of input data.

2.1. Hydrologic submodel

Figure 1 shows the inputs, outputs and flow pathways considered in the hydrologic submodel. The mathematical equations are presented in Table 1 and the definition of symbols in Table 2.

The inputs to the system are diverted irrigation water (Q_{diw}), precipitation (Q_p) and rim inflows from lateral systems (Q_{rim}) (Eq. 1). The volume of irrigation water that evaporates directly from the soil surface or the plant canopy (Q_{evdiw}) is defined through the irrigation water evaporation coefficient (iwec) (Eq. 4), given as an input to the model. The volume of water that

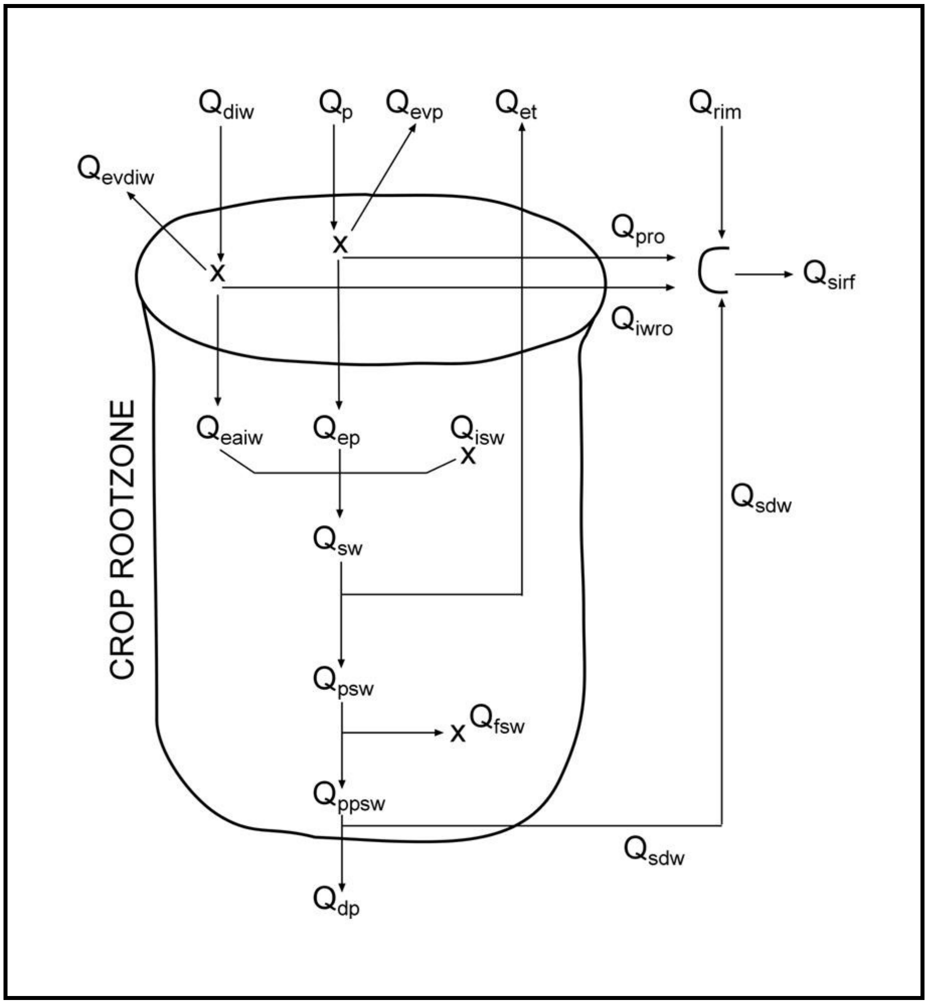

Figure 1. Diagram of the hydrologic submodel, focusing on crop root zone. The symbol Q denotes quantity of water.

effectively infiltrates the soil or “effective applied irrigation water (Q_{eaiw})” is defined through the coefficient E_{iae}, the irrigation application efficiency (Eq. 5). The rest of Q_{diw} that does not infiltrates the soil or evaporates is regarded as the volume lost as surface runoff (Q_{iwro}) (Eq. 6).

Precipitation (Q_p) follows the same pathways than irrigation: precipitation evaporation (Q_{evp}), precipitation runoff (Q_{pro}) and effective precipitation (Q_{ep}) (Eq. 8, 9 and 10, where pec = precipitation evaporation coefficient and prc = precipitation runoff coefficient).

The soil water available for evapotranspiration (Q_{sw}) is obtained by adding the effective irrigation water (Q_{eaiw}), the effective precipitation (Q_{ep}) and the initial stored soil water (Q_{isw}) (Eq. 14).

The evapotranspiration (Q_{et}) is considered at this point, being Q_{psw} the volume of water remaining in the soil after evapotranspiration. The evapotranspiration concentration factor (ETCF), defined as the ratio Q_{sw} / Q_{psw} (Eq. 16), indicates the concentration factor of the soil water due to ET. The volume of water after ET (Q_{psw}) is decomposed in its three components: the effective applied irrigation water after ET (Q_{sweaiw}), the effective precipitation after ET (Q_{swep})

and the initial soil water after ET (Q_{swisw}) (Eq. 15). The final stored soil water (Q_{fsw}), an input to the model, is subtracted from Q_{psw} to obtain the water available for subsurface drainage and deep percolation (Q_{ppsw}) (Eq. 17).

Table 1. Mathematical equations describing the hydrologic submodel. Q denotes volume of water.

Hydrological inputs and outputs
(1) $Q_i = Q_{diw} + Q_p + Q_{rim}$
(2) $Q_o = Q_{iwro} + Q_{pro} + Q_{et} + Q_{evdiw} + Q_{evp} + Q_{dp} + Q_{sdw} + Q_{rim}$
Diverted irrigation water
(3) $Q_{diw} = Q_{eaiw} + Q_{evdiw} + Q_{iwro}$
(4) $Q_{evdiw} = evdiw \cdot Q_{diw}$
(5) $Q_{eaiw} = Q_{diw} \cdot E_{iae}$
(6) $Q_{iwro} = Q_{diw} \cdot (1 – evdiw - E_{iae})$
(7) $Q_{sweaiw} = Q_{eaiw}$ / ETCF
Precipitation
(8) $Q_p = Q_{pro} + Q_{evp} + Q_{ep}$
(9) $Q_{evp} = pec \cdot Q_p$
(10) $Q_{pro} = prc \cdot Q_p$
(11) $Q_{ep} = (1\text{-}prc\text{-}pec) \cdot Q_p$
(12) $Q_{swep} = Q_{ep}$ / ETCF
Initial stored soil water
(13) $Q_{swisw} = Q_{isw}$ / ETCF
Water inputs to root zone
(14) $Q_{sw} = Q_{eaiw} + Q_{ep} + Q_{isw}$
(15) $Q_{psw} = Q_{sw} – Q_{et} = Q_{sweaiw} + Q_{swep} + Q_{swisw}$
(16) ETCF = Q_{sw} / Q_{psw}
Final stored soil water
(17) $Q_{ppsw} = Q_{psw} – Q_{fsw}$
Water outputs from root zone
(18) $Q_{dp} = dpc \cdot Q_{ppsw}$
(19) $Q_{sdw} = (1 – dpc) \cdot Q_{ppsw}$
(20) $Q_{sw} = Q_{et} + Q_{fsw} + Q_{dp} + Q_{sdw}$
(21) $D_l = Q_{ppsw}$ / A
Surface irrigation return flows
(22) $Q_{sirf} = Q_{iwro} + Q_{pro} + Q_{sdw} + Q_{rim}$
Water use efficiency, leaching fraction
(23) WUE = $Q_{et} / (Q_{eaiw} + Q_{ep})$
(24) LF = $Q_{ppsw} / (Q_{eaiw} + Q_{ep})$

Outputs below the crops root zone are the deep percolation (Q_{dp}) and the subsurface drainage (Q_{sdw}). The deep percolation coefficient (dpc), an input to the model, gives the percentage of the water available for subsurface drainage and deep percolation (Q_{ppsw}) that percolates as Q_{dp} (Eq. 18).

The surface Irrigation return flows (Q_{sirf}) are the sum of the subsurface drainage (Q_{sdw}), irrigation runoff (Q_{iwro}), precipitation runoff (Q_{pro}) and rim inflows (Q_{rim}) (Eq. 22).

Two additional equations calculate the water use efficiency (WUE) that gives the fraction of the infiltrated irrigation and precipitation that undergoes evapotranspiration (Eq. 23), and the leaching fraction (LF) that gives the portion of the infiltrated irrigation and precipitation that percolates below the root zone (Eq. 24).

Table 2. Symbols used in the hydrologic submodel. Q denotes volume of water.

Symbol	Definition
A	Surface
D_l	Depth of water available for leaching
dpc	Deep percolation coefficient
D_r	Average rooting depth
E_{iae}	Irrigation application efficiency
ETCF	Evapotranspiration concentration factor
evdiw	Irrigation evaporation coefficient
LF	Leaching fraction
pec	Precipitation evaporation coefficient
prc	Precipitation runoff coefficient
Q_{diw}	Diverted irrigation water
Q_{dp}	Deep percolation
Q_{eaiw}	Effective applied irrigation water
Q_{ep}	Effective precipitation
Q_{et}	Evapotranspiration
Q_{evdiw}	Evaporation of irrigation water
Q_{evp}	Evaporation of precipitation
Q_{fsw}	Final stored soil water
Q_i	Hydrologic inputs
Q_{isw}	Initial stored soil water
Q_{iwro}	Irrigation water runoff
Q_o	Hydrologic outputs
Q_p	Precipitation
Q_{ppsw}	Water available for subsurface drainage and deep percolation
Q_{pro}	Precipitation runoff
Q_{psw}	Soil water after ET
Q_{rim}	Rim inflow/outflow
Q_{sdw}	Subsurface drainage water
Q_{sirf}	Surface irrigation return flow
Q_{sw}	Soil water before ET
Q_{sweaiw}	Effective applied irrigation water after ET
Q_{swep}	Effective precipitation after ET
Q_{swisw}	Initial soil water after ET
SP	Saturation Percentage obtained in the soil saturation paste
WUE	Water use efficiency

2.2. Salinity submodel

Figure 2 shows the inputs, outputs and flow pathways considered in the salinity submodel. The mathematical equations are presented in Table 3 and the definition of symbols in Table 4. The inputs to the system are the salt concentration and salt mass in diverted irrigation water (C_{diw}, M_{diw}), precipitation (C_p, M_p) and rim inflows from lateral systems (C_{rim}, M_{rim}). In all cases, the salt mass of each component is calculated from the product of the corresponding volume of water and salt concentration and a unit conversion factor (SMCF) (Eqs. 29, 36 and 73).

To calculate the concentration of the effective applied irrigation water (C_{eaiw}) the increase in the salt concentration of the irrigation water due to evaporation (1/(1-iwec)) is considered (Eq. 30). The salt mass in the effective applied irrigation water (M_{eaiw}) is calculated as the product of salt concentration (C_{eaiw}), water volume (Q_{eaiw}) and the unit conversion factor (SMCF) (Eq. 31).

Irrigation can dissolve some of the salts present at the soil surface (C_{iwrosp}, an input to the model) being C_{iwro} the final salt concentration of irrigation runoff (Eq. 32). Salt load in irrigation runoff is obtained as the product of its concentration (C_{iwro}), the volume of irrigation runoff (Q_{iwro}) and the unit conversion factor (SMCF) (Eq. 33).

The TDS of precipitation (C_p) is concentrated based on the precipitation evaporation coefficient (pec) to give the concentration of the effective precipitation (C_{ep}) (Eq. 39). The salt load in the effective precipitation (M_{ep}) is calculated as the product of the volume of effective precipitation (Q_{ep}), its concentration (C_{ep}) and the unit conversion factor (SMCF) (Eq. 40).

CIFLE also considers that precipitation runoff (Q_{pro}) can dissolved part of the salts present at the soil surface (C_{prosp}), being C_{pro} the final concentration of precipitation runoff (Eq. 37). The salt load in precipitation runoff (M_{pro}) is obtained from Eq. 38.

The electrical conductivity of the soil saturation extract (ECe), an input to the model, is used to account for soil salinity. When there is “excess gypsum” in the soil, the ECe of the initial soil water is corrected by gypsum solubility (EC_{gype}) to give C_{se} by means of Eq. 46. “Excess gypsum” in the soil is considered when the amount of gypsum in the soil (Gypsum, an input to the model) is sufficient to saturate the soil water after ET (Q_{psw}). This correction is performed because the TDS of a gypsum-saturated solution cannot be significantly concentrated during evapotranspiration. To calculate the amount of gypsum potentially soluble in soil water the model uses a gypsum solubility of 2.63 kg/m^3 or 21 mM/L (Tanji, 1969) and a value of the EC at saturation of 2.2 dS/m. Although these values are for deionized water and the approach has limitations because gypsum solubility depends on other soil variables (Tanji, 1969), it is preferred over that where it will be allowed to freely evapo-concentrate due to ET. If there is no “excess gypsum” in the soil, then $EC_{gype} = 0$ and $TDS_{gyp} = 0$.

The corrected ECe for the “excess gypsum” condition is converted into TDS (C_{se}) using the conversion factor of 1 dS/m = 720 mg/l of dissolved salts. This conversion factor was taken from the approximate average for the surface waters of the Ebro river basin in Spain with similar fractions of Cl, SO_4 and HCO_3 (meq/L) in the solution (CHE, 2006). The TDS of the initial soil solution (C_{isw}) is obtained from C_{se}, and the ratio between water content at saturation ($SP \cdot Dr \cdot A \cdot D_b$) and the initial soil water content (Q_{isw}) (Eq. 47). To avoid unreasonable low C_{isw} values in cases where gypsum is the main source of salinity, the condition $C_{isw} > C_{min}$ was imposed, where C_{min} is the salt concentration of the soil solution in equilibrium with the salt concentration of the irrigation water. The computation of C_{min} is explained below.

The salt load of the initial soil water (M_{isw}) is the product of the volume of the initial stored soil water (Q_{isw}), its salt concentration (C_{isw}) and the salt mass conversion factor (SMCF) (Eq. 49). The salt load in the soil water before ET (M_{sw}) is calculated as the sum of the salt loads in effective irrigation, effective precipitation and initial soil water (Eq. 55). The concentration of soil water before ET (C_{sw}) is obtained as the ratio between the salt mass (M_{sw}) and the volume of water (Q_{sw}) and the salt mass conversion factor (SMCF) (Eq. 56).

Since crop's evapotranspiration is free of salts, the salinity of the soil solution after ET (C_{psw}) is concentrated by the ET concentration factor (ETCF), but the salt load (M_{psw}) remains unchanged (Eq. 57). C_{psw} is calculated as the ratio of the salt mass (M_{psw}) to the volume of water (Q_{psw}) and the salt mass conversion factor (Eq. 58).

As the soil solution is concentrated during the evapotranspiration process, some low soluble minerals (as gypsum and calcium carbonate) may precipitate if their solubility products are exceeded. Also, lime or gypsum can dissolve if they are readily available in the soil. *CIRFLE* computes the term M_{sp} - M_{sd} (salt pickup – salt deposition, or mineral dissolution – mineral precipitation) using the model Watsuit (Wu et al., 2009). Watsuit calculates the extent to which applied irrigation water, as it becomes concentrated in the soil solution due to evapotranspiration, effectively dissolves $CaCO_3$ from the soil or precipitates out $CaSO_4 \cdot 2H_2O$ and $CaCO_3$. A linear regression equation that relates $C_{sp} – C_{sd}$ with the leaching fraction (LF) is given in *CIRFLE* to account for this effect (Eq. 52). Values of the intercept and slope of this equation have been calculated for different irrigation water types with ionic compositions and EC values considered representative of most irrigation districts. Nevertheless, the user may introduce its own empirical values if desired. The salt mass due to salt pickup-salt deposition (M_{sp}-M_{sd}) is obtained as the product of Q_{eaiw}, (C_{sp} - C_{sd}) and the salt mass conversion factor (Eq. 53).

Salt pickup due to gypsum dissolution (M_{gsp}) in the "excess gypsum" scenario is now considered. *CIRFLE* assumes a gypsum solubility of 2.63 kg/m^3 and gypsum is dissolved until the soil water after ET (Q_{psw}) is gypsum-saturated.

Adding the salt mass in the soil solution after ET (M_{psw}), the salt pickup minus salt deposition ($M_{sp} – M_{sd}$) and the dissolution of gypsum (M_{gsp}) gives the total mass of salts M'_{psw} (Eq. 59). The corresponding salt concentration (C'_{psw}) is calculated as the ratio of M'_{psw} to Q_{psw} and the salt mass concentration factor (Eq. 60).

CIRFLE considers at this point the leaching efficiency of salts present in the soil using the empirical approach developed by Hoffman (1986). The proportion of salts remaining in the soil (C_f) with respect to the salts initially present (C_i) after a depth of water D_l has percolated through a given depth of soil (D_r) is calculated as:

$$\frac{C_f - C_{\min}}{C_i - C_{\min}} = \frac{k}{\frac{D_l}{D_r} + k}$$

where C_{min} is the salt concentration in the soil water after ET in equilibrium with the irrigation and precipitation waters. C_{min} considers the dissolution-precipitation of calcite and the precipitation of gypsum in the soil (C_{sp}-C_{sd}) (Eq. 61). The empirical coefficient *k* takes into account the inefficiency of salt leaching that, among others, depends on soil physical and chemical characteristics, as pore size distribution, macropore bypass or soil water content. Information on the parameter *k* is provided in section 3.1 (input variables).

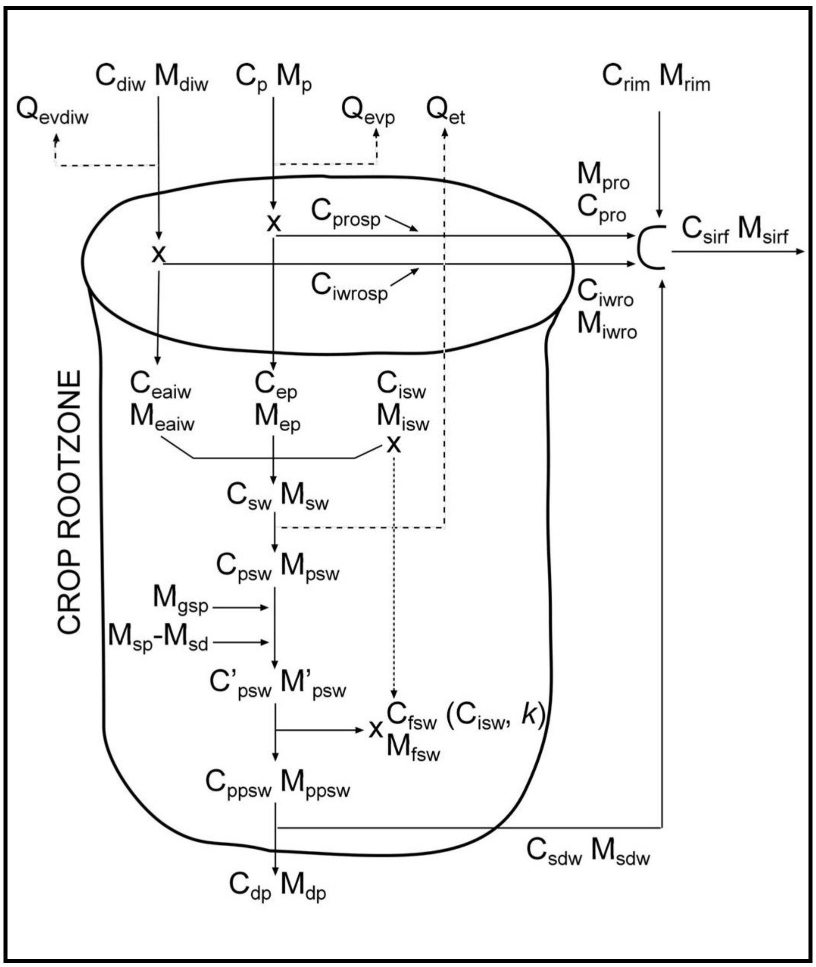

Figure 2. Freebody diagram of salinity submodel, focusing on crop root zone. The symbols C and M denote total dissolved solids and mass of salts, respectively.

The final concentration of soil water (C'_{fsw}) is obtained from the initial concentration of soil water using the leaching efficiency coefficient (*k*) and considering the amount of percolating water (Q_{ppsw}/A) per unit depth of soil (Dr) (Eq. 62).

Table 3. Mathematical equations describing the salinity submodel

Salt inputs and outputs and change in storage

(25) $M_i = M_{diw} + M_p + M_{rim}$

(26) $M_o = M_{iwro} + M_{pro} + M_{dp} + M_{sdw} + M_{rim}$

(27) $M_s = M_{fsw} - M_{isw} + M_{sd} - M_{sp} - M_{gsp}$

Lateral contributions

(28) $M_{rim} = C_{rim} \cdot Q_{rim} \cdot SMCF$

Diverted irrigation water

(29) $M_{diw} = C_{diw} \cdot Q_{diw} \cdot SMCF$

(30) $C_{eaiw} = C_{diw} / (1 - iwec)$

(31) $M_{eaiw} = C_{eaiw} \cdot Q_{eaiw} \cdot SMCF$

(32) $C_{iwro} = C_{eaiw} + C_{iwrosp}$

(33) $M_{iwro} = C_{iwro} \cdot Q_{iwro} \cdot SMCF$

(34) $C_{sweaiw} = (M_{sweaiw} / Q_{sweaiw}) / SMCF = C_{eaiw} \cdot ETCF$

(35) $M_{sweaiw} = M_{eaiw}$

Precipitation

(36) $M_p = C_p \cdot Q_p \cdot SMCF$

(37) $C_{pro} = C_{ep} + C_{prosp}$

(38) $M_{pro} = C_{pro} \cdot Q_{pro} \cdot SMCF$

(39) $C_{ep} = Cp / (1 - pec)$

(40) $M_{ep} = C_{ep} \cdot Q_{ep} \cdot SMCF$

(41) $C_{swep} = C_{ep} \cdot ETCF$

(42) $M_{swep} = M_{ep}$

Initial soil water corrected by gypsum solubility

(43) $Gypsum = A \cdot D_r \cdot D_b \cdot (PG)$

(44) $M_{gyp} = 2630 \cdot Q_{psw} \cdot SMCF$

(45) If $M_{gyp} \leq Gypsum$: $EC_{gype} = 2.2$ and $TDS_{gyp} = 2630$ (Saturation)

(46) $C_{se} = (EC_e - EC_{gype}) \cdot 720$

(47) $C_{isw} = C_{se} \cdot (SP \cdot D_r \cdot A \cdot D_b / Q_{isw})$

(48) If $C_{isw} < C_{min}$: $C_{isw} = C_{min}$

(49) $M_{isw} = C_{isw} \cdot Q_{isw} \cdot SMCF$

(50) $C_{swisw} = (M_{swisw} / Q_{swisw}) / SMCF = C_{isw} \cdot ETCF$

(51) $M_{swisw} = M_{isw}$

Gypsum, salt pickup-salt deposition

(52) $C_{sp} - C_{sd} = a + b \cdot LF$

(53) $M_{sp} - M_{sd} = (C_{sp} - C_{sd}) \cdot Q_{eaiw} \cdot SMCF$

(54) If $M_{gyp} \leq Gypsum \Rightarrow M_{gsp} = M_{gyp}$

Table 3 (cont). Mathematical equations describing the salinity submodel

Salt input to root zone

(55) $M_{sw} = M_{eaiw} + M_{ep} + M_{isw}$

(56) $C_{sw} = (M_{sw} / Q_{sw}) / SMCF$

(57) $M_{psw} = M_{sw} = M_{sweaiw} + M_{swep} + M_{swisw}$

(58) $C_{psw} = (M_{psw} / Q_{psw}) / SMCF = C_{sw} \cdot ETCF$

(59) $M'_{psw} = M_{psw} + M_{gsp} + (M_{sp} – M_{sd})$

(60) $C'_{psw} = (M'_{psw} / Q_{psw}) / SMCF$

Final Soil water

(61) $C_{min} = ((C_{eaiw} + C_{sp} - C_{sd}) \cdot Q_{eaiw} + C_{ep} \cdot Q_{ep}) / (Q_{sweaiw} + Q_{swep})$

(62) $C'_{fsw} = [k / (D_l / D_r) + k)] \cdot (C_{isw} - C_{min}) + C_{min}$

(63) $NPV = (D_l / D_r) / [1 – (D_b / 2.65)]$

(64) If $k = 0$ and $NPV < 1$: $C'_{fsw} = [(1 – NPV) \cdot M_{isw} / Q_{fsw}] / SMCF + C_{min}$

(65) $C_{fsw} = C'_{fsw} + TDS_{gyp}$

(66) $M_{fsw} = C_{fsw} \cdot Q_{fsw} \cdot SMCF$

Salt output from root zone

(67) $M_{ppsw} = M'_{psw} - M_{fsw}$

(68) $C_{ppsw} = (M_{ppsw} / Q_{ppsw}) / SMCF$

(69) $C_{dp} = C_{ppsw}$

(70) $M_{dp} = C_{dp} \cdot Q_{dp} \cdot SMCF$

(71) $C_{sdw} = C_{ppsw}$

(72) $M_{sdw} = C_{sdw} \cdot Q_{sdw} \cdot SMCF$

Rim inflow-outflows

(73) $M_{rim} = C_{rim} \cdot Q_{rim}$

Salt load in irrigation return Flows

(74) $M_{sirf} = M_{iwro} + M_{pro} + M_{sdw} + M_{rim}$

(75) $C_{sirf} = (M_{sirf} / Q_{sirf})/ SMCF$

For a value of $k = 0$, the model assumes a piston-flow displacement of salts from the soil. Thus, the amount of salts leached from the soil depends of the number of pore volumes (NPV) displaced with the water available for subsurface drainage and deep percolation (Q_{ppsw}). To calculate NPV, a density of solids of 2.65 g/cm^3 is used (Eq. 63). If NPV = 1, all the soluble salts initially present in the soil (M_{isw}) are displaced from the soil. If NPV < 1, the final concentration of soil water (C'_{fsw}) is composed of two terms: the first, proportional to (1-NPV), gives the amount of salts initially present (M_{isw}) that remain in the soil, and the second (C_{min}) gives the concentration of soil water in equilibrium with irrigation and precipitation waters (Eq. 64).

In the "excess gypsum" scenario, C'_{fsw} does not include gypsum as C_{isw} and M_{isw} have been corrected by gypsum dissolution. The gypsum contribution to the saline concentration of the final soil water is added through TDS_{gyp} (TDS_{gyp} = 2630 mg/L). For the rest of cases without "excess gypsum", it is assumed that $TDS_{gyp} = 0$. The salt mass in the final stored soil water (M_{fsw}) is given by Eq. 66.

The model does not consider a leaching efficiency coefficient for gypsum in the "excess gypsum" scenario because it is assumed that drainage waters are gypsum-saturated. This is a reasonable hypothesis supported by the ionic concentrations measured in waters draining from soils high in gypsum (Basso, 1994, Quílez et al., 1987b, Isidoro et al, 2006).

The salt mass in the soil available for subsurface drainage and deep percolation (M_{ppsw}) is calculated from the difference between M'_{psw} and M_{fsw} (Eq. 67) and its concentration (C_{ppsw}) from the ratio between M_{ppsw} and Q_{ppsw} times the salt mass conversion factor (Eq. 68).

Once the mass of salts in the final stored soil water (M_{fsw}) is calculated by the model, the soil solution is subdivided into two components of equal salt concentration (C_{ppsw}): deep percolation (C_{dp}), and collected subsurface drainage water (C_{sdw}). The mass of salts in deep percolation (M_{dp}) and subsurface drainage (M_{sdw}) are obtained as the product of the above concentrations times their respective volumes (Q_{dp}, Q_{sdw}) and the unit conversion factor (SMCF) (Eqs. 70 and 72).

Salt load in surface irrigation return flows (M_{sirf}) is the sum of the salt mass in subsurface drainage (M_{sdw}), runoff components (M_{pro} and M_{iwro}), and lateral contributions (M_{rim}) (Eq. 74) and the salt concentration of surface irrigation return flow (C_{sirf}) is the volume-weighted average of the concentrations in the three components (Eq. 75).

Table 4. Symbols used in the salinity submodel

Symbol	Definition
a	Intercept of the equation C_{sp}-C_{sd}= a + b · LF
b	Slope of the equation C_{sp}-C_{sd}= a + b · LF
C_{diw}	TDS of diverted irrigation water
C_{dp}	TDS of deep percolation
C_{eaiw}	TDS of effective applied irrigation water
C_{ep}	TDS of effective precipitation
C_{fsw}	TDS of final stored soil water
C'_{fsw}	TDS of final stored soil water not including gypsum
C_{isw}	TDS of initial stored soil water, corrected for gypsum solubility if "excess gypsum"
C_{iwro}	TDS of irrigation runoff
C_{iwrosp}	Salt pickup by irrigation runoff
C_{min}	Soil water concentration in equilibrium with irrigation and precipitation concentrations
C_p	TDS of precipitation
C_{ppsw}	TDS of soil water available for subsurface drainage and deep percolation
C_{pro}	TDS of precipitation runoff
C_{prosp}	Salt pickup by precipitation runoff
C_{psw}	TDS of soil water after ET
C'_{psw}	TDS of soil water after ET, M_{gsp} and M_{sp} - M_{sd}
C_{rim}	TDS of rim inflow/outflow
C_{sdw}	TDS of subsurface drainage
Cse	TDS of soil saturation extract corrected by gypsum solubility
Csirf	TDS of surface irrigation return flow

Table 4 (cont.). Symbols used in the salinity submodel

Symbol	Definition
$C_{sp} – C_{sd}$	Salt pickup – salt deposition
C_{sw}	TDS of soil water before ET
C_{sweaiw}	TDS of applied irrigation water after ET
C_{swep}	TDS of precipitation after ET
C_{swisw}	TDS of initial stored soil water after ET
D_b	Soil bulk density
EC_e	EC (25ºC) of soil saturation extract
ECgyp	EC (25ºC) of initial soil water due to gypsum if “excess gypsum”
ECgype	EC (25ºC) of soil saturation extract due to gypsum if “excess gypsum”
Gypsum	Amount of gypsum in the soil
k	Leaching efficiency coefficient
M_{diw}	Salt mass in diverted irrigation water
M_{dp}	Salt mass in deep percolation
M_{eaiw}	Salt mass in effective applied irrigation water
M_{ep}	Salt mass in effective precipitation
M_{fsw}	Salt mass in final stored soil water
M_{gsp}	Amount of gypsum dissolved in soil water after ET
Mgyp	Amount of gypsum potentially soluble in soil water after ET
Mi	Salt inputs
Misw	Salt mass in initial stored soil water, corrected by gypsum solubility if “excess gypsum”
M_{iwro}	Salt mass in irrigation runoff
M_o	Salt outputs
M_p	Salt mass in precipitation
M_{pro}	Salt mass in precipitation runoff
M_{ppsw}	Salt mass available for subsurface drainage and deep percolation
M_{psw}	Salt mass in soil water after ET
M'_{psw}	Salt mass in soil water after ET, M_{gsp} and $M_{sp} – M_{sd}$
M_{rim}	Salt in rim inflow/outflow
M_s	Change in salt mass stored in the crop’s root zone
M_{sdw}	Salt mass in subsurface drainage water
M_{sirf}	Salt mass in surface irrigation return flow
$M_{sp} – M_{sd}$	Salt pickup - salt deposition
M_{sw}	Salt mass in soil water before ET
M_{sweaiw}	Salt mass in effective applied irrigation water after ET
M_{swep}	Salt mass in effective precipitation after ET
M_{swisw}	Salt mass in initial soil water after ET
M_{ua}	Salt mass in IRF per unit irrigated area
NPV	Number of pore volumes
PG	Percentage of gypsum in the soil
SMCF	Salt mass unit conversion factor
TDS_{gyp}	TDS of initial and final soil water due to gypsum if “excess gypsum”

3. INSTALLING *CIRFLE*

CIRFLE works under the Microsoft .NET framework, which only operates under the newer Windows operating systems. Minimum system requirements are:

- **Supported Operating Systems**: Windows Server 2003; Windows Server 2008; Windows Vista; Windows XP
- **Processor**: 400 MHz Pentium processor or equivalent (Minimum); 1GHz Pentium processor or equivalent (Recommended)
- **RAM**: 96 MB (Minimum); 256 MB (Recommended)
- **Hard Disk**: Up to 500 MB of available space may be required
- **CD or DVD Drive**: Not required
- **Display**: 800x600, 256 colors (minimum); 1024x768 high color, 32-bit (recommended)

Insert the *CIRFLE* CD in the computer, double click on the file *InstallCirfle.exe* to initiate the installation process, and then follow the on-screen directions. The installation program will install *CIRFLE* in the ”program files” directory, but this directory can be changed during the installation process.

CIRFLE needs the Microsoft Data Access (MDA) components and the .NET framework be installed in the computer. The installation program will install the Microsoft data access 2.7 if necessary. You have to accept the terms of the License agreement of the program by clicking in the box “I accept all the terms of the preceding license agreement“ and then clicking on “Next”. Once the setup program has checked the file used in the computer, click “Finish” to begin the installation of MDA. When setup is completed, press “Close” to exit the MDA setup and continue with the *CIRFLE* installation.

If the .NET framework is not installed in your computer a window with the message “.NET runtime library is not installed¨” will open, click “OK” to continue. In the “Welcome to Microsoft .Net Framework 2.0 setup” window click “Next” to start the Microsoft .NET Framework 2.0 installation. You have to accept the terms of the License agreement of .NET by clicking in the box “I accept the terms of the License agreement“. Then click “Install”. This will install the components of the .Net framework in your computer. Please be patient, the installation of .NET Framework can take time and resources used in your computer. When the “Setup Complete” window appears in your screen press “Finish” to continue with the *CIRFLE* setup.

When the setup program finishes installing *CIRFLE* you should click “Finish” to exit the program. Double click in the shortcut in the screen desktop to start using *CIRFLE*.

Note that if you have other background programs running during the installation process, *CIRFLE* may not install properly. If you encounter an error message "file access error occurred", please close all the background programs running in you computer.

4. RUNNING *CIRFLE*

4.1. *CIRFLE* application

The first step is to identify the time interval or simulation period for which the model is to be applied. *CIRFLE* has been designed to be applied to large systems and for long periods, such as an irrigation season, a hydrologic year, or a series of consecutive years. The model cannot be applied for short periods as, in general, steady state conditions do not hold.

The model's variables and parameters are spatial and temporal averages. Thus, *CIRFLE* must be applied to areas with homogeneous characteristics or the results can be misleading. So, the second step in the application of *CIRFLE* is the identification and delimitation of areas with similar characteristics within the study area. Special attention should be paid to (1) soil characteristics (in particular, $\mathbf{EC_e}$, presence or absence of native gypsum, salt leaching efficiency, $\boldsymbol{k}$, and soil depth, $\mathbf{D_r}$); (2) method of irrigation (surface, sprinkler, drip, furrow,..) that affects the volume of applied irrigation water, the irrigation application efficiency or the irrigation evaporation coefficient; and (3) crop characteristics that determine the volume of evapotranspiration and the rooting depth.

Based on this and other variables, the irrigation project should be divided in as many homogeneous areas as necessary. Inputs for each area must be entered separately in the "*Input Data for the Area*" screen. After calculation, *CIRFLE* returns the outputs in the "*Output Data for the Area*" screen. Once the volume of water, salt concentration and mass of salts in the surface irrigation return flows of each area are computed, *CIRFLE* integrates the values of all the areas to give the volume of water, salt concentration and salt load in the surface irrigation return flows for the whole project in the "*Irrigation Project Output*" screen.

After an introductory window, you will find the main screen of the program. Two menus are included in the upper bar of the program: "*Project*" and "*Area*".

The *Project* menu has six options:

- "*New project*", to create a new project.
- "*Open project*", to retrieve a saved project.
- "*Save project*", to save data for a new project or to save modifications to already saved projects.
- "*Delete project*", to delete a project
- "*Generate output project*", to save the output of the project to a pdf or excel file.
- "*Exit*", to exit the program

The main screen has two sections. In the left part of the screen, you will see the name of the *Irrigation Project* that unfolds in as many areas as the project is sub-divided; each of the areas is identified by its name. When you select in the left screen one of the Areas, in the right hand side of the screen you activate two tabs. The first tab "*Input Data for the Area*" shows the 25 variables or parameters that are inputs to the model. The second tab "*Output data for the Area*" gives the outputs of the model for the selected Area.

When you select the name of the *Project* in the left part of the screen, in the right part you get also two tabs. The "*Irrigation Project Input*" presents the different *Areas* in which the project has been divided, with information of its surface area and the volume of water applied for irrigation. The "*Irrigation project Output*" gives the volume, saline concentration and mass of salts in the irrigation return flows individually for each of the *Areas* and integrated for the entire *Irrigation Project*.

4.2. "*Project*" menu

New project

The "*New Project"* option assists to input data for the new projects. When you press the new project tab a window opens asking for some basic information on the project that should be answered (Figure 3). First, you have to write the name of the project in the space designated in the blank line under New Project. Use only letters and numbers for the name of the project, the use of special symbols like "/" can produce errors. Then, you have to choose the units of the input data. It is possible to choose between four different units for water volume: Hm^3, mm, m^3/ha and ha-m. The unit ha-m (1 hm^3 = 100 ha-m) is preferred over hm^3 when the hm^3 unit is too large for the size of the irrigation project. You select the unit by clicking with the mouse in the circle located on the left of the unit you want to select. You will have to enter all the water volume data (Q) in that unit. In addition, all the outputs for volume of water will be given in the same unit.

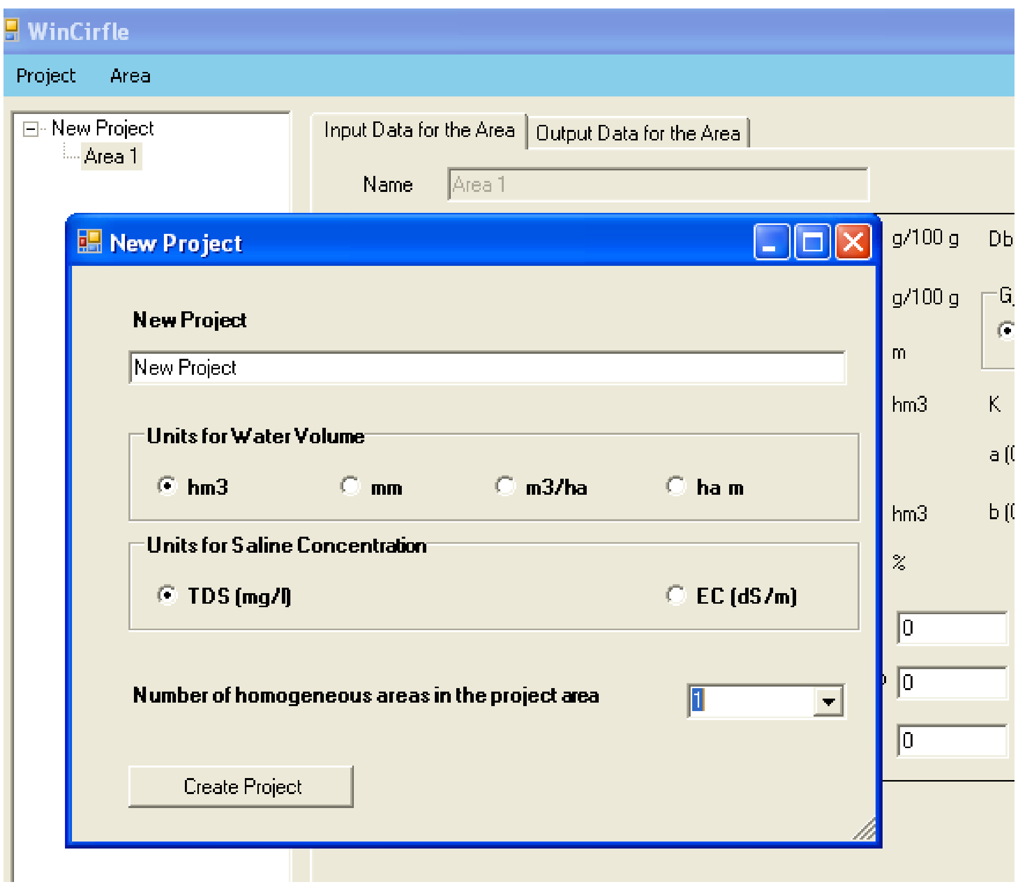

Figure 3. *"New project"* menu

Although *CIRFLE* works with salt concentrations (C) in mg/L, there are two possibilities to enter salinity: salt concentration in mg/L and electrical conductivity in dS/m. To choose a particular unit, click with the mouse on the white circle on the left of the desired unit. If you choose EC units for the saline concentration of the input variables (C_{diw}, C_{rim}, C_{iwrp}, C_p, C_{prosp}) you have to enter the EC values in dS/m. You have also to enter a conversion factor (Fc) to convert EC into C [C (mg/L) = $F_c \cdot C$ (dS/m)]. Conversion factors for seven different types of water ionic compositions are included in *CIRFLE* (Tabla 10).

Finally, the number of homogeneous areas that constitute the project need to be chosen by clicking in the down arrow located at the right of the cell "*number of homogeneous areas in the project area*" and choosing a number in the opening list. Once you choose the number of areas the tag "*Create project*" will be active. Click [Create Project] and a new window will open. In this window you can introduce the names of the different areas of the project (as many as you entered in the previous step). Once you are finished, click [Create Areas] at the bottom of the screen to start entering the data to the project. If you do not see [Create Areas] enlarge the window downwards. Use only letters and numbers for the name of the area, the use of special symbols like "/" can produce errors.

The name of the project will now appear in the left window, and below the different Areas that integrate the project will unfold. The input data window for each of the areas will open in the right window by clicking the name of the area in the left window. In the upper part of the "*Input Data for the Area*" window, the name of the area appears over the input frame that encloses the 25 input variables. In addition, the conversion factors (fc) from EC to TDS for variables C_{diw}, C_p and C_{rim} should be input when the variable selected for salt concentration be EC. You will find in section 4.4. "*Input Data For the Area*" how to enter the data in this window.

Open project

With the *open project* option, you can retrieve projects already saved. Projects are stored in a relational data base file (cirfledb.mdb) that contains the name of each *Project* and the input data for the *Areas* of each project. When you choose the *open* project button, you get a list with the names of the projects stored in the database. To select one project click in its name and then in [Open Project]; the data for that project will be retrieved in the different windows. You can modify the values of the input variables in any of the *Areas*, or add new *Areas* to the *Project*. When you modify the value of a variable be sure to press [Calculate] to get the modified outputs in the "*Output Data for the Area*" tab. If you do not press the *Calculate* button, the outputs will not be modified.

Save project

This tab saves the data of the project in the database file, i.e., the name of the project and the input data for each of the areas. If you want to modify some of the input data for a project already saved you should open the project, change the value of the variable(s) you want to modify, press [Calculate], and press the *save project* tab to store the modified inputs.

Generate output project

This tab saves the output of the project in a pdf or xls file The pdf file present in the first page a resume of the volume, salt concentration and salt load in irrigation return flows from the different areas that integrate the project and in the next pages the detailed outputs of all the intermediate variables and the graphic outputs for each of the areas of the project. In the xls format the detailed outputs are presented in different sheets, one for each area of the project. The "*generate output project*" can also be found in the lower part of the "irrigation project output" window when selecting the whole project on the left part.

4.3. "*Area"* menu

Using the "*Area"* menu, you can create a new area or delete an area in your project. If you select the tab "*Create Area"*, a window opens where you should enter the name of the new area and then press [New Area] to create the new Area. Selecting the new Area in the left of the screen you can input its corresponding data in the right part of the screen (Figure 4). To delete an Area just select the name of that area in the left part of the screen and then the option "*Delete Area*" under the "*Area"* menu.

4.4. "*Input Data For the Area*" menu

The "*Input Data for the Area*" (Figure 4) is active when you select one of the Areas in the left of the main screen. This window allows to enter the values of the input variables for an *Area*. If the user opens a *Project* it will show the input data for the areas defined in the Project. In the user creates a new project, all the cells for the values of the input variables will be blank.

The "*Input Data for the Area*" window presents the name of the *Area* in the first line. Below the name, you will find the 25 inputs to the model. By clicking in the cell close to each input, a description of it is given below "description". At the bottom of the screen, there are three buttons: [Calculate] that computes the outputs for the model, [Sensitivity Analysis] that performs the sensitivity analysis of the model, and [New Water Type] that allows the user to define new conversion factors to transforms EC into TDS.

You have to enter the values of each input in the blank cells located in the right side of each input. Use always "." for the decimal symbol. The Inputs are given by acronyms, but a full description of each one is given by clicking inside each cell. This description helps to identify the acronyms used for the names of the inputs. At the right of each input cell, you find the units for each of the input variables, except for the dimensionless ones (iwec, prc, pec, k); be sure to enter the value of each variable in the units indicated in the screen.

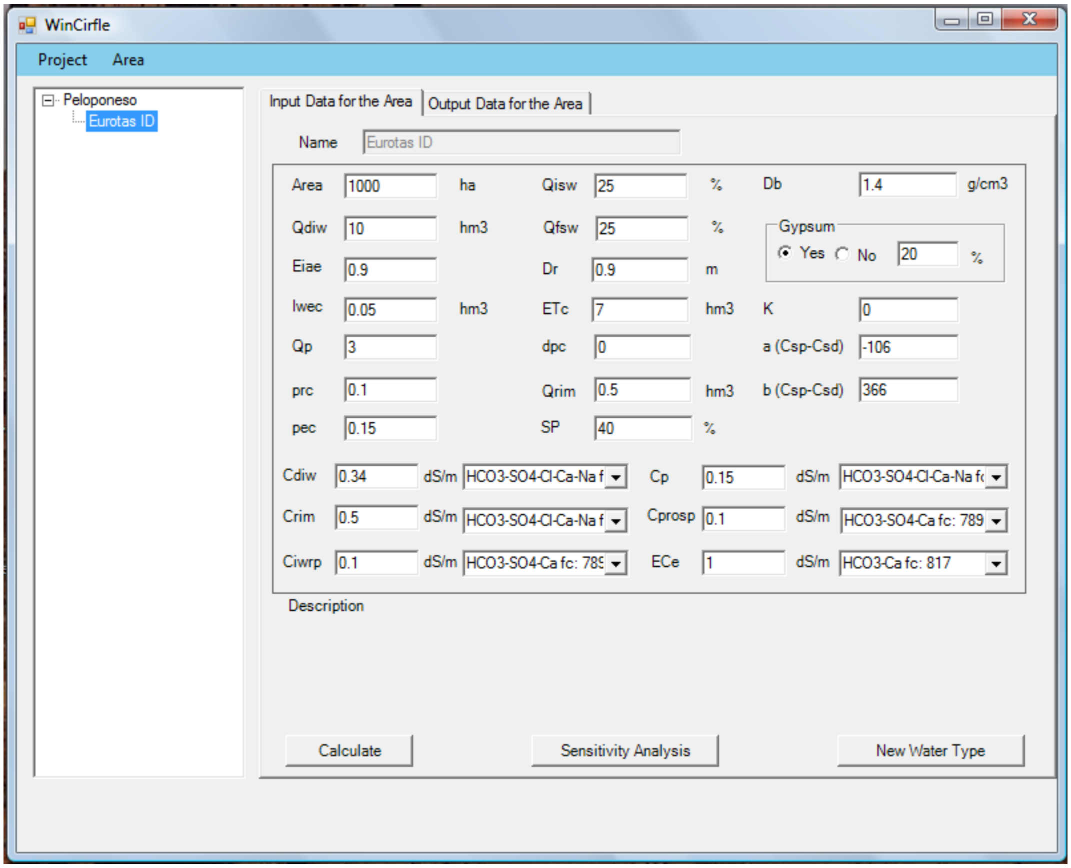

Figure 4. "*Input data for the Area*" menu

If you selected the option EC for saline concentrations (section 4.2), it is necessary to introduce a conversion factor (fc) to transform EC into TDS for each of the five input concentrations (C). For each C, you have to select one conversion factor in the unfoldable menu at the right of that concentration. *CIRFLE* includes seven most frequent types of water (Table 10). If you know the fc for your water type, you can input it by clicking the New Water Type button located at the bottom right corner of the screen.

The parameters *a* and *b* of the equation $C_{sp} – C_{sd}$ = a + b LF are located in the middle of the right column. When you press inside the input cell of anyone of these two parameters, you will see in the description line the values of *a* and *b* estimated for different irrigation water types (Table 9). You can use this values or introduce you own values.

4.5. "*Output Data for the Area*" menu

The "*Output Data for the Area*" screen presents the outputs for each of the Areas of a project. It is only active when you have previously selected an Area in the left part of the screen.

The outputs for the model are given in four columns (Figure. 5). The first column gives the volume of water Q (in the units selected for the project), the second the saline concentrations C (mg/L), the third the mass of salts M (tons), and the fourth some parameters of interest. A description of each parameter is given when clicking in each of them.

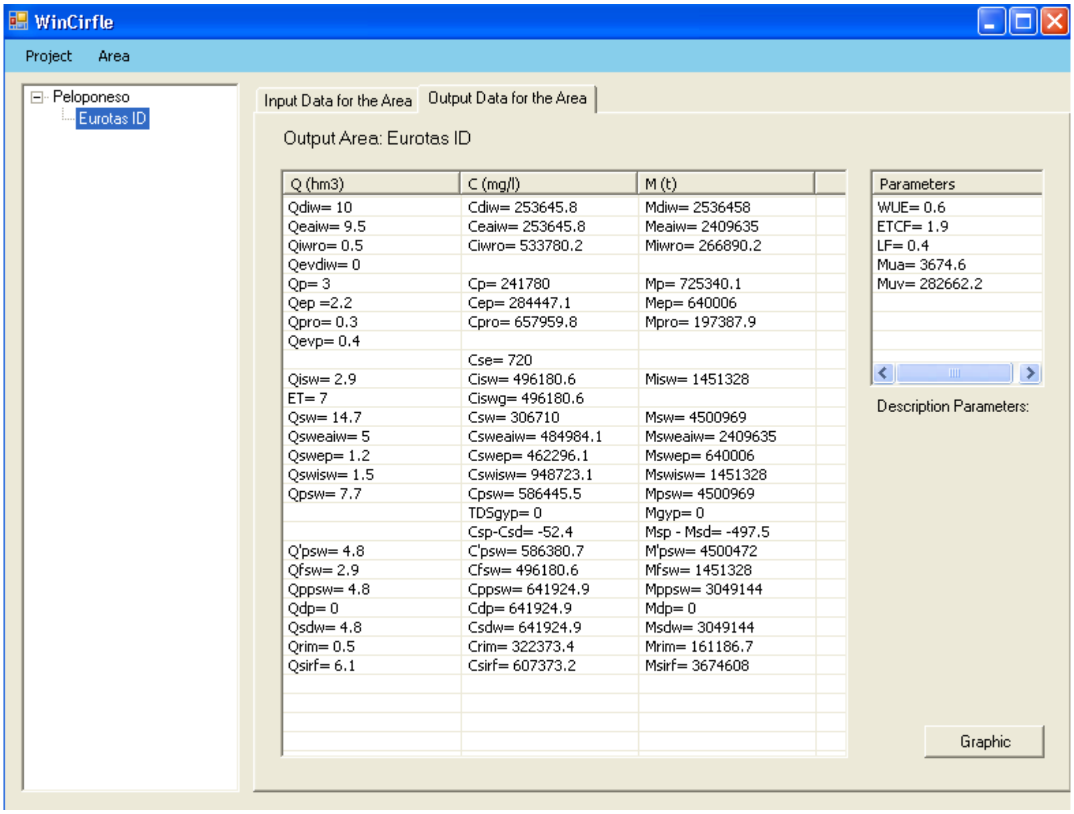

Figure 5. "Output *data for the Area*" menu

The [Graphic] button in the lower right prompts a graphical summary of the water and salt fluxes in the Area resulting from the simulation. The graphic output is a diagram that represents the flows of water and salt in the system following the scheme presented in Figures 2 and 3. To save the outputs from an area you need to save the whole project in the "Irrigation Project Output" tab (see 4.7)

4.6. "*Sensitivity Analysis*" menu

The Sensitivity analysis gives the option to analyze how variations in the values of the input parameters will affect the outputs of the model for a selected Area.

To perform a sensitivity analysis (SA) press the [Sensitivity Analysis] button located at the middle bottom of the *Input data for Area* screen, and the SA window will open. Under the *Options* menu located in the lower left of the screen you can select either a manual or an automatic SA. In both cases you can select up to 2 variables to modify in the two boxes under the *select variables* line. The variables that can be changed are Q_{diw}, E_{iae}, Q_p, prc, pec, Q_{isw}, Q_{fsw}, Dr, Q_{et}, dpc, Q_{rim}, C_{rim}, C_{diw}, C_{iwrosp}, C_p, C_{prosp}, EC_e, SP, Db, Gypsum and k.

Under the manual option, the boxes corresponding to the variables selected will activate so that you can enter the new value(s) of the variable(s). In the automatic option, you have to define an interval to perform the SA entering a lower limit and upper limit and the interval.

If you select only one variable, the automatic SA will modify the value of the variable from a minimum set value (lower limit * value of the variable /100) to a maximum set value (upper limit * value of the variable /100) using fixed interval increments (interval * value of the variable /100). The number of different values obtained (N) is defined by N = ((UpperLimit – Lower Limit) / Interval)). The SA will calculate the outputs for the resulting N values of the variable. If you select two variables, the same values of lower limit, upper limit and interval are used for the two variables. The SA will calculate the outputs for the resulting N^2 combinations of the values of the two variables.

When you press Calculate in the bottom center, a window will open asking for the format in which you want to save the output (excel or pdf). You should select one, as well as the folder where you want to save the resulting output. The output file will be stored in the selected folder with the name of the AREA. The excel file presents a complete list of the inputs, intermediate, and outputs variables, and the management parameters for the different values of the variable(s). The pdf file presents first a summary output of the volume, salt concentration and salt load in irrigation return flows (Q_{sirf}, C_{sirf}, M_{sirf}, respectively) for the different values of the variable(s) and then the completed output.

4.7. "*Irrigation Project Input*" and "*Irrigation Project Ouput*" menus

When you select the name of the *Project* in the left side of the main window, two tabs are activated in the upper part of the window: "*Irrigation Project Input*" and "*Irrigation Project Output*".

The "*Irrigation Project Input*" menu records the different *Areas* in which the project has been divided, with information of the surface area (*Area*) and the volume of diverted irrigation water (*Qdiw*) for each Area, as well as the surface area and the volume of diverted irrigation water for the entire *Irrigation Project* .

The "*Irrigation project Output*" gives for each Area (Area *Name*) the volume (*Qsirf*), salt concentration (*Csirf*), mass of salts (*Msirf*), mass of salts per unit irrigated area (*Mua*) and Mass of salts per unit water inflow (mg/L) in the irrigation return flows for each of the *Areas* of the Irrigation Project and for the entire *Irrigation Project*. *Qsirf* and *Msirf* for the entire *Irrigation Project* is obtained by adding the volume and salt mass for the individual *Areas*, and *Csirf* is obtained from *Msirf/Qsirf* (volume weighted average concentration).

You can save the outputs of the projects to a file selecting the Generate Output Project at the bottom of the screen. You can save the outputs in pdf or excel formats. The pdf file present in the first page a resume of the volume, salt concentration and salt load in irrigation return flows from the different areas that conform the project, and in the next pages the detailed outputs of all the intermediate variables and the graphic outputs for each of the areas of the project. In the xls format the detailed outputs are presented in different sheets, one for each area of the project. The information is saved in a file with the name of the project. If that file name already exist in the directory consecutive numbers (1,2 ….) area added at the end of the project name.

5. DESCRIPTION OF INPUTS

CIRFLE requires 25 inputs variables and parameters for each of the homogenous *Areas* in which the *Irrigation Project* is disaggregated. Figure 4 shows the "*Input data for the Area*" menu and Table 5 summarizes the names of the variables and their acronyms. A description of each of these inputs variables and parameters follows.

Table 5. Variable names and acronyms of *CIRFLE* input variables and parameters.

#	Variable name	Acronym
1	Irrigated surface	Area
2	Volume of diverted irrigation water	Q_{diw}
3	Irrigation water evaporation coefficient	evdiw
4	Irrigation application efficiency	E_{iae}
5	Volume of Precipitation	Q_p
6	Precipitation surface runoff coefficient	prc
7	Precipitation evaporation coefficient	pec
8	Initial stored soil water	Q_{isw}
9	Final stored soil water	Q_{fsw}
10	Average crop's rooting depth	Dr
11	Volume of total real crop's evapotranspiration	Q_{et}
12	Deep percolation coefficient	dpc
13	Volume of surface rim inflows and outflows	Q_{rim}
14	Saturation Percentage	SP
15	Soil bulk density	Db
16	Gypsum percentage in the soil	Gypsum
17	Salt leaching efficiency coefficient	k
18	Intercept of the equation Csp - Csd= a + b · LF	a (Csp-Csd)
19	Slope of the equation Csp - Csd= a + b · LF	b (Csp-Csd)
20	Salt concentration (or EC) of irrigation water	C_{diw}
21	Salt concentration (or EC) of surface rim inflows	C_{rim}
22	Salt pickup by irrigation runoff	C_{iwrosp}
23	Salt concentration (or EC) of precipitation	C_p
24	Salt pickup by precipitation runoff	C_{prosp}
25	Electrical Conductivity of soil saturation extract	ECe

5.1. Inputs defining the water balance

Numbers before each input refer to # in Table 5. Remember to use always "." for the decimal symbol.

1- Irrigated surface (Area)

Refers to the surface area of the irrigation district, that is the area that can be irrigated during the period of simulation. Always introduce the Area in hectares (ha).

2- Volume of diverted irrigation water (Q_{diw})

Refers to the total volume of water diverted for irrigation in the simulation period (normally yearly or seasonal volume). It is given in the same units chosen in the "New Project" menu [hm^3, mm, m^3/ha or ha-m (hectare · m)]. Note that the units hm^3 (1 hm^3 = 10^6 m^3) and ha-m (1 ha-m = 10^4 m^3) are units of volume, whereas mm (1 mm = 10 m^3/ha) and m^3/ha are units of volume per unit area.

The volume of water applied through each of the different water delivering systems should be measured and added to obtain the total volume of diverted irrigation water in each area during the studied period.

3- Irrigation water evaporation coefficient (evdiw)

Refers to the fraction (0 to 1) of Q_{diw} that is lost as winds drift or that evaporates form the crop canopy, soil or the distribution systems before it infiltrates the soil.

Although *evdiw* is generally low in surface and drip-irrigated systems, it may be high in sprinklers systems subject to high winds. Thus, wind drift and evaporation losses (WDEL) may be as high as 0.3 (Faci and Bercero, 1989) to 0.4 (Dechmi et al. 2004). In order to estimate WDEL in high-wind areas from the average wind velocity, the following regression (Dechmi et al., (2004) may be used: WDEL = 12.02 W $^{0.626}$ [R^2 = 0.79], where W is the wind speed at 2m height. This equation has been obtained at the plot scale; however, at the irrigated district scale (normally the usual size for *CIRFLE* application) these losses could be much lower as the losses in one plot may be gains in the neighboring plots. Whether WDEL are actual losses or not depends mainly on drop size (smaller drops tend to evaporate and larger ones tend to fall).

4- Irrigation application efficiency (Eiae)

Refers to the fraction (0 to 1) of Q_{diw} that actually infiltrates the soil. Besides wind drift and evaporation losses already mentioned in *evdiw*, *Eiae* must account for all losses in the distribution system after reading of the water meters (OL), such as secondary canal seepage or operational losses, tail-waters from irrigation ditches (TW) and irrigation runoff at the plot scale (Runoff). The volume fraction of all these losses must be subtracted from one to obtain *Eiae* as: *Eiae* = 1 – (TW + OL + Runoff) – *evdiw*). If the sum of *Eiae* and *evdiw* is more than 1, *CIRFLE* prompts an error message.

The value of *Eiae* should be established for each Area. If actual measurements are not available you can use sensible guesses of these losses. A few directions on their magnitude for different irrigation systems follow:

(i) **Flood irrigation systems** with open channel distribution: the losses take place both as *operational losses* (OL) at the end of the irrigation ditches and as *runoff* from irrigated plots —tail-waters (TW). The sum of both flows (and possibly some seepage from the main canals) was found to be 17% of Q_{diw} in a fixed-schedule distribution system in Spain (Isidoro et al., 2004) [Thus: *Eiae* = 0.83 – *evdiw*]. Lecina et al. (2004) found that surface runoff in flood irrigated basins in the Bardenas district (Spain) was about 10.6% in coarse-textured soils with high infiltration rates, and 11.2% in fine-textured valley soils [Thus: *Eiae* = 1 – 0.106 (or 0.112) – OL – *evdiw*]. In systems with fixed irrigation shifts (where farmers receive water on fixed dates and must use it whether or not they actually need it on that date), OL is likely higher than in more flexible systems. Normally, higher irrigation flows will lead to reduced percolation losses and enhanced uniformity, but will increase TW. In border- or basin-irrigated plots (with no outlets at the end of the plots), TW = 0. In furrow irrigation systems (with opened ends), siltation in the furrow bottoms may enhance runoff (Al-Qinna and Abu-Awwad, 1998).

(ii) **Sprinkler irrigation systems:** OL should be negligible whereas the magnitude of TW depends on the slope of the fields, soil's infiltration rate and the right application of the irrigation. When the irrigation rate or the sprinkler discharge (mm/h) is lower than the soil's infiltration rate (i.e., adequate design of the irrigation system), TW should also be negligible. But in other situations TW may be high. Schneider and Howell (2000) found a mean runoff of 12% in 0.25% slope furrows on a clay loam soil (Texas, USA) and 22% runoff in low-energy precision application sprinkler systems (when irrigation was 100% of crop needs). Ben-Hur et al. (1995) documented runoffs varying from 0 in the first irrigation to 37.5% in the later ones in a 3% slope silt loam soil in Neguev (Israel). As crust formation leads to higher runoff, in areas where crust formation is known to be a problem, *Eiae* should be reduced accordingly (higher TW). Al-Qinna and Abu-Awwad (1998) reported up to 20.3% runoff values in a sprinkler irrigated experiment with a low sprinkler rate of 6.2 mm/h and up to 48.3% with a high sprinkler rate of 28.4 mm/h rate in fine silt soils with surface crust problems in Jordan.

(iii) **Drip irrigation systems:** OL, TW and *evdiw* should be negligible or very low.

5- Volume of precipitation (Q_p)

Refers to the volume of precipitation during the simulation period expressed in the selected units. *Qp* should be measured in different locations distributed in the study area since it may vary depending on climatic and topographic characteristics.

6- Precipitation surface runoff coefficient (prc)

Refers to the fraction (0 to 1) of *Qp* that becomes runoff over the soil surface, without infiltrating the soil. This term must account for the total runoff in the *Area* during the simulated period; it may be estimated from surface runoff estimation methods such as the Curve Number method.

7- Precipitation evaporation coefficient (pec)

Refers to the fraction (0 to 1) of *Qp* that evaporates before infiltrating the soil. Both *prc* and *pec* define the proportion of *Qp* that actually infiltrates the soil [(1 – *prc* – *pec*)]. When the input data for *prc* and *pec* are such that *prc* + *pec* > 1, *CIRFLE* prompts an error message.

8, 9- Volume of initial (Qisw) and final (Qfsw) stored soil water

They refer to the mean root-zone soil water contents at the beginning (*Qisw*) and end (*Qfsw*) of the simulation period. The unit is percent weight or gravimetric water content (g H_2O/100 g dry soil or cm^3 H_2O/100 g dry soil).

When the simulation period is the hydrological year (the recommended period for *CIRFLE* application), Q_{isw} and Q_{fsw} can be taken as equal (assuming that the water contents in the same date of consecutive years are approximately equal). For long-term simulations of average conditions, it may also be assumed that $Q_{isw} = Q_{fsw}$.

When the simulation is performed for periods lower than a hydrologic year (it is not recommended to use *CIRFLE* for periods shorter than an irrigation season ~ 6 month) an estimate or actual field measurement of both Q_{isw} and Q_{fsw} is needed. Determining Q_{isw} and Q_{fsw} in large irrigated areas is costly and time consuming. The more homogeneous the selected area, the lower the number of samples needed. In absence of actual soil water measurements and for a hydrological year period, using field capacity (FC) for both Q_{isw} and Q_{fsw} is recommended. In all cases, the range of values should be normally above the wilting point (WP) and below field capacity (FC) of the soil.

As a help for the selection of Q_{isw} and Q_{fsw} when no measured data are available and only the general soil properties are known, Table 6 includes the usual range of WP and FC for different soil textures. A rule of thumb if other information is not available is that FC is about two times WP.

10- Average crop's rooting depth (D_r)

Refers to the mean rooting depth (m) of the crops grown in the irrigated soils of the selected *Area*. For very deep soils, *Dr* is taken as the average rooting depth of the crops. For shallow soils limiting root growth, Dr is taken as the average depth of the growth-limiting soil.

Table 6. Usual ranges (minimum, maximum and mean) of gravimetric water contents at field capacity (FC) and permanent wilting point (WP) for several soil textures (Source: FAO, 1979)

	FC (cm^3 H_2O/100 g dry soil)			WP (cm^3 H_2O/100 g dry soil)		
Texture	**Minimum**	**Average**	**Maximum**	**Minimum**	**Average**	**Maximum**
Sandy	6	9	12	2	4	6
Sandy Loam	10	14	18	4	6	8
Loam	18	22	26	8	10	12
Clay Loam	23	27	31	11	13	15
Silty Clay	27	31	35	13	15	17
Clay	31	35	39	15	17	19

11- Volume of total real crop's evapotranspiration (Q_{et})

Refers to the volume of water actually evapotranspired by the irrigated crops. It includes the evapotranspiration (ET) of all the irrigated crops in the selected *Area* and the ET of natural vegetation (if it is known and deemed important). If there are several crops in the Area, Q_{et} is the sum of the ET's calculated for each crop (when given in hm^3/ha or ha-m) or the area-weighted Q_{et} for each crop (when given in mm or m^3/ha).

It should be emphasized that Q_{et} refers to the actual or real ET, not ETo (reference ET) or ETc (maximum or potential crop's ET calculated from ETo and the crop's coefficients, Kc).

Note that this term is critical in defining the water balance in the irrigated soils of the Area and it must be estimated as accurately as possible.

We suggest following the FAO guidelines (Allen et al, 1998) to calculate the ETc for each crop. In Areas where crops are not subject to any kind of stress (in general, an unrealistic scenario), it may be accepted that the real crop ET (Q_{et}) is equal to ETc. This could be approximately the case for drip-irrigated or sprinkler-irrigated areas with frequent irrigations that avoid water stress. In areas where irrigation intervals are longer and crops suffer of water stress, Q_{et} is lower that ETc and the lower values should be estimated according to the observed lower yields. In many instances a soil bucket-type balance in the soil (based on estimates of FC and WP and the actual distribution of rainfall and irrigation for each crop; Allen et al, 1998) may be sufficient to estimate Q_{et}. Other biotic or abiotic stresses that may reduce yield and ETc should also be taken into account if possible, to obtain a better estimate of Q_{et}.

12- Deep percolation coefficient (dpc)

Refers to the fraction of deep percolation waters (waters flowing below the crop's root zone) that is not collected by the surface drainage systems present in the study areas and, thus, do not contribute to to the surface return flows. This "percolating" volume flows towards deeper regional aquifers not linked to the aquifers intercepted by the drainage system.

For irrigation systems underlain by impervious materials or in the absence of important and conductive groundwater systems, it can be assumed that $dpc = 0$. If during *CIRFLE* calibration the error in the water balance is high and the predicted outputs (Q_{sirf}) are noticeably lower than the measured outflows, it might well happen that some fraction of the deep percolation waters are not intercepted by the drainage system. In these cases, one step of the calibration procedure may be to set a *dpc* value that will decrease the error in the water balance (i.e. $dpc > 0$).

13- Volume of surface rim inflows and outflows (Q_{rim})

Refers to lateral surface inflows into the study area or lateral shallow ground-water inflows that are collected by the surface drainage system therefore contributing to the outflows from the irrigated area.

In the calibration process of *CIRFLE*, large errors in the water balance (i.e., Q_{sirf} higher than measured outflows) may be potentially explained by the presence of significant unmonitored lateral flows into the Area. Surface rim inflows can be monitored by means of gauging stations, but shallow groundwater inflows are difficult to estimate. In dry climates and when the contributing dry land area is small, groundwater Q_{rim} could be neglected.

Often, in old irrigation systems, especially with unlined canals, seepage may be substantial and it should be inputted in *CIRFLE* as Q_{rim}. If the rest of the water balance components are well known, Q_{rim} may be estimated as the error in the water balance. Lateral inflows from outside the area should include an estimate of the seepage from the main canals (upstream of the diversions where Q_{diw} is actually measured). This seepage can be very important in old irrigation schemes and especially in systems with earth (unlined) conveyance structures.

5.2. Inputs defining salt loading and salt leaching

14- Saturation percentage (SP)

Refers to the amount of distilled water added to an air-dry, ground and sieved (< 2 mm) soil to prepare the saturated paste (units of g of water per 100 g of dry soil).

If the *SP* is not determined in the lab, it may be estimated from the Sand fraction (0 to 1) in the soil through the regression: $SP = 1.03 - 0.796 \cdot \text{Sand}$ [$R^2 = 0.63$] obtained from the data of Banin and Amiel (1969) for 33 soil samples in Israel. These authors reported *SP*'s in the range from 25% (soil with 98% Sand) to 114% (soil with 67% Clay). If the texture of the soil is known, the *SP* range for each soil textural class may be estimated from Table 7.

Table 7. Usual ranges of SP for several soil textural classes (source: Slavich and Petterson, 1993).

Textural class	SP range (%)
Sandy, Loamy sand, Clayey sand	<20
Sandy loam, Fine sandy loam, Light sandy clay loam	20 - 41
Loam, Loam fine sandy, Silt loam, Sandy clay loam	41 - 46
Clay loam. Silty clay loam, Fine sandy clay loam, Sandy clay, Silty clay, Light clay, Light medium clay	46 - 53
Medium clay	53 - 72
Heavy clay	> 72

15- Soil bulk density (D_b)

Refers to the average bulk density of the soil for the whole rooting depth (units of g/cm^3). D_b is required to convert Q_{isw} and Q_{fsw} (% weight) into volumes of water and to determine the amount of gypsum (in Mg) present in the soil from the % Gypsum given as an input.

Table 8 (National Resources Conservation Service, NRCS-USDA) gives some guidelines to estimate bulk density from textural classes when D_b is not measured. As indicated by NRCS the guidelines provide estimates for moderately consolidated soils (i.e. moderate grade of structure and generally friable consistence).

Table 8. Usual ranges of Db for several soil textural classes (source: Natural Resources Conservation Service, USDA. http://www.mo10.nrcs.usda.gov/references/ guides/properties/moistbulkdensity.html)

Texture	**coarse sand**	**sand/ fine sand / loamy coarse sand**	**very fine sand / loamy sand / loamy fine sand**
Bulk density	1.70 - 1.80	1.6 - 1.7	1.55 - 1.65
Texture	**loamy very fine sand coarse sandy loam**	**sandy loam / fine sandy loam**	**very fine sandy loam / loam / silt loam / sandy clay loam /silty clay loam**
Bulk density	1.55 - 1.6	1.5 - 1.6	1.45 - 1.55
Texture	**silt / clay loam / silty clay**	**sandy clay / clay (35-50%)**	**clay (35-50%)**
Bulk density	1.40 - 1.5	1.35 - 1.45	1.25 - 1.35

These estimates will be higher in soils that have high or very high consolidation (i.e. weak structure or massive and generally very firm consistence [e.g. "Cd horizon, natric horizon"]) and lower in soils with strong structure and generally loose consistence.

16- Gypsum percentage in the soil (Gypsum)

Refers to a dichotomous input that accounts for the presence (*Yes*) or absence (*No*) of gypsum in the soil. If the gypsum percentage (PG) is known, it can be inputted in the window to the right of the Gypsum box. If the Yes button is activated but the % Gypsum is not introduced, *CIRFLE* uses a default value of 20% to guarantee gypsum saturation. As the soil solution becomes easily saturated with gypsum with low gypsum contents in the soil, this % is usually not important and the actual value must not be specified. Only for very low gypsum contents in the soil (gypsum < 1%) it should be specified.

Gypsum dissolution is an important contribution to the salinity of soil water. Thus, the presence of gypsum in the soil must be assessed beforehand. In semi-arid environments, when the 1:5 extract yields an *EC* of around 2 to 2.5 dS/m, the presence of gypsum is almost certain.

17- Salt leaching efficiency coefficient (k)

CIRFLE estimates the mass of salts leached from the root zone during the simulation period using equations 61 to 68. The model uses the empirical approach developed by Hoffman (1986) to estimate the final concentration of soil water (C'_{fsw}) from the initial concentration of soil water (C_{isw}) by using a leaching efficiency coefficient (*k*) and considering the amount of water that percolated below the crop's root zone (Q_{ppsw}/A) per unit depth of average crop's rooting depth (D_r) as:

$$\frac{C'_{fsw} - C_{min}}{C_{isw} - C_{min}} = \frac{k}{\frac{Q_{ppsw}/A}{D_r} + k}$$

The leaching efficient coefficient is an empirical parameter that depends on soil factors (structure, texture, salinity) and management factors (irrigation systems and management). As *k* increases, the efficiency of leaching decreases. For *k* = 0, piston flow is simulated (i.e., leaching efficiency = 100%). For *k* = ∞, a hypothetical null displacement of salts is assumed (i.e., leaching efficiency = 0%).

Typical *k* values for continuous ponding are around 0.1 for sandy loam soils (i.e., high leaching efficiency), 0.3 for clay loam soils (i.e., moderate leaching efficiency) and 0.45 for peat soils (i.e., low leaching efficiency). In intermittent ponding and sprinkler systems where leaching takes place at soil water contents below saturation, *k* is around 0.1 (i.e., high leaching efficiency) and independent of soil texture. If the value of k is too low (k<0.1); the estimated concentration of subsurface drainage and deep percolation can be untruthful and extremely high.

18, 19- Intercept (a) and slope (b) of the salt pick-up minus salt deposition vs. leaching fraction (LF) equation [a (C_{sp}-C_{sd}), b (C_{sp}-C_{sd})]

Up to this point, *CIRFLE* has only considered gypsum dissolution if present in the soil. However, calcite is frequently present in many arid and semiarid soils and may be dissolved by the percolating waters. Also, gypsum and calcite may precipitate in the soil depending on the concentrations of Ca, HCO_3 and SO_4 in the irrigation waters and on the ETCF (concentration factor of the irrigation water in the soil due to crop's evapotranspiration). The potential dissolution ("salt pick-up", C_{sp}) of the calcite present in the soil and the potential precipitation ("salt deposition", C_{sd}) of calcite and gypsum in the soil due to the ETCF of the irrigation water are accounted empirically through an equation that relates C_{sp}-C_{sd} with the leaching fraction: (C_{sp}-C_{sd}) = a + b · LF.

Inputs to the *CIRFLE* model are the coefficients *a* (intercept) and *b* (slope) that are included in the model for different types of water (Table 9). These coefficients were obtained through simulations with the model *Watsuit* (Wu et al., 2009) for several water types present in the Ebro River Basin and in many other arid and semiarid basins around the world. For each water type, the mean irrigation water concentrations of Ca, Mg, Na, K, Cl, SO_4 and HCO_3 were used as inputs and run with the option "*saturated with calcite*" that allows for the dissolution of calcite up to its chemical saturation. Five LF values were used (0.05, 0.10, 0.20, 0.30, 0.40) to obtain the linear regression equations (C_{sp}-C_{sd}) = a + b · LF. Table 9 gives the EC range, slope, intercept and coefficient of determination values of these regressions.

These water types cover many usual irrigation waters, but there may be other types of irrigation waters. If the exact composition of the irrigation water applied in the study area is known, (C_{sp}-C_{sd}) may be estimated using *Watsuit*. The results for calcite dissolution and precipitation and gypsum precipitation for the five soil boundaries in *Watsuit* must be weighted by the leaching fraction computed by *Watsuit* for each boundary. Take into account that the sign convention in *Watsuit* is the opposite to the sign convention in *CIRFLE*: deposition is negative and pick-up is positive. Obviously, if a local experimental relationship between C_{sp}-C_{sd} and the actual LF is known, it should be used instead of those indicated in Table 9.

In general, the contribution of C_{sp}-C_{sd} to the overall salt fluxes is low. Even so, the values of *a* and *b* can be modified in the final, fine-tuning of the calibration process.

Table 9. Parameters (*a* and *b*) and coefficients of determination (R^2) of the regressions C_{sp}-C_{sd} = a + b · LF for each water type.

Water type	EC range (dS/m)	a	b	R^2
HCO_3-Ca	0.10 – 0.45	-107	366	99%
HCO_3-SO_4-Ca	0.45 – 0.70	-223	478	99%
HCO_3-SO_4-Cl-Ca-Na	0.70 – 1.05	-206	463	99%
SO_4-HCO_3-Cl-Ca-Na	1.00 – 1.40	-386	670	96%
SO_4-Ca	1.30 – 1.90	-353	611	99%
Cl-HCO_3-Na-Ca	1.00 – 1.40	-517	1263	89%
SO_4-Ca (hyper SO_4)	> 2.00	-2019	3932	99%

25- Electrical conductivity of soil saturation extract (ECe)

Refers to the concentration of soluble salts obtained in a soil saturation extract (units of dS/m). *CIRFLE* convert EC_e (dS/m) into TDS (mg/L) through the factor F_C = 702 (mg/L) / (dS/m). This Fc value was obtained as the mean for many waters with typical ionic compositions in the Ebro river basin.

Soil salinity is generally highly variable in time and space, and may be the most important salt source in many arid and semiarid study areas. Thus, the delineation of the homogeneous areas is usually performed based on *ECe*. To this end, time and space-averaged *ECe* values for each delimited area should be estimated with the maximum reliability. The spatial variability of salinity in the study area should be analyzed in detail, using all the information available (geomorphology, soil maps, etc.) and, if possible making surveys with electromagnetic devices, the best way to obtain the needed soil salinity maps.

5.3. Inputs defining salinity in the input water fluxes

20, 21, 22, 23 and 24- Salt concentrations in irrigation, precipitation and rim inflows

Salt concentrations of the irrigation waters should be monitored for all the sources of irrigation. The average salt concentration of irrigation water (C_{diw}) is the volume-weighted average of these salt concentrations. Salt concentrations in precipitation (C_p) and rim inflows (C_{rim}) must be determined in the same way.

The fraction of irrigation and precipitation flowing over the soil surface as surface runoff is assumed to pick-up some salts as they convey towards the surface drainage system. These increases in salt concentration (Ciwrsop for irrigation water runoff and Cprosp for precipitation runoff) are typically low. The term Ciwrosp refers to the salt pick-up in runoff from irrigated plots, operational losses and seepage from secondary irrigation ditches (after the water meters defining Qdiw). In general, this pick-up term is low, compared to other salt sources. It can be estimated measuring EC at the input and output points of irrigation in some fields.

5.4. Conversion factors for estimating TDS from EC

In the “New Project” menu (Figure 3), the user may choose between TDS or EC as “Units for Saline concentration”. If EC is selected, in the “Input data for the Area” menu the salt concentrations C_{diw}, C_{rim}, C_p, and are given in dS/m and they must be converted into TDS in order to obtain salt loads using the Fc values given in Table 10. According to the ionic compositions for each water, the appropriate Fc values are introduced in *CIRFLE* in the windows to the right of each of the above salt concentrations. If F_C is known by the user for the irrigation water diverted to the study area, it can be introduced directly into *CIRFLE* with the option “*New Water Type*” shown at the bottom right of the “*Input Data for the Area*” menu.

Table 10. Water types and conversion factors (F_C) to convert electrical conductivity (EC) into total dissolved solids (TDS).

Water type*	Ionic composition	EC range (dS/m)	F_C (mg/L)/(dS/m)
HCO_3-Ca	HCO_3-Ca ≈ 70%	0.10 – 0.45	815
HCO_3-SO_4-Ca	50% < HCO_3-Ca < 70%	0.45 – 0.70	788
HCO_3-SO_4-Cl-Ca-Na	HCO_3 ≈ SO_4 ≈ Cl; Ca ≈ 50%	0.70 – 1.05	732
SO_4-HCO_3-Cl-Ca-Na	Ca ≈ 50%	1.00 – 1.40	767
SO_4-Ca	SO_4 ≈ 70%; Ca ≈ 60%	1.30 – 1.90	705
Cl-HCO_3-Na-Ca	Cl-Na ≈ 50%	1.00 – 1.40	819
SO_4-Ca (hyper SO_4)	SO_4 ≈ 80%; Ca ≈ 70%	> 2.00	893

* Waters are named after Schoukarev's criterion: the anions and cations that represent more than 25% of the respective sums (in meq/L) are listed from higher to lower percentage.

Alternatively, the following two regression equations may be used to calculate concentration in mg/L

$$\text{TDS}\,(mg/L) = 749.0 + 66.3 \cdot \text{EC} - 3.9 \cdot \text{rCl} + 1.3 \cdot \text{rHCO}_3\,; \quad R^2 = 0.91; \quad s = 15.24\,,$$

where EC is the electrical conductivity in dS/m, and r is % of Cl or HCO_3 over the sum of anions (Cl+SO_4+HCO_3) in meq/L.

$$\text{TDS}\,(mg/L) = 698.2 + 116.0 \cdot \text{EC} - 55.6 \cdot \text{SI}_{gyp} - 99.9 \cdot (\text{Cl/HCO}_3) - 1.3 \cdot \text{rNaK}\,; \quad R^2 = 0.92; \quad s = 14.78$$

where EC is the electrical conductivity in dS/m, SI_{gyp} is the saturation index for gypsum [calculated with a geochemical model such as WATEQ4F], Cl/HCO_3 is the ratio of Cl to HCO_3 in meq/L, and rNaK is the percentage (%) of sodium plus potassium over the sum of cations (Na+K+Ca+Mg) in meq/L.

6. DESCRIPTION OF OUTPUTS

Figure 5 shows the "*Output Data for the Area*" menu and Table 11 summarizes the names and acronyms of the main outputs. The outputs for *CIRFLE* are organized in three columns: (1) water volume (Q) (given in the units specified in the "New Project" menu), (2) salt concentration (C) (given in mg/L), and (3) salt mass (M) (given in Mg (mega-grams), Mg = t = 1000 kg). Some Parameters characterizing irrigation performance and salt outputs are given in the small window to the right of the "*Output Data for the Area*" menu.

6.1. Water and salt fluxes

Each row of the "*Output Data for the Area*" menu gives the volume of water, the salt concentration and the mass of salts associated to each model component. When the flow components are in the vapor phase (Q_{evdiw}, Q_{et} and Q_{evp}), C = M = 0 and the two right columns are empty. Similarly, the salt fluxes originating from dissolution or resulting in precipitation (salt pick-up – salt deposition and gypsum dissolution) are only shown as concentrations and masses and the first column corresponding to the volume of water is empty.

It should be noted that C_{isw} is the salt concentration of the initial stored soil water once the effect of gypsum, when present, is removed. Thus, if *Gypsum* = Yes, then C_{isw} = EC_e (in TDS units) - 2630 mg/L (the concentration of a gypsum-saturated solution).

The last row of the "*Output Data for the Area*" menu gives the three most important outputs of *CIRFLE*: volume (Q_{sirf}), salt concentration (C_{sirf}) and mass of salts (M_{sirf}) in surface irrigation return flows. Q_{sirf} results from the mixing of drainage waters (Q_{sdw}), rim inflows (Q_{rim}) and surface runoff waters (Q_{iwro} and Q_{pro}) (Figure 1); M_{sirf} is the sum of the mass of salts in these flows (Figure 2), and C_{sirf} is calculated as M_{sirf}/Q_{sirf}. As all the subcomponents of Q_{sirf} and M_{sirf} are given in the screen, simple operations allow to obtain, for instance, the salt exports from the irrigated soils only (Q_{rim} excluded) or other particular results of interest.

All the intermediate *Q*, *C* and *M* components are also shown in this screen, allowing to quantify for the most important sources of salts and its impact on drainage waters, irrigation return flows, etc., for a particular simulation.

When clicking in the "Graphic" buttom of the "*Output Data for the Area*" menu, a summary figure with the most important *CIRFLE* inputs and outputs for *Q*, *C* and *M* is shown (Figure 6).

Table 11. Definition of intermediate and final variables in the *Output data for the Area* menu (Q = volume of water; C = salt concentration; M = mass of salts)

Symbols			Definition
Q_{diw}	C_{diw}	M_{diw}	Diverted irrigation water
Q_{eaiw}	C_{eaiw}	M_{eaiw}	Effective applied irrigation water
Q_{iwro}	C_{iwro}	M_{iwro}	Irrigation water runoff
Q_{evdiw}			Evaporation of diverted irrigation water
Q_p	C_p	M_p	Precipitation
Q_{ep}	C_{ep}	M_{ep}	Effective precipitation
Q_{pro}	C_{pro}	M_{pro}	Precipitation runoff
Q_{evp}			Evaporation of precipitation
	C_{se}		TDS of soil saturation extract corrected by gypsum solubility
Q_{isw}	C_{isw}	M_{isw}	Initial stored soil water
Q_{et}			Actual Evapotranspiration
Q_{sw}	C_{sw}	M_{sw}	Soil water after irrigation and precipitation/ before ET
Q_{psw}	C_{psw}	M_{psw}	Soil water after ET
	TDS_{gyp}		Concentration derived from soil gypsum dissolution
	C_{sp}-C_{sd}		Concentration derived from calcite pick-up/dissolution
Q'_{psw}	C'_{psw}	M'_{psw}	Soil water after ET, salt pick-up/dissolution and gypsum dissolution
	C'_{fsw}		Final stored soil water corrected by gypsum
Q_{fsw}	C_{fsw}	M_{fsw}	Final stored soil water
Q_{ppsw}	C_{ppsw}	M_{ppsw}	Water available for subsurface drainage and deep percolation
Q_{dp}	C_{dp}	M_{dp}	Deep percolation
Q_{sdw}	C_{sdw}	M_{sdw}	Subsurface drainage water
Q_{rim}	C_{rim}	M_{rim}	Rim inflow/outflow
Q_{sirf}	C_{sirf}	M_{sirf}	Surface irrigation return flow

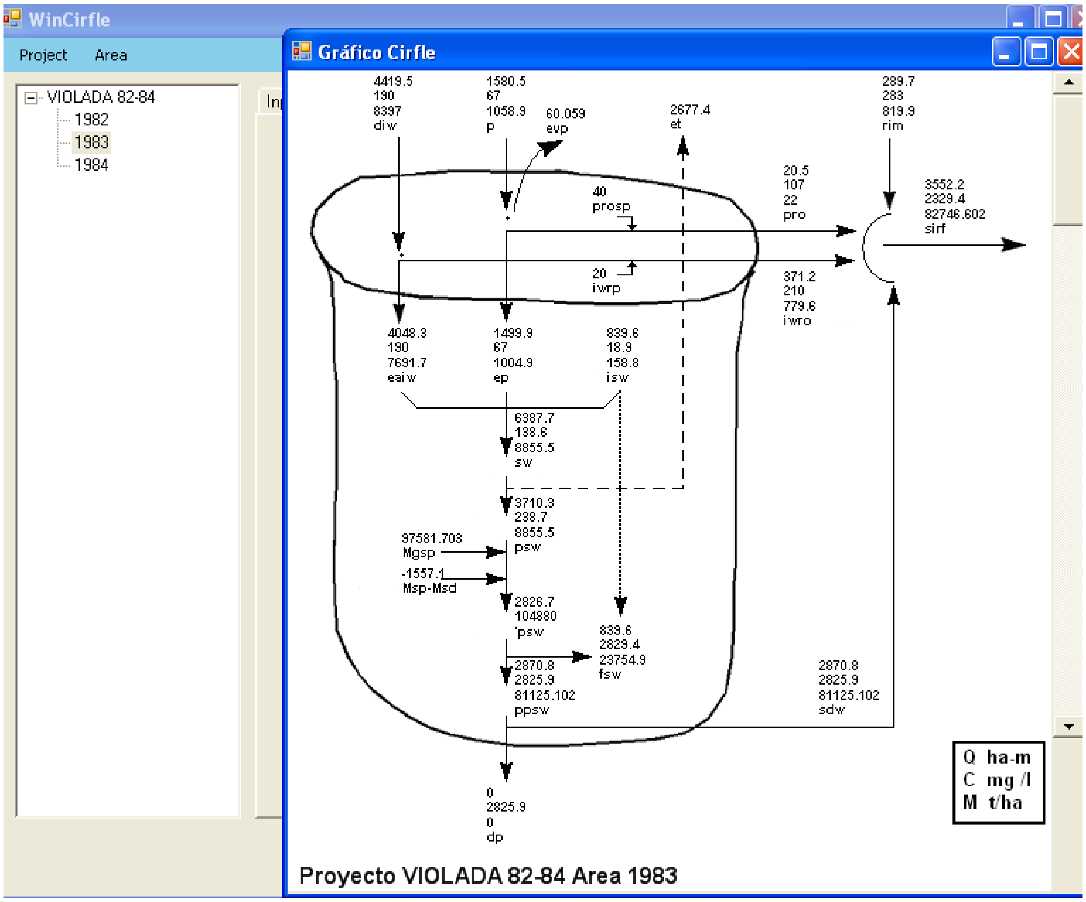

Figure 6. ***CIRFLE*** **figure summarizing the most important inputs and outputs. For each of them, the first line is volume of water (Q), the second line is salt concentration (C) and the third line is mass of salts (M)**

6.2. Irrigation performance and salt loading parameters

Some key parameters characterizing the quality of irrigation management and the relative magnitude of salt fluxes are presented in the parameter output box to the right of the output menu. When clicking on each of the parameters, a brief description is shown below the box. The list of parameters is not exhaustive and the user may calculate other parameters of interest (for his particular situation) from the output values in the main water and salt fluxes window in the left.

Three parameters characterize the movement of water through the soil: the water use efficiency (WUE), the ET concentration factor (ETCF) and the leaching fraction (LF).

The WUE is defined as the portion of the infiltrated irrigation and precipitation that undergoes evapotranspiration

$$WUE = \frac{Q_{et}}{Q_{eaiw} + Q_{ep}}$$

The ETCF is the ratio between the water in the soil “before” ET (Q_{sw}) and “after” ET (Q_{psw}) and gives an indication of how much the water in the soil gets concentrated due to the evapotranspiration process (assumed salt free) during the simulated period

$$ETCF = \frac{Q_{sw}}{Q_{psw}}$$

Te leaching fraction (LF) is the ratio of the water draining below the root zone (Q_{ppsw}) to the water flowing into the soil from irrigation and precipitation (Q_{eaiw} + Q_{ep}).

$$LF = \frac{Q_{ppsw}}{Q_{eaiw} + Q_{ep}}$$

Two parameters are calculated for the salt load of irrigation return flows: M_{ua} and M_{uv}. The parameter M_{ua} is the mass of salts per unit irrigated area (Mg TDS / irrigated hectare) and is calculated as:

$$M_{ua}(Mg/ha) = \frac{M_{sirf}(Mg)}{Area(ha)}$$

The M_{ua} is the mass of salts contributed by unit irrigated area (ha), possibly the most important result form the model application. Strictly as defined, this parameter includes the mass of salts carried by the rim inflows. When Q_{rim} is important (or when the salt contribution of the irrigated area alone is to be determined), the M_{rim} can be subtracted from the numerator. Other modifications may be implemented likewise by the user from the main output data as required.

The other parameter is the mass of salts per unit applied water volume (rainfall and irrigation) calculated as:

$$M_{uv}(Mg/hm^3 = mg/L) = \frac{M_{sirf}(Mg)}{(Q_{diw} + Q_p)(hm^3)}$$

Again, if M_{rim} is not negligible, the contribution of the irrigated area to the salt load of the irrigated area could be better assessed subtracting M_{rim} in the numerator and Q_{rim} in the denominator. This parameter has the units of concentration. It gives the concentration that result from dissolving all the salts in the Area outflows (M_{sirf}) in the volume of input water (Q_p + Q_{diw}). The comparison of this theoretical concentration with the input concentration (C_{diw} or an averaged mean of C_{diw} and C_p) gives a hint of the salt removal from the irrigated soils, much in the same way as the salt balance index (Kaddah and Rhoades, 1976). Neglecting minor terms, if there were no gypsum or calcite dissolution in the soil (no loading) all the increase in salt concentration in the drainage flow would result from evapoconcentration, and the ratio M_{uv}/C_{diw} should be close to the ETCF. The difference between these terms is due first to the removal of salts/gypsum from the soil and to the additional loading in surface flows and rim inflows.